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DESIGN AND FABRICATION OF LINEAR GANTRY ROBOTTIC SYSTEM TO AUTOMATE TRANSFORMER CORE STACKING PROCESS

PROJECT REPORT

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DECLARATION

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ACKNOWLEDGEMENTS

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ABSTRACT

The study highlights the solution of problem, that is not pre-engineered, through identifying the problem extensively using napkin sketch, budgeting, loads and speeds. Those key design considerations include movement, space requirements, and loads for our end customer. Cycle time, accuracy, precision, speeds are also decisive parameters in selection of actuator mechanisms. Belt and drive mechanism decision evaluation matrices are developed with selection criteria and our opted choice. Torque profile calculations are performed using modified approach of kinematics on Peter Corks' robotics toolbox kit MATLAB which inculcates DH parameters, velocity-time graphs, and torque profiles for motor selection.

This design on Vention.io platform demonstrates the effectiveness of using off-the-shelf components and evaluating cartesian robots' components. Vention.io's components are designed to be modular, which means they can be easily assembled and customized to fit specific industrial applications. This reduces the time and cost of robot development and allows for quick modifications to the system.

The system uses compressed air to actuate linear motion in the gantry, providing a low-cost and reliable solution for material handling and assembly processes. This study highlights the advantages of the pneumatic system and its suitability for a range of industrial applications. The selection of pneumatic system is carried out after considering alternate options our application.

LIST OF FIGURES

CHAPTER 1

1.0 WORKSPACE EVALUATION

The workspace evaluation requires the process of stacking mechanism for sheets to be extensively studied before approaching to the problem itself. ‘Top Down’ approach has been used for the given problem of less accuracy and redundancy and higher operational costs which leads us to the possible solutions for automating the assembly line for transformer core staking procedure i.e SCARA Robot (Selective Compliance Articulated Robot Arm) and Linear Gantry Robottic System. At industrial site PEL, the stacking procedure is being performed with 4 labor workers on one station and right now, the sheets being stacked is 12,000 sheets per day but the company wants to scale up their production and hence, the requirement reaches upto 28,000 sheets per day. The industrial assembly line is susceptible to environmental conditions and thus, reliability factor for belts, bearings and cuppings should be taken into account.

2.0 END CUSTOMER REQUIREMENTS

2.1 Movement Space and Loads

Speed	Up and Down motion	0.2 m/s (0.5m travelled in 2.5sec)
	Back and forth motion	0.2 m/s (1m travelled in 5sec)
Acceleration	Up and Down motion	0.13m/s^2
	Back and forth motion	0.13 m/s

CHAPTER 2

2.1 Decision Matrices for Mechanisms

A decision matrix evaluates and prioritizes a list of options and is a decision-making tool. The team first establishes a list of weighted criteria and then evaluates each option against those criteria. This is a variation of the L-shaped matrix.

DECISION MATRIX					Our Decision
Decision regarding					
	DECISION EVALUATION CRITERIA				
	1. Accuracy	2. Speed	3. Cost	4. Self-Locking Mechanism	
1. Ball Screw Mechanism	High Accuracy	Low Speeds	Low Cost and Readily Available	Available	Rack and Pinion drive for up & down motion of robotic arm
2. Rack and Pinion Drive Mechanism	Less Accuracy	Relatively High Speeds	High Cost due to Gear Box Manufacturing	Available using Gear Box	

2.1.1 Ball Screw Mechanism

Ball screw actuators are electro-mechanical actuators that translate rotational motion to linear motion with little friction; they are used in precise engineering and particularly in additive manufacturing and aerospace sector. [1]

2.1.2 Rack and Pinion Drive Mechanism

Rack and pinion provide precise motion because of its rigid structure for an unlimited time scale when compared with ball screw mechanism. Rack and pinion mechanism has minimal wear with long life operation time, and it's preferred for industrial assembly lines with harsh environmental conditions, thus having more reliability factor. The helical gear design makes the smooth, less-friction motion, and it would have zero backlash if the designer has chosen some play to avoid jamming when the gears are meshed. The transmission of power in rack and pinion drive is better as a result of its constant stiffness (97%).

In our application, rack and pinion drive could be a better option as we need relatively higher speeds to reduce the overall cycle time.

Advantages	**Disadvantages**
Precision Motion	Gear Box is required for speed and torque control

Long Life Span	High costs associated than ball screw mechanism
Preferable for higher speeds	Less mounting options
Excellent transmission of power	
Resilient to contamination in harsh environments (High Reliability)	

2.2 Self-locking gears:

In most gear drives, when driving torque is suddenly reduced as a result of power off, torsional vibration, power outage, or any mechanical failure at the transmission input side, then gears will be rotating either in the same direction driven by the system inertia, or in the opposite direction driven by the resistant output load due to gravity, spring load, etc. The latter condition is known as back driving. However, there are also solutions in the gear transmission that prevent inertial motion or back-driving using self-locking gears without any additional devices. The most common one is a worm gear with a low lead angle.

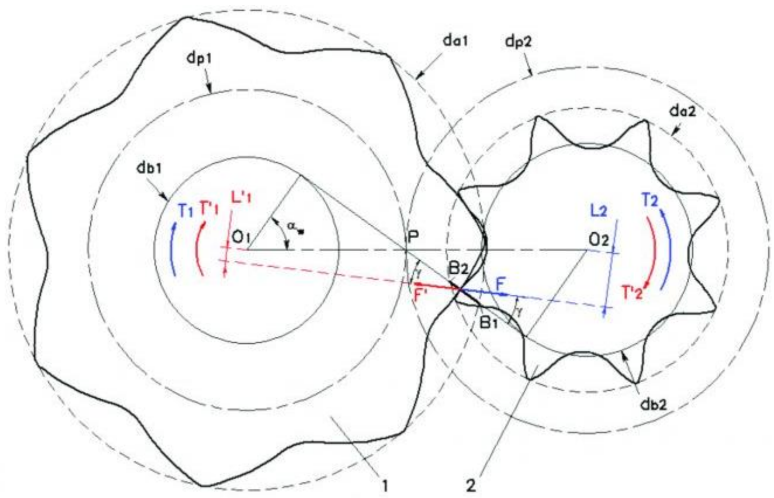


Fig. Conventional (left) and self-locking (right) gears

2.2.1 Design of Self-Locking Mechanism:

Self-locking gears are custom. They cannot be fabricated with the standards tooling with, for example, the 20 (degree) pressure and rack.

$$f > \frac{1}{(1+u)\times \tan\alpha_w - u\times \tan\alpha_{a2}}$$

$u = n_2/n_1$ – gear ratio,
n_1 and n_2 – pinion and gear number of teeth,

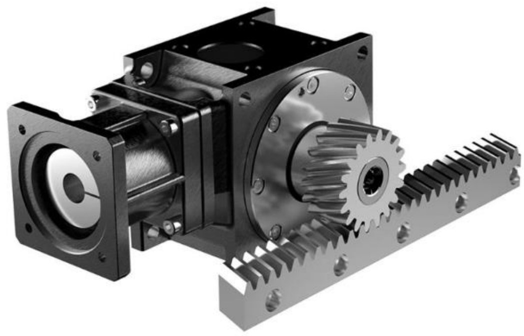
For gears with symmetric teeth:

Another condition of self-locking is to have a sufficient friction angle g to deflect the force f' beyond the center of the pinion O_1.

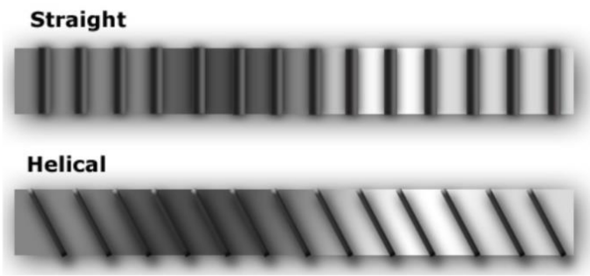
$$\gamma > \arctan[\frac{1}{(1+u)\times\tan\alpha_w - u\times\tan\alpha_{a2}}]$$

$$inv(\alpha_w) = \frac{1}{1+u}\times[inv(v_1)+u\times(inv(v_2)-\frac{\pi}{n_1}],$$

$$\varepsilon_\alpha = \frac{n_1}{2\pi}\times[\tan\alpha_{a1}+u\times\tan\alpha_{a2}-(1+u)\times\tan\alpha_w];$$



Rack and Pinion Drive



Straight and Helical Gears

2.3 Pneumatic Suction System vs Electromagnetic System

DECISION MATRIX					Our Decision
Decision regarding					
	DECISION EVALUATION CRITERIA				
	1. Accuracy	2. Speed	3. Cost	4. Self-Locking Mechanism	
1. Electromagnetic Suction	High Accuracy	Low Speeds	Low Cost and Readily Available	Available	Rack and Pinion drive for up &

2. Pneumatic Suction	Less Accuracy	Relatively High Speeds	High Cost due to Gear Box Manufacturing	Available using Gear Box	down motion of robotic arm

2.3.1 Electromagnetic Suction

Any moving electric charge creates a magnetic field around it. A loop of wire with a current creates a magnetic field through the loop. You can increase the strength of this field by piling up a lot of loops. The more loops, the stronger the magnet. Like a bar magnet, this coil of wire now has a north pole and a south pole, and is an electromagnet.

2.3.2 Pneumatic Suction System

CHAPTER 3:

3.1 MOTOR CALCULATIONS

3.1.1 Torque required for constant velocity

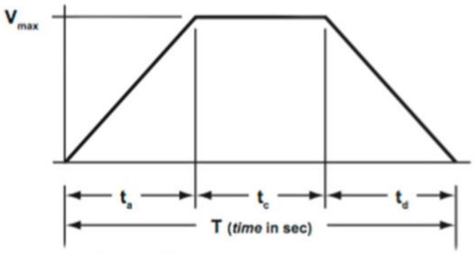


Figure 2 showing Torque Profile

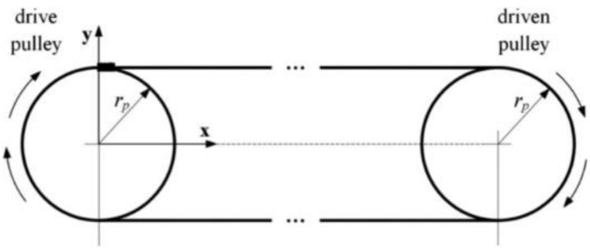


Figure 1 showing transmission of power through pulleys

$$T_c = F_a.r1$$

Tc = Torque required during constant Velocity

Fa = Axial Force in newtons

R1 = Radius of Drive Pulley

η =Efficiency of belt drive systems

$$F_a = m.g.\mu$$

m= mass of moved load (external load + weight of belt)

μ =Coeffecient of friction of guide

3.1.2 Torque Required for Acceleration

$$T_a = T_c + T_{acce}$$

Tacc = Toque Required during Acceleration

Tc= Torque required during constant velocity

$$T_{acce} = J_T x \alpha$$

Jt =Total Inertia of the system (kgm^2)

a = Angular Acceleration (rad/s^2)

$$J_T = J_m + J_C + J_{p1} + J_{p2} + J_l$$

Jm = inertia of motor (provided by manufacturer) (kgm^2)

Jc = inertia of coupling (provided by manufacturer) (kgm^2)

Jp1 = inertia of drive pulley (provided by manufacturer, or calculate) (kgm^2)

Jp2 = inertia of idler pulley (provide by manufacturer, or calculate) (kgm^2)

Jl = inertia of load (kgm^2)

3.1.3 Torque Required for deacceleration:

The torque required for deacceleration is as follows:

$$T_d = T_C - T_{acc}$$

3.1.4 Continuous Torque:

Now that we know the motor drive torques required during acceleration, constant velocity, and deceleration, we can take the root mean square of these values to determine the continuous torque required by the motor.

$$T_{RMS} = \frac{\sqrt{T_a^2 \cdot t_a + T_c^2 \cdot t_c + T_d^2 \cdot t_d}}{t_{total}}$$

3.2 Inverse Kimematics using RoboAnalyzer

3.2.1 Introduction to Robo Analyzer

3.3 Inverse Kinematics using Matlab Robotics Toolbox

3.3.1 Matlab Code

3.3.2 Peter Corks Robotics Toolbox Kit

3.3.3 Results

Chapter 4

4.1 End Effector

Schematic Diagram of the End Effector:

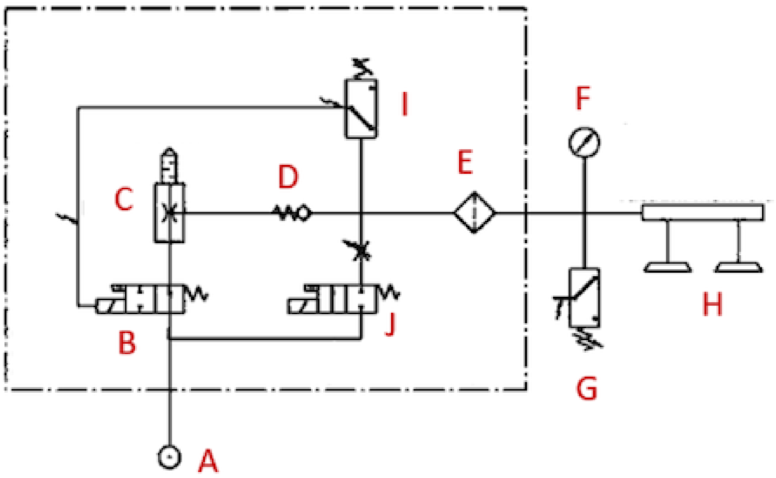


Figure 2: Vacuum pick and place application components: compressed air entry point (A), compressed air control valve (B), vacuum generator (C), non-return valve (D), vacuum filter (E), vacuum pressure gauge (F), external vacuum switch (G), vacuum suction cups (H), internal vacuum switch (I), & compressed air blow-off valve (J).

4.1.1 Components involved in the end-effector:

1. Vacuum grippers
2. Vacuum generators

3. Compressed air
4. Hoses
5. Fittings
6. Valves

1. **Vacuum grippers/Suction cups**

Vacuum grippers (or suction cup) are the pneumatic components that make direct contact with an object during a pick and placement operation. A vacuum generator creates a vacuum by withdrawing air between the workpiece and the surface of the suction cup. This results in a pressure lower than atmospheric pressures between the workpiece and the cups. This pressure differential causes the suction cups to stick to the workpiece. This type of pick and place operation is widely used in the packaging and palletizing industry.

4.2 Vacuum Suction Pump Selection Criteria

In order to select the right vacuum suction cup, we should consider the following parameters:

1. Surface
2. Material
3. Coefficcient of friction
4. Safety Factor
5. Holding Force

4.2.1 Surface

The surface of the workpieces determines whether certain types and materials of vacuum suction cups are preferable than others.

The most used vacuum suction cup types are:

Flat Cup:

- For flat or slightly curved surface
- Has good stability

Oval Cup:

- For narrow or elongated surfaces
- Used when High force required

Bellow Cup:

- For uneven surface
- For delicate products

4.2.2 Material

Vacuum suction cups come in a wide variety of materials. The application justifies the material to be used. Some materials are suitable for working with glass, plastics and wood while others are made to cater to more fragile applications (e.g., electronics).

The following table shows some of the suction cups materials offered.

Vacuum Cup Material	Nitrile Butadiene Rubber (NBR)	Silicone	Polychloroprene	Polyurethane
Advantages	• Good compressibility • Wear resistance • elongation • Lowest cost of rubber seals • More readily available in market	• Long life-span, • Best sealant for colder temperatures	• Good weather resistance	• Tear-resistant • Inexpensive • Good load-bearing capacity • Oil-resistant

Disadvantages	• Not suitable for use in polar solvents	• Expensive	• Hardens at low temperature • Expensive	• Poor weatherability

The environment of operation is:

Temperature range(throughout year)	**3**°C - **39**°C
Pressure	1s atm
Object to be moved	Metal sheet
Any liquid nearby	No
Flame in vicinity	No

According to the above environment of operation, Flat NBR suction cups is most suitable.

We are choosing the cups to be flat because our object to be moved is flat. The suction cup will not be in contact with lubricants or flames. Moreover, NBR suction cups are relatively very cheap and more widely used.

4.2.3 Coefficient of friction

The coefficient of friction tells us about how well the suction cups will grip and seal the surface of a workpiece. It gives the relationship between frictional forces and normal forces.

Some generally used values of friction coefficient for different types of workpiece surfaces are:

Surface	Friction Coefficient
Oily surface	0.1
Glass	0.5
Stone	0.5
Dry Plastic	0.5
Wood	0.5
Metal	0.5
Moist or wet surface	0.2 – 0.4
Sandpaper	1.1

4.2.4 Safety Factor

The safety factor of the holding force is adjusted according to the surface conditions of the workpiece. A dense and smooth surface (like sheet metal), a safety factor of 1.5 can be used. On the other hand, a safety factor of 2 can be used for rough, heterogeneous, or oily surfaces.

4.2.5 Holding Force

The holding force of the vacuum suction cup should never exceed the theoretical holding force. The theoretical holding force is calculated as:

$$\mathbf{F = \Delta P \times A.}$$

F = holding force,

ΔP = difference between pressure inside the suction cup and atmospheric pressure

A = effective suction area

We can see from the above formula that the holding force is proportional to the effective suction area. Therefore, the greater the suction area will result in higher holding force.

Vacuum pressure

The formula of holding force is:

$$F = m \times (g + a/\mu) \times S$$

Using the above formula, we find vacuum pressure using the formula:

$$P_0 = \frac{m \times (g + a) \times S}{\mu \times n \times (\frac{d}{1.12})^2}$$

Where,

- F = holding force(N)
- m = weight of the workpiece (kg)
- g = acceleration due to gravity(m/s^2)
- a = acceleration of the system(m/s^2)
- S = safety factor
- μ = coefficient of friction
- d = effective diameter (in cm)
- P_0 = Vacuum (bar)

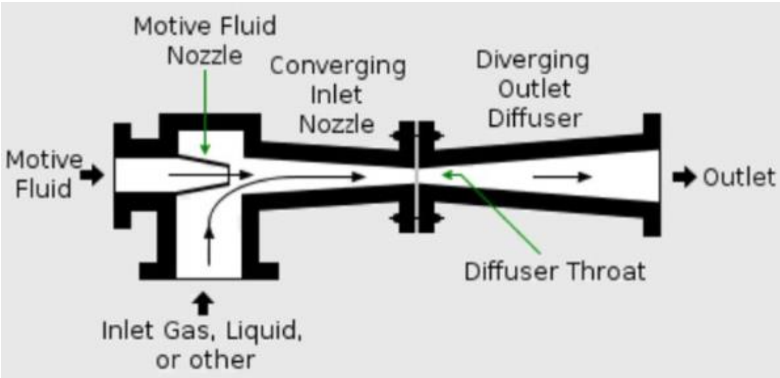
- n = number of suction cups

4.3 Vacuum generators

A vacuum generator is used to generate the required level of vacuum needed using compressed air. Therefore, finding the suction rate is key for proper selection of vacuum generator. Problems arise with low suction rate is that there would be no proper adhesion in the suction cup. On the other hand, if high suction is used then the object could be moved even if there was a clearance between it and the suction cups. This could reduce accuracy, which is the prime goal of this project. So medium suction remains the only valid option. Also, increasing the vacuum line length lead to increase in response time.

4.4 Compressed air

Compressed air is used to produce a venturi effect in the vacuum generator. It is where Bernoulli's principle come into play, which is that air achieves highest speed in the smallest cross-section in a venturi meter resulting in a drop in pressure.



4.5 Hoses

Pneumatic hoses are needed for transporting the compressed air for the grabbing application. The hoses are designed to endure high pressure needed to work with compressed air to prevent any leakages. Thick tubing is required as it does not collapse under vacuum or reasonable temperature. The sizes of the hoses should be such to fulfill the requirement of flow volume and fit the suction cups properly.

4.6 Fittings

Vacuum tools are usually paired with detachable or fixed fittings that connects them to a line of compressed air. If fittings are installed properly, they allow compressed air to follow an appropriate flow path. Fittings come in various sizes, so their selection is dependent on the type and size of suction cup used. The porosity of the handled workpiece, required pressure and temperature for application are is also an important consideration. Moreover, much care is needed to match the right bore size of the fittings and the size of the vacuum line. The most common materials used for fittings are brass and aluminum.

4.7 Valves

In order to monitor the level of vacuum and make sure that compressed air is properly supplied to the system, a valve is used. Different types of valves with different purposes are connected between the suction cups and the source of compressed air. For typical pick and place application using vacuum, the types of valves used are:

- **Non-return valve:** also called check valves, they allow the compressed air to flow in just one direction within the system. Usually installed after the vacuum generator.
- **Compressed air control valve:** usually, pneumatic solenoid valves are used in the compressed air system for controlling the main air supply or the actuators. When these valves open, the air between suction cup and valve is removed which creates a vacuum. This allows the suction cups to stick to the workpiece.

When installing vacuum valves, the direction of the flow of the air needs to be considered carefully. Due to the fact that the valve has air flow in one direction, compressed air is supposed to pass from high pressure port to a lower pressure port. In other words, the vacuum side in the application is supposed to be connected to the outlet.

CHAPTER 5

Structural Optimization

Introduction

The basis of design of the Gantry mechanism is the gantry robot, also known as a Cartesian robot. A gantry robot contains a minimum of three elements of motion, each of which represents a linear motion in a single direction. These motions are arranged to be perpendicular to each other and are typically labeled X, Y, and Z. X and Y are in the horizontal plane and Z is vertical. The interior of this box is referred to as the working envelope, the space in which the robot can move things anywhere. The Gantry Mechanism designed in this thesis, has one more degree of freedom, which is rotation in the X-Y plane. The fourth degree of freedom enables the user to horizontally observe the workspace by rotating the end-effecter.

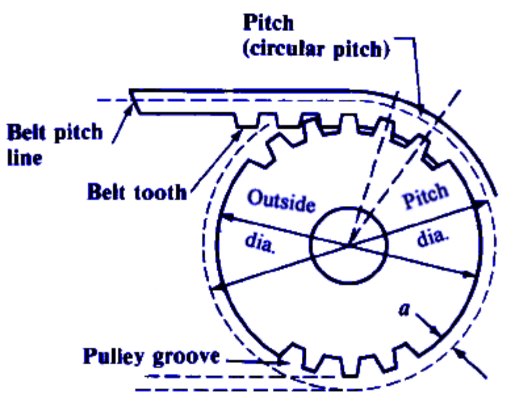
The design of a gantry robot mechanism is also widely known as a cartesian robot mechanism. There are primarily 3 axes motion, which is typically in X, Y, and Z coordinate axes. The working envelope, or the area in which the robot may move objects about freely, is the term used to describe this box's interior.

Design and selection of mechanical parts

The motion in the gantry's X and Y direction is achieved by the timing belts and pulleys assemblies, while the Z direction motion is achieved by the help of rack and pinion mechanism.

Timing belts and pulley

The timing belt is typically used to synchronize the movement of the gantry's drive motors and ensure precise linear motion. The timing belt is connected to a pulley on the drive motor and to a pulley on the gantry's linear guide. As the drive motor turns, the belt moves and causes the gantry to move along the linear guide.



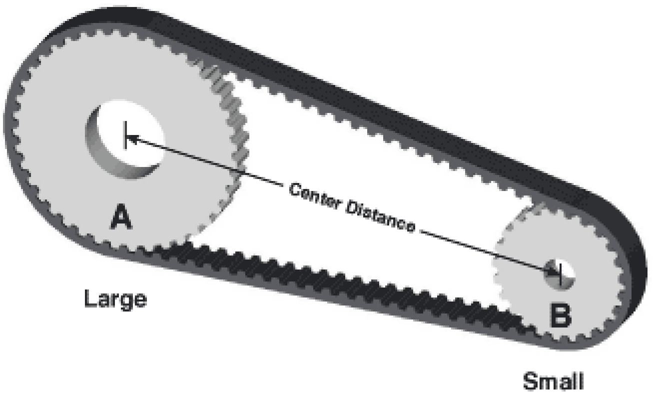


Figure 3 Timing belt and Pulley Explanatory Diagram

Figure 5.1

The timing belt is crucial for ensuring accurate and precise movement of the gantry, and it must be properly tensioned and maintained to prevent issues such as slipping or misalignment. These belts have an operating efficiency of about 98% and they can operate successfully between 8000 and 12000 hrs.

Rack and pinion mechanism

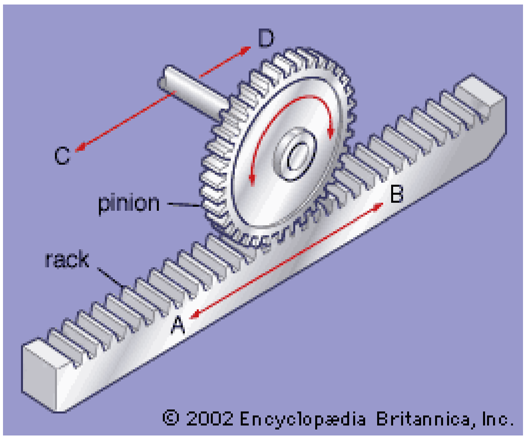


Figure 4 Rack and pinion Labelled Diagram

A particular kind of linear actuator that transforms rotational motion into linear motion is a rack and pinion mechanism. It is composed of a gear (the pinion) and a linear gear (the rack). A motor or other power source turns the pinion, a tiny gear that is attached to a shaft and used as a drive. The rack is a fixed-position linear gear with teeth carved out along one edge. The rack moves along its length because of the pinion's rotational interaction with the teeth on the rack. The pinion's rotational axis determines the direction of the rack's movement.

The rack and pinion mechanism is widely utilized in many different applications, including raising and lowering systems, CNC machines for linear motion, and vehicle steering. They are well-liked for their ease of use, dependability, and excellent weight-to-power ratio. Additionally, they are highly positionally accurate and repeatable.

It is significant to note that regular maintenance, such as lubrication and alignment checks, are necessary for rack and pinion mechanisms to maintain smooth and precise functioning. The gears can soon wear out if they are not properly maintained, leading to backlash and subpar performance.

Computer Aided Design (CAD)

Designing the CAD for the robot has never been easier with the help of online tools like Vention.io. With the help of the web application Vention.io, users can quickly and simply create and buy unique mechanical parts including brackets, connections, and other structural elements. It is a web-based platform that offers a collection of pre-designed components that may be merged and altered to produce a special solution for a certain application. Before placing an order, users may see how their elements will fit together and interact thanks to the tool's 3D depiction of the design.

Additionally, the Vention.io platform makes it simple to share and collaborate, enabling numerous people to work on a design at once. Additionally, users may simply transition between several variations of a design after creating and saving them.

Using this, the design phase was fairly easier as it has already mechanical components which are available in market.

Structural Analysis

A linear gantry robot's structural analysis entails figuring out the structure's overall strength and stiffness as well as forecasting how the robot will respond to different loading scenarios. The base, the column(s), the crossbeam(s), and the moving platform are the principal parts of a linear gantry robot that require structural analysis.

The robot's base serves as the framework for the entire construction and must be sturdy enough to handle the robot's own weight as well as any payloads it could be carrying. The robot's main load-bearing components are its column(s) and crossbeam(s), and both of these components must be built to withstand the forces produced by the moving platform and any external loads. The moving platform, often known as the "gantry," must be created in such a way that it can move smoothly and precisely along the column(s) and crossbeam while supporting the cargo (s).

FEA is commonly used to analyze the structural behavior of a linear gantry robot. The robot is modeled as a collection of interconnected elements, and various loading conditions are applied to the model to simulate real-world scenarios. The results of the analysis can be used to optimize the design of the robot and ensure that it can safely and reliably perform its intended tasks.

It is important to note that the structural analysis is just one part of the design process of a robot. Other considerations such as kinematics, dynamics, control and safety must also be taken into account to ensure the robot will function properly.

Finite Element Analysis (FEA)

A numerical technique called finite element analysis (FEA) is used to investigate and resolve issues involving complicated systems of differential equations. The behaviour of structures, fluids, and other physical systems under diverse situations is frequently studied in engineering and physics. In FEA, a complicated system is broken down into smaller, easier components, and the overall behaviour of the system is calculated by solving equations for each of these components. The technique may be used to improve designs and spot possible weak spots since it accurately predicts how a system will react to different loads and boundary conditions.

After designing the basic Frame for our Gantry, the next phase starts which is the analysis. To make sure the design is able to withstand the physically critical conditions.

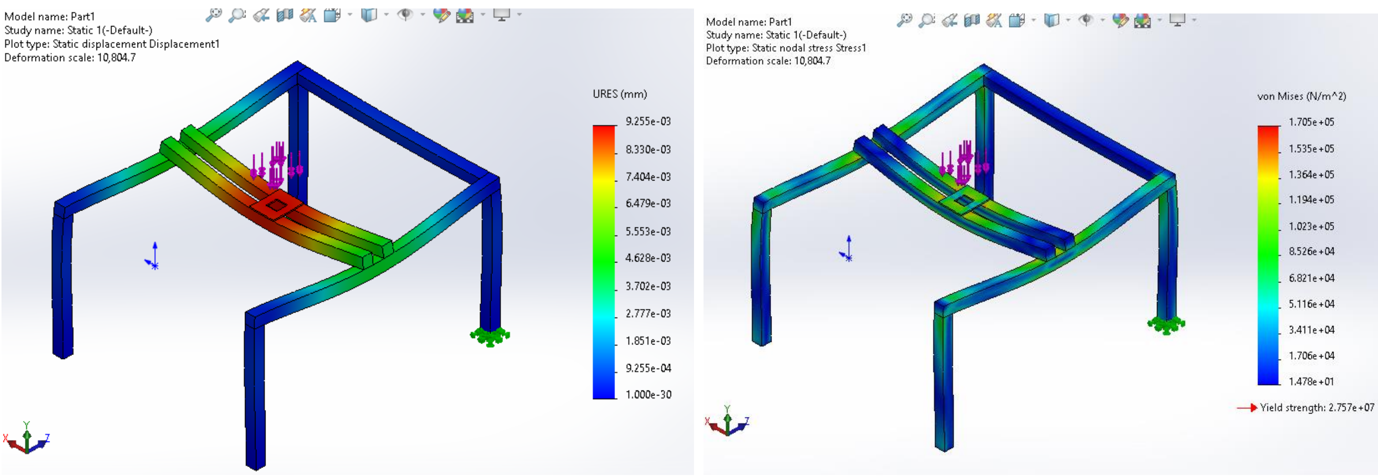


Figure 5 Showing the results of Von Mises Stress and Maximum Deformation

The analysis were performed on SolidWorks, with a force of 20N for the end factor and the overall weight of the target mass. The results from the simulation give us the value of maximum stress 1.07x10^5 N/m^2 yet the maximum deformation is merely 9.225e-5 mm. As the application is not load intense, structural optimization isn't our main point of concern.

CHAPTER 6

6.1 Sourcing

Components:
A liner gantry system is a type of automated material handling system that is used to move and position heavy loads. The components of a liner gantry system include pumps, motors, extrusions, rack drivers, pinion gears, suction cups, sliding bearing assemblies, timing belt assemblies, timing belts, pipes, and motor mounts. These components work together to provide the necessary power and movement to position and move the heavy loads. The pumps and motors provide the necessary power to move the gantry, while the extrusions, rack drivers, pinion gears, suction cups, and sliding bearing assemblies provide the necessary movement and positioning. The timing belt assemblies, timing belts, pipes, and motor mounts help to keep the system running smoothly and efficiently. Overall, the liner gantry system is a complex system that requires a variety of components to function properly.

Pumps: Pumps are used in a liner gantry system to provide the necessary fluid power to move the gantry. The type of pump used will depend on the specific application and the materials being moved. For example, a high-pressure pump may be used for moving heavy loads, while a low-pressure pump may be used for more delicate materials.

Motors: Motors are used to convert electrical energy into mechanical energy to power the pumps and other components of the liner gantry system. The type of motor used will depend on the specific application and the materials being moved. For example, a high-torque motor may be used for moving heavy loads, while a low-torque motor may be used for more delicate materials.

Extrusions: Extrusions are used to provide structural support and stability to the liner gantry system. They are typically made of aluminum or steel and are designed to withstand the weight and forces of the heavy loads being moved.

Rack drivers: Rack drivers are used to convert rotary motion into linear motion. They are typically used to move the gantry along a set path.

Pinion gears: Pinion gears are used to transfer power from the motor to the rack driver. They are typically used to move the gantry along a set path.

Suction cups: Suction cups are used to hold and move materials securely. They are typically used to hold and move delicate materials without causing damage.

Sliding bearing assemblies: Sliding bearing assemblies are used to support the gantry and allow for smooth movement. They are typically used to reduce friction and wear on the system.

Timing belt assemblies: Timing belt assemblies are used to transfer power and movement between components of the liner gantry system. They are typically used to synchronize the movement of the gantry and other components.

Timing belts: Timing belts are used to transfer power and movement between components of the liner gantry system. They are typically used to synchronize the movement of the gantry and other components.

Pipes: Pipes are used to transport fluids, such as oil or water, to and from the various components of the liner gantry system.

Motor mounts: Motor mounts are used to secure the motors to the gantry. They are typically used to reduce vibration and noise and to protect the motors from damage.

Motor gears: Motor gears are used to transfer power from the motor to other components of the liner gantry system. They are typically used to increase or decrease the speed of the gantry and other components.

Component	Quantity	Price	Properties
Pump	1		
Motors	5	Rs.1900-Nema17 Rs.1600-Nema23	• Nema17 • Nema 23
Extrusions	10	Rs.1330-800mm Rs.1600-1000mm	• Length-800mm & 1000mm • Cross section 20x20mm • Material: Aluminum Alloy 6063-T5
Rack Driver	1	Rs.5200	• Linear Actuator 12V, • DC Linear Actuator, • Maximum Push/Pull Up to 500N,
Pinion Gears	1	Rs.10	• Material: Plastic • Tooth profile: Herringbone Gear • Shape: Cylindrical Gear • Size: 6mm x 5mm x1.95mm • Teeth: 10 teeth
Suction Cups	5	Rs.250	• Inlet Diameter:5mm
Sliding Bearing Assemblies	5		
Timing Belts	4	Rs.300	• Body Material: Neoprene Rubber • Tooth Facing Material: Nylon • Width: 6 (mm) • Pitch: 2 (mm)

Pipes	2	Rs.350	• Diameter 5mm
Motor Mounts	5	R230	• Mounting plate size: NEMA 17 • Thickness: 3mm • Gross weight: 95g • Material: Mild steel
Motor Gears		Rs.200-400	• 26 Teeth • Bore=5mm • Outer Diameter=11mm • Height=11mm

SUMMARY/LIMITATIONS

The problem itself is extensively identified in the chapter 1 using based on the end customer requirements. Then, for those requirements, this report highlights the decision matrices for various actuator selection mechanisms depending upon various deciding parameters in chapter 2. In chapter 3, numerical methodology of motor calculations is being explained depending upon the loads for each machine component. Furthermore, chapter 4 of the thesis explains the structural stability analysis on Ansys.

In chapter 5, we have compiled sourcing of each machine components with its price range and specifications required. Later on, in chapter 6, the recommendations for future work has been explained based on the current research going on gantry robots.

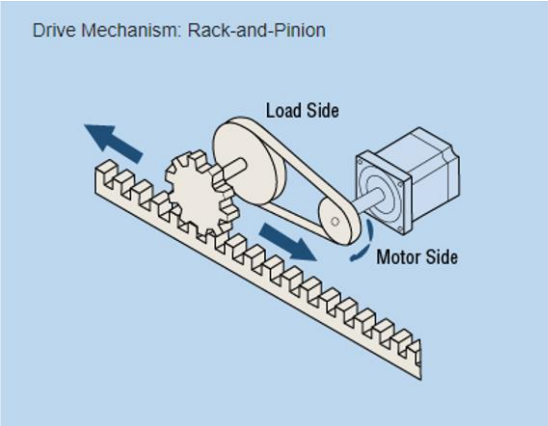
Recommendations for Future Work

Machine Learning: Preventive Maintenance is significant, as it reduces the total operational costs for the linear gantry robotic system, hence making automated assembly lines more lucrative for industries. Hence, new non-contact measurement technique has been introduced for monitoring the integrity of ball screw actuators. The monitor balls are used on ball screw actuators using Hall effect sensors to detect faults. Data are post-processed with a new approach based on time domain analysis [1]

Magnetic lead screws (MLS): have many desirable characteristics applicable to modular robots, including a tolerance for slight misalignments, high efficiency, zero backlash, robustness, inherent series elasticity, high force capability, and the ability to gracefully separate and reattach. Motivating this work is the core idea that high performance actuators as well as inexpensive, precise and repeatable connectors are the key ingredients required for useful real-world self-reconfiguring machines. [2]

APPENDIX

Motor Selection 1:



Selection Parameters for Rack and Pinion Drive

Selection Parameters	**Contribution**	**Values**
Load Mass	Payload	0.3 kg
	End Effector Plate	
	Cuppings	
Pinion	Diameter	0.24kg
	Mass	48 mm
	Efficiency	0.1 kg
Force	External Force	2.95 N
	Drive Mechanism Angle	90 deg
Friction Coefficient of Guide	Supporting Box (Aluminum) with PLA	0.28

Calculation Method: Travel Amount Time

Operation Pattern: Acceleration/Deacceleration

Instantaneous Stop: No

Results		Units
Load Torque	0.204	Nm
Maximum Speed	79.58	(r/min)
Load Inertia	3.398 x10^(-4)	(kg/m^2)
Rotation	200	(mm/s)
Speed Reduction Ratio	1	

Product Type:
Single Phase: 220 VAC

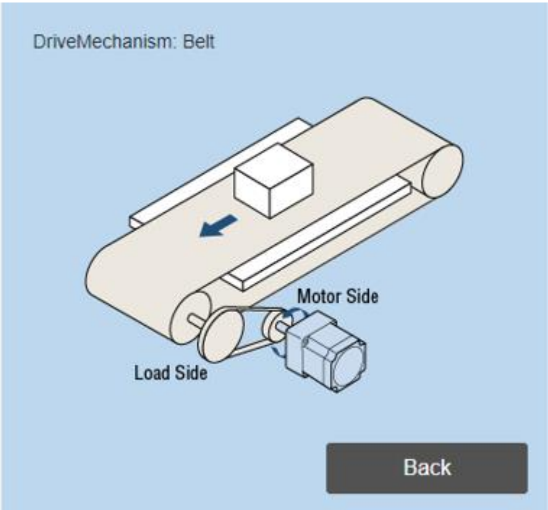
Electromagnetic Brake: Equipped

Gear Type: Planetary Gear

Driver Type: Pulse Input

Safety Factor: 1.5

Motor Selection 2:



Selection Parameters	Contribution	Values	Units
Load Mass	Payload	1.5	kg
	End Effector Plate		
	Cuppings		
Puley	Diameter	25.4	mm
	Mass	0.01	kg
	Efficiency	0.9	
Force	External Force	16.4	N
	Drive Mechanism Angle	0	deg
Friction Coefficient of Guide	Aluminium on Aluminium	0.1	

Results		**Units**
Load Torque	0.252	Nm
Maximum Speed	79.58	(r/min)
Load Inertia	2.427 x10^(-4)	(kg/m^2)
Rotation	200	(mm/s)
Speed Reduction Ratio	1	

Pneumatic Suction Calculations:

$d = 2.5\ cm$

$S = 1.5$

$\mu = 0.5$

$g = 0.5\ m/s^2$

$$a = 1.0\ m/s^2$$

$n = 3$

$$m = 0.1\ kg$$

Substituting the available data into the formulae above,

$$P_0 = \frac{0.1 \times (9.81 + 1) \times 1.5}{0.5 \times 3 \times (\frac{2.5}{1.12})^2}$$

$$\boldsymbol{Po = -0.22\ Bar}$$

REFERENCES:

[1] A. Garinei and R. Marsili, “A new diagnostic technique for ball screw actuators,” *Measurement*, vol. 45, no. 5, pp. 819–828, Jun. 2012, doi: 10.1016/j.measurement.2012.02.023.

[2] “Self-Reconfiguring Robotic Gantries Powered by Modular Magnetic Lead Screws.” https://ieeexplore.ieee.org/abstract/document/9811863 (accessed Jan. 15, 2023).