International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 05 | May 2023 www.irjet.net p-ISSN: 2395-0072

Design, Simulation & Optimization of Gravity Spiral Roller Conveyer with Auto Collision Avoidance System

Mr. Pratik Anil Chougule[1], Mr. Manohar Milind Pitre [2], Mr. Gaurav Kadu Bhamare[3], Ms. Anushka Rajesh Gorad[4] , Mrs. Ami R. Barot[5]

[1,2,3,4]BE Mechanical Students, Mechanical Engineering Department, Pune Vidyarthi Griha's College of Engineering and Technology and G.K. Pate (Wani) Institute of Management, Pune – 411009
[5]Project Guide & Assistant Prof. Mechanical Engineering Department, PVG's COET & GKPIOM, Pune – 411009

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Abstract - *The aim of this paper is to design, simulate, analyze and optimize the vertical gravity spiral roller conveyor for defined problem statement of 5 storey building. This paper also aims to design an advanced auto collision avoidance system to avoid collision of wooden boxes coming from previous floor and the entry from current floor using mechatronics system. Solid modelling was done using CAD software and linear, modal analysis using finite element analysis software. Design is optimized for weight reduction, cost effectiveness without affecting its strength and durability. This paper also includes mathematical calculations, conceptual and detailed design with analysis for various parts of conveyor system which are designed.*

Key Words: **Material Handling, Spiral Conveyor, Optimized Design, Reduced Weight, Collision Avoidance**

1.INTRODUCTION

Conveyors are machines used for continuously or intermittently moving bulk or unit loads from one point to another along a fixed path. The primary function of a conveyor is to transport materials. Roller conveyors, specifically, consist of a series of rollers mounted on bearings between two side frames that are supported by stands or trestles placed on the floor. The rollers are spaced in a manner that ensures that the unit load is supported by at least three rollers at all times.

Roller conveyors are categorized into two groups: unpowered and powered. Unpowered roller conveyors rely on manual force or a moving chain or rope or gravitational force to move the loads, while powered roller conveyors are driven by one or more motors. The powered conveyors can be installed at a slight incline and can move the load in either direction by changing the direction of the roller rotation. Roller conveyors are suitable for conveying unit loads with a rigid, flat surface and are widely used in various industries such as manufacturing, assembly, packaging, and warehousing. However, they are limited in that they can only be used for objects with rigid flat surfaces and for relatively short distances. Additionally, gravity roller conveyors require side guards to prevent the load from falling off and have the risk of accelerating loads.

2. PROBLEM DEFINITION

To design a vertical gravity spiral conveyor for transfer of boxes of maximum sizes 2ft × 2ft × 1.5ft weighing 60 kg each and for 5 story building from 5th, 4th, 3rd, 2nd, 1st to ground floor to dispatch.

Table -1: Components of designed conveyor system:

Sr. No	Component	Material	Qty.
1.	Roller	Mild Steel	464
2.	Bearing	OEM	928
3.	Shaft	Mild Steel	464
4.	Frame	Mild Steel	1

3. OBJECTIVES

1. To study the existing conveyor systems
2. To design the optimized solution for defined problem statement
3. To reduce the weight and cost of overall system.
4. To implement the automatic system for collision avoidance of boxes.

4. SCOPE OF WORK

1. Design of Helix angle based on principle of conservation of energy for vertical gravity spiral conveyor.
2. Design of roller (shaft, pipe, bearing and sealing arrangement)
3. Identification of number rollers in contact with each box based on minimum and maximum box sizes.
4. Design of spiral conveyor with box entry at every floor.

5. Solid model of vertical gravity spiral conveyor (using CAD software).
6. Simulation, static structural and modal analysis of spiral conveyor using analysis software.
7. Preparation of Detailed manufacturing drawings and Bill of Material (BOM) for Spiral Conveyor.

5. STUDY OF EXISTING CONVEYOR SYSTEMS

Conveyor systems are material handling systems that are designed to transport materials, products, and packages from one place to another. They play a crucial role in industries such as manufacturing, distribution, and warehousing, and are often used to transport heavy, bulky, or awkward items that would be difficult to move by hand.

There are several types of conveyor systems, each designed to meet specific needs and requirements. Here are some of the most common types of conveyor systems:

Belt Conveyors: These are the most commonly used conveyors and are ideal for transporting products that require continuous handling. They use a continuous belt to move items along a horizontal or incline path.

Roller Conveyors: These are used for heavy-duty loads and are particularly useful for transporting products that are awkward to handle, such as large boxes or crates. They consist of a series of rollers that rotate to move items along a horizontal path.

Chain Conveyors: These are similar to roller conveyors and are used for heavy-duty loads. They use chains to move items along a horizontal or incline path.

Flexible Conveyors: These are designed to handle light to medium loads and are ideal for transporting items in tight spaces or around corners. They consist of a flexible belt that can bend and turn to follow the desired path.

Spiral Conveyors: These are used for vertical transportation and are ideal for moving products up or down between levels. They consist of a spiral conveyor belt that rotates to transport items vertically.

Pneumatic Conveyors: These are used for transporting lightweight products and use air pressure to move items along a horizontal or incline path. They are ideal for handling delicate or fragile items.

Overhead Conveyors: These are used for moving products along an overhead path and are ideal for transporting items in a factory or warehouse. They consist of a series of trolleys that move along an overhead track.

Conveyor systems play a vital role in the efficient handling of materials, products, and packages in various industries. By selecting the right type of conveyor system for a specific application, businesses can improve productivity, reduce costs, and ensure the safe and efficient transportation of their goods.

6. DESIGN OF PARTS IN CONVEYOR SYSTEM

Parts designed:

1. Roller Assembly
2. Frame
3. Column

6.1 DESIGN OF ROLLER ASSEMBLY:

Roller pitch in a gravity roller conveyor design refers to the spacing between the rollers that support the load. The maximum pitch should not be more than half the length of the load being carried and even less for goods that are sensitive to jerks or shaking.

The design calculations in this conveyor focus on determining the force needed to move the load and the incline angle required for the conveyor to work. The resistance to motion of the load is made up of:

1. Friction between the load and rollers.
2. Friction in the roller bearings.
3. The resistance from the load sliding on the rollers and the force required to get the rollers moving.

Table -2: Standards for roller parameters:

Roller Parameters	Type of Roller		
	Medium	Heavy	Extra Heavy
Roller diameter, mm	73	105	155
Maximum load per roller, kg.	300	600	1200
Axle diameter at the journal, mm	20	30	45

Rolling resistance:

$$tan\theta = \frac{Rise}{Run} \quad ; \quad F_{Fr} \cdot r = Rf \quad ; \quad Fr_{Fr} = \frac{Rf}{r}$$

$$tan\emptyset = \frac{F_{Fr}}{W} \quad ; \quad F_{Fr} = Wtan\emptyset \quad ; \quad F_{Fr} = Wsin\emptyset$$

$$F_{Fr} = \frac{W \cdot f}{r} \quad ; \quad F_1 = \frac{W \cdot k}{R}$$

Frictional resistance on roller journal:

$$F_2 = \frac{(W_{total}) \cdot \mu r}{R} \quad ; \quad F_2 = \frac{(W + wn') \cdot \mu r}{R}$$

w = Weight of each roller

n' = Number of rollers supporting load

r = Journal radius

W' = Part of weight of each load carried by each roller

$\mu_\circ$ = Kinetic coefficient of friction

Friction sliding force during time t' is = $W'\mu_\circ$

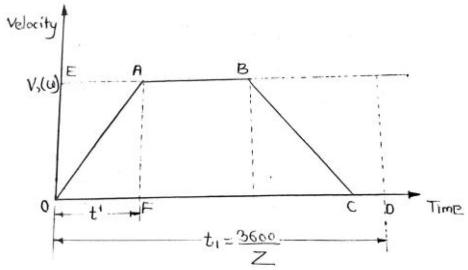


Fig -1: Velocity Diagram

Work done by the load = $\omega'\mu_\circ vt'$

Where, vt' = Distance moved by load

t' = time ; v = Linear velocity of load

Distance travelled by any point on the periphery of the roller will be $\frac{vt'}{2}$ (area OAF),

Which is also sliding path. This shows that half of the work done by load is spent in overcoming the friction and other half is used in imparting kinetic energy to the roller.

If $'w'$ is weight of roller, then KE

$$KE = 1/2[w/g](v^2q)$$

$q =$ factor of value between 0.8 to 0.9 because not all the mass of the roller moving parts is on the periphery not moving with velocity V

Therefore, work done due to sliding & acceleration of one roller is given by,

$$= 2 \times 1/2 \times (w/g) \times v^2q$$

$$= \frac{wv^2q}{g}$$

There are 'n' number of rollers in a total length 'L', Total work done in 'n' number of rollers for moving one load throughout the length of conveyor.

$$= \frac{n\,wv^2q}{g}$$

Average resistance to motion on one load due to sliding & acceleration,

$$F_{3'} = \frac{nwv^3q}{gL}$$

If there are $Z_\circ$ number of loads moving simultaneously on the conveyor, then average total resistance dur to sliding & acceleration will be,

$$F_3 = \frac{Z_\circ nwv^2q}{gL} \cdots (iii)$$

∴ Total resistance to motion of the loads, which is the force required to move the loads on a unpowered conveyor is,

$$F = F_1 + F_2 + F_3$$

$$F = \left[\frac{W \times k}{R}\right] + \left[(W + wn') \times \frac{\mu r}{R}\right] + [q \times (Z_\circ nwv^2/gL)] \cdots (iv)$$

We can define equivalent resistance to motion factor $'f'$ by an equation, $F = Wf$

$$\therefore f = \frac{F}{W} = \frac{F_1}{W} + \frac{F_2}{W} + \frac{F_3}{W}$$

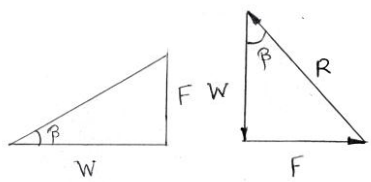
$$f = (\frac{k}{R}) + [(1 + \frac{wn^1}{W})(\frac{\mu r}{R})] + [q \times (\frac{Z_\circ nwv^2}{gLW})$$

let, D = Roller diameter = 2R

d = Journal diameter = 2r

$$\therefore f = [\frac{2K}{D}] + \{[1 + (\frac{wn'}{W})] \times (\frac{\mu d}{D})\} + \{q \times (\frac{Z_\circ nwv^2}{gLW})\}$$

For calculating the minimum inclination angle 'β' of a gravity conveyor, which will allow movement of a load due to gravity only, resistance to only one load need to be considered, which should be overcome by the component of gravitational force on the load along inclination of the conveyor.



$$f = tan\beta = \frac{F}{W'}$$

$$f = [\frac{2k}{D}] + \{[1 + (\frac{wn''}{w'})] \times [\frac{\mu d}{D}]\} + [q \times (\frac{nwv^2}{gLw'})]$$

n'' = number of rollers supporting each load

G' = Weight of each load = $\frac{n'}{Z_\circ} = \frac{G}{Z_\circ}$

$$\therefore n''/G' = \frac{[n'/Z_\circ]}{[W/Z_\circ]} = \frac{n'}{W}$$

$$\therefore tan\beta = [\frac{2k}{D}] + \{[1 + (\frac{wn'}{W})] \times [\frac{\mu d}{D}]\} + [q \times (\frac{Z_\circ nwv^2}{gLW})]$$

Roller Calculations:

Pitch = 200 mm [At any time, a minimum of 3 rollers will be in contact with load]

Total length of conveyor = 2 meters = 2000 mm

No of roller necessary = 2000/200 = 10

$K = rolling friction factor (wood - steel) = 1.2$

$D = Roller\ diameter = 73\ mm$

$w = Weight\ of\ roller = 5.4\ Kg$

$n' = 3 \cdots (Number\ of rollers\ under\ load)$

$w = 120kg$

$\mu = Coefficient\ of\ friction\ at\ journel = 0.5$

$d = Journal\ diameter = 30\ mm$

$q = Factor\ of\ Value\ 0.8\ to\ 0.9\ because\ not\ all\ the\ mass\ of\ the\ roller\ moving\ parts\ is\ on\ periphery$

$z_0 = number\ of\ load\ moving\ simultaneously\ on\ the\ conveyor = 1 (Assumed)$

$n = number\ of\ rollers = 10$

$v = Linear\ velocity\ of\ load = 0.2m/s\ (Assumed)$

$g = 9.81\ m/s^2$

$L = Total\ lenght = 2m$

$$tan\beta = \left[\frac{2 \times 1.2}{73}\right] + \left[1 + \left(\frac{5.4 \times 3}{120}\right)\right] \times \left[0.5 \times \frac{30}{73}\right] + \left[\frac{8 \times 5.4 \times 0.22}{9.81 \times 2 \times 120}\right]$$

$= 0.264$

$\beta = 14.82^\circ \approx 15^\circ$

$c = P \times (1/3) \times 194.472$

Bearing Selection:

For simplicity, deep groove ball bearing is used.

Relationship between dynamic load carrying capacity, equivalent dynamic load & bearing life:

$L_{10} = [c/P]^n$

$c = Basic\ dynamic\ load$

$P = Equivalent\ dynamic\ bearing\ load$

$n = Exponent\ of\ the\ life\ equation$

$-for\ ball\ bearings, n = 3\ (Point\ Contact)$

$-for\ roller\ bearings, n = (10/3)(Line\ Contact)$

Relationship between life in million revolutions and life in working hours is given by:

$L_{10} = 60nL_{10h}/10^6$

$L_{10h} = Rated\ bearing\ life(hrs)$

$n = rpm$

$P = (weight\ of\ load + weight\ of\ rollers) \times 9.81$

$= (120 + 5.4) \times 9.81 = 1230.174\ N$

$V = (\pi Dn)/60$

$0.2 = (\pi \times 0.105 \times n)/60$

$n = 36.38\ rpm$

$L_{10h} = 20000 \cdots [For\ 1\ shift\ operation\ minimum\ L_{10}\ life\ hours\ from\ table]$

$L_{10} = (60 \times 37 \times 20000)/10^6 = 44.4$

$C = 1230.174 \times (44.4) \times (1/3) = 4356.06\ N$

6.2 DESIGN OF FRAME:

For Mild steel:

$E = 2.10 \times 10^5 MPa$; $\rho = 7860\ Kg/m^3$

$\sigma_{yt} = 590\ Mpa$

Constant UDL & FOS = 2

$$\sigma_{allowed} = \frac{\sigma_{yt}}{FOS} = 295\ Mpa$$

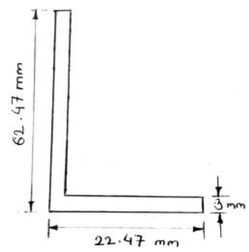
60 Kg weight is acting on the rollers then total 200 kg is acting for 10 rollers at a time + additional (2.5×10)

$Total\ Load = 200 + 25 = 225\ Kg\ on\ both\ channel$

$$Total\ load = \frac{225}{2} = 112.5Kg\ on\ each\ channel$$

$\sigma_{allowed} = 295\ Mpa$

L Channel:



$L = 2060mm$; $h = 62.47mm$; $w = 22.47mm$

$t = 3mm$

Considering SSB with UDL,

$$\frac{wL^2}{8} = \frac{WL}{8}$$

$w = UDL \ in \ Kg/m$; $L \ in \ meter$

$$= \frac{112.5 \times 2.06 \times 9.81}{8}$$

$$= 284.18 \ Nm$$

$$Max \ \sigma_b = M_{max} \times y/I \cdots (\sigma_b = Bending \ stress)$$

$$= \frac{M_{max}}{Z}$$

$$Z = (bh^2/6) - \left[\frac{(b-t) \times (h-t)^2}{6}\right] \cdots Section \ modulus \ for \ L \ section$$

$$= \left[\frac{22.47 \times 62.47^2}{6}\right] - \left[\frac{(22.47-3) \times (62.47-3)^2}{6}\right]$$

$$Z = 224657.22 mm^3$$

$$Z = 0.00022465 m^3$$

$$\sigma_b = \frac{284.18}{0.00022465} \ ; \quad \sigma_b = 1264989.984 \ N/m^2$$

$$\sigma_b = 1.264 Mpa$$

Max Defection,

$$y_{max} = \frac{5wL^4}{384EI} \cdots (w = load \ per \ unit \ lenght \ for \ UDL)$$

$$y_{max} = \frac{5WL^3}{384EI} \cdots (Total \ load \ W = w \times L)$$

$$= \frac{5 \times 112.5 \times 2.06^3 \times 9.81}{384 \times 2.10 \times 10^{11} \times 4.8299 \times 10^{-6}}$$

$$= 1.2387 \times 10^{-4} m$$

As compared to length 2060mm deflection of 0.123mm is very negligible hence selected channel is safe.

7. CAD MODELLING USING SOLIDWORKS SOFTWARE:

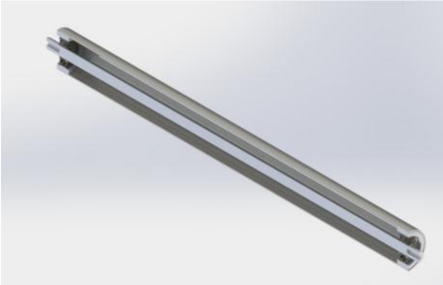


Fig -2: CAD Model of roller assembly

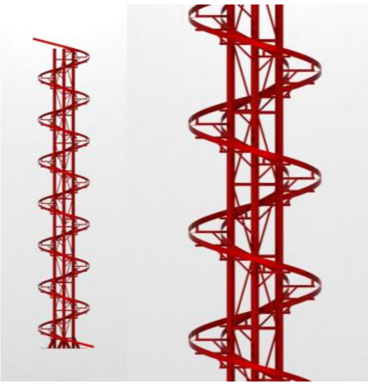


Fig -3: CAD Model of Frame

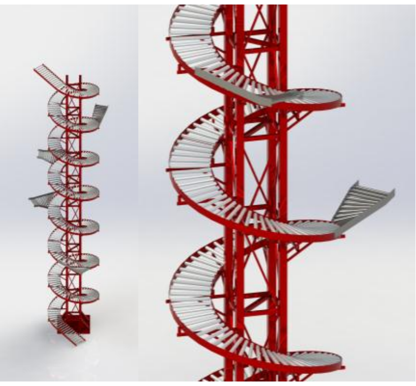


Fig -4: CAD Model of overall assembly

8. ANALYSIS AND OPTIMIZATION:

We have used Ansys software for Computer Aided Analysis of designed components.

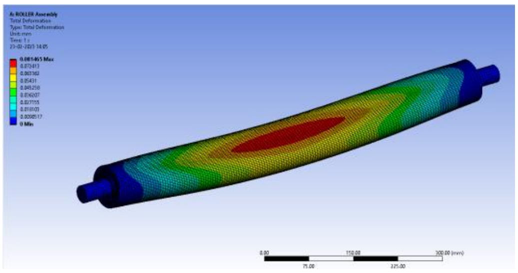
8.1 STATIC STRUCTURAL ANALYSIS:

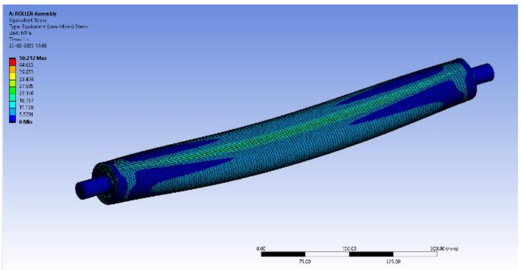
A static analysis is a method that calculates the impact of constant loads on a structure, while ignoring the effects of inertia and damping caused by varying loads over time. However, static analysis can still consider steady inertia loads such as gravity and rotational forces. This method can be used to design and analyze roller conveyors for weight optimization and material savings based on their velocity. Additionally, time-varying loads can be approximated as static equivalent loads, such as wind and seismic loads commonly defined in building codes. To perform a static analysis, elements are selected, and material properties are applied to determine the displacement, stress, strain, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. The analysis assumes that the loads and the structure's response change slowly over time, and the conditions remain constant.

Critical load condition:

Load act on any three rollers hence by considering 120kg load act on three rollers maximum deflection, maximum stress values are checked for existing design.

Static Structural Analysis of roller:





Stress: 50.212 MPa

Strain: 0.081 mm

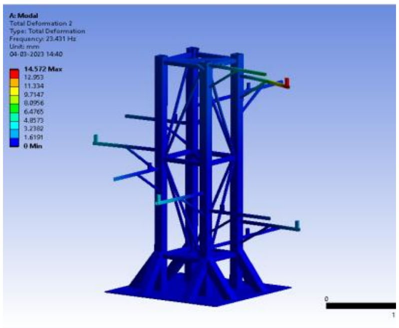
FOS: 250/50.212 = 4.97

8.2 MODAL ANALYSIS:

Modal analysis is a technique used to identify the natural frequencies and mode shapes of a system. It helps to create a mathematical model that describes the system's dynamic behavior by determining its inherent dynamic characteristics like natural frequencies and damping factors. When the loading is in the vertical direction due to gravity, it is essential to identify the mode shapes that demonstrate movement in the same direction. Modal analysis helps engineers to understand the dynamic characteristics of a structure, how it responds to different types of dynamic loading, and avoid resonant vibrations that can cause damage. It is an essential tool for engineers to optimize the design and ensure the safety of the structure.

Design	Weight (Ton)	% Material required compared to earlier design	% Material saved compared to earlier design
Using Truss over round column	6.1737	80.45%	19.55%

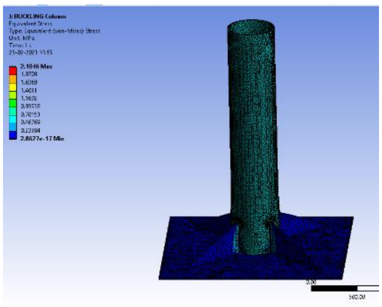
Modal Analysis of Designed Truss frame:



Deformation: 14.572 mm

Frequency: 23.431 Hz

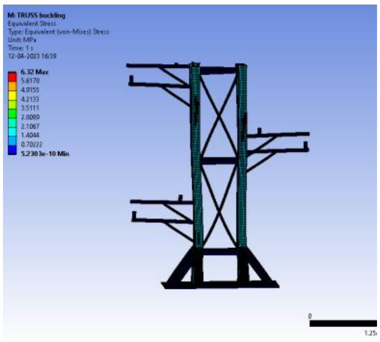
8.3 COMPARISON BETWEEN COLUMN AND TRUSS FOR DESIGN OF FRAME:



Stress: 2.104 MPa

Strain: 0.009 mm

FOS: 250/2.104 = 118.5



Stress: 6.32 MPa

Strain: 0.032 mm

FOS: 250/6.32 = 39.55

Design	Max. Def (mm)	Natural Freq. (Hz)
Column	25.008 mm	25.983 Hz
Truss	24.379 mm	25.822 Hz

The maximum deflection of Truss is at 25.822 Hz which is less than the natural frequency of column.

As factor of safety of roller sub assembly and rollers is very high there is scope of weight reduction in this component.

Also factor of safety of other components like frame and supports is also greater than 1.5 so we can reduce the weight.

9. AUTO COLLISION AVOIDANCE SYSTEM:

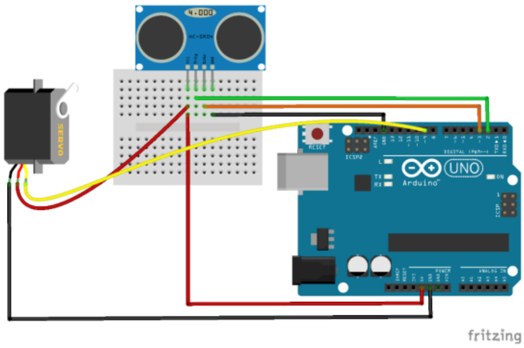
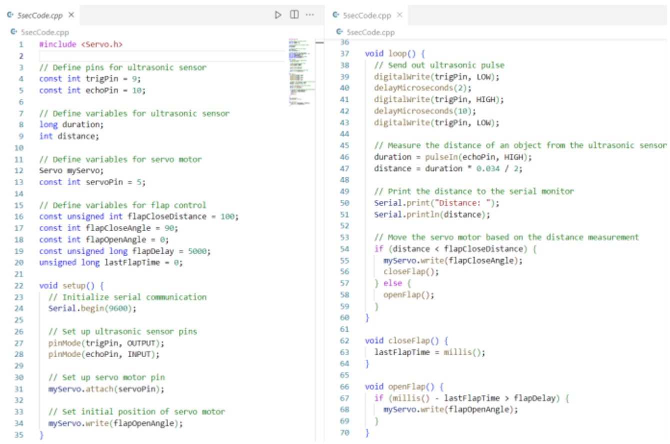


Fig -4: Circuit Diagram



```
#include <Servo.h>

// Define pins for ultrasonic sensor
const int trigPin = 9;
const int echoPin = 10;

// Define variables for ultrasonic sensor
long duration;
int distance;

// Define variables for servo motor
Servo myServo;
const int servoPin = 5;

// Define variables for flap control
const unsigned int flapCloseDistance = 100;
const int flapCloseAngle = 90;
const int flapOpenAngle = 0;
const unsigned long flapDelay = 5000;
unsigned long lastFlapTime = 0;

void setup() {
  // Initialize serial communication
  Serial.begin(9600);

  // Set up ultrasonic sensor pins
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);

  // Set up servo motor pin
  myServo.attach(servoPin);

  // Set initial position of servo motor
  myServo.write(flapOpenAngle);
}

void loop() {
  // Send out ultrasonic pulse
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // Measure the distance of an object from the ultrasonic sensor
  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034 / 2;

  // Print the distance to the serial monitor
  Serial.print("Distance: ");
  Serial.println(distance);

  // Move the servo motor based on the distance measurement
  if (distance < flapCloseDistance) {
    myServo.write(flapCloseAngle);
    closeFlap();
  } else {
    openFlap();
  }
}

void closeFlap() {
  lastFlapTime = millis();
}

void openFlap() {
  if (millis() - lastFlapTime > flapDelay) {
    myServo.write(flapOpenAngle);
  }
}
```

Fig -5: C++ Code for Arduino Uno

In this code, the **closeFlap()** function is called whenever a box is detected within the range of 100 cm of the ultrasonic sensor. This function sets the position of the servo motor to **flapCloseAngle**, which should close the flap attached to the servo motor. Additionally, the **lastFlapTime** variable is updated to the current time using the **millis()** function, which will be used to determine when to open the flap again.

The **openFlap()** function is called when a box is not detected within range of the ultrasonic sensor. This function checks if at least 5 seconds have passed since the last time the flap was closed using the **lastFlapTime** variable and the **millis()** function. If at least 5 seconds have passed, the position of the servo motor is set to **flapOpenAngle**, which should open the flap attached to the servo motor.

Note that we may need to adjust the values used for distance measurements and flap control based on specific needs and hardware setup. Additionally, we may need to adjust the **myServo.attach(servoPin)** line to use the correct pin for our servo motor.

10. CONCLUSIONS

1. Designed optimized vertical gravity spiral conveyor for transfer of boxes of maximum sizes 2ft × 2ft × 1.5ft weighing 60 kg each and for 5 story building from 5th, 4th, 3rd, 2nd, 1st to ground floor to dispatch.
2. Reduced weight by 20% using truss column over round column.
3. Implemented Auto Collision Avoidance system to avoid collision between boxes.

11. ACKNOWLEDGEMENT

We are acknowledging **Mr. Mahendra Khollam** (MD, Mahendra Technologies, Pune), **Prof. Dr. H.G.Phakatkar** (Phakatkar Engineering Academy), **Prof. Ami Barot** (Project Guide, Mechanical Department, PVG's COET, Pune), **Prof. Dr. M. M. Bhoomkar** (HOD Mechanical Department, PVG's COET, Pune) for kind guidance and support.

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13. BIOGRAPHIES

Mr. Pratik Anil Chougule
BE Mechanical student at
PVG's COET, Pune.

Mr. Manohar Milind Pitre
BE Mechanical student at
PVG's COET, Pune.

Mr. Gaurav Kadu Bhamare
BE Mechanical student at
PVG's COET, Pune.

Ms. Anushka Rajesh Gorad
BE Mechanical student at
PVG's COET, Pune.