Bottle Filling Production Line
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Introduction

A production line is a set of sequential operations established in a factory whereby materials are put through a refining process to produce an end product that is suitable for onward consumption or components are assembled to make a finished article.

Early production lines were linear with many starts and stops for the whole process, newly rotary production line was produced to get continuous operation with very big afford capacity.

The purpose of this project is to design a rotary production line for bottle filling process, shortly the whole process is aim to get a filled bottles with cap from empty bottles.

This report will include the mechanical, electrical and control design depending on the user requirements that we specify.

Conveyor Belt Standards

The available standard in this system is for conveyor belt only, since all components have many standard and many companies.

- Carcass Fabric:
  Nylon (synthetic yarns)
  Polyester (synthetic yarns)
  Polyester-Nylon (synthetic yarns)
  Steel fabric FERROFLEX
  Aramide (synthetic yarns)

- Belt width
  300, 400, 500, 600, 650, 800, 1000, 1200, 1400, 1600, 1800, 200 and 2200 in mm
  The permitted tolerances on the belt width are:
  Belt width 300-500 ±5 mm
  Belt width 600 or wider ±1%

- Tensile strength of the belt
  160, 200, 250, 315, 400, 500, 630, 1000, 1250, 1600, 2000, 2500, 3150 in N/mm
- Cover thickness
  10 mm ±1 mm

**Bottle specifications**

<table>
<thead>
<tr>
<th>Bottle specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Neck size</td>
</tr>
<tr>
<td>Milk volume</td>
</tr>
<tr>
<td>Material</td>
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</tbody>
</table>

**User requirements**

1) Size, Capacity
   - Number of filling positions: 12
   - Number of capping positions: 1
   - Capacity: 2000 BPH

2) Safety, Reliability, Maintainability, and Availability
   - Safety
     The worker must be fully protected from all dangerous parts since some workers will not be completely careful all time so it’s my responsible to protect them.
   - Reliability
     It is important to note that the operations in this system is totally depends on each other, in another word operations are act in series, so one part fail the whole system will fail.

**Calculations**

\[
\text{Time Between Failures} = (\text{down time} - \text{up time})
\]
\[ MTBF = \frac{\text{down time} - \text{up time}}{\text{number of failures}} \]
\[ MTTR = \frac{\sum \text{time to repair}}{\text{number of reparations}} \]

Where:
MTBF: Mean Time Between Failures
MTTR: Mean Time To Repair

\[ \text{Reliability} = e^{-\frac{\text{time}}{MTBF}} \]
\[ \text{Availability} = \frac{MTBF}{MTBF + MTTR} \]

- **Maintainability**
  The system must be maintainable when any problem occurs or when any check is needed. All devices with periodic failure must be reachable.

3) **System Dynamics**
   System dynamics are important for different reasons, like the response of the actuator that controls the conveyor belt to get accurate positioning. In addition to that, the response of the filling part to get an accurate amount of milk.

4) **Accuracy, Precision**
   - **Accuracy**: The machine will fill by 1.2L±0.5% and depends on the size of the bottle.
   - **Precision**: From 100 bottles (5-7) will be different by 5mL.

5) **Cost**
   10000$

6) **Environment Conditions (IP)**
   The system must have IP54 since it will work with liquid.

7) **User Friendliness**
   The worker is not an engineer, so the dealing with the system must be easy to him.

8) **Energy Consumption**
   The factories are very concerned with power consumption, since less power consumption means less waste. Actuators are the parts that
consume the most power so the focus will be on it for this part, but also if low motor power consumption is choose the system will not work probably so a compromise between power consumption and performance must be exist.

9) Space, Weight
- Weight: 500kg
- Space:
  - Length: 6m
  - Width: 1m
  - Height: 2m

**Mechanical Design**

![Figure 1 Top view of the system](image1)

![Figure 2 front view of the system](image2)
In feed and Out feed conveyer belts design

Conveyor belt is the transportation of material from one location to another. Belt conveyor has high load carrying capacity, large length of conveying path, simple design, easy maintenance and high reliability of operation.

Twelve bottles will be on the conveyer at same time, and 2.6 cm space will be between each two bottles, then the length of the conveyer is 128 cm. but later a screw feeder will be added at the end of the conveyer with length of 55 cm. so, the whole length of the conveyer is approximately 190 cm.

For width selection, depending on the width of the bottle which is 8 cm, a 3 cm clearance at each side is added, so whole width is 14. Thickness has been chosen as 1 mm to suit the length and width.

According to the dimensions of the conveyer the suitable diameter depending on standard tables of pulley selection is 22.5 cm and it has the same width of the conveyer.

The materials for belt and pulley are metal with 7500 kg/m³ density and polyurethane with 1200 kg/m³ density respectively. Metal has been chosen to sustain the factory environment, but the bottle may slip while it is moving so a track is added at the conveyer before the screw stage.

- Motor selection
  To select motor; second moment of mass and angular acceleration must be calculated.

Second moment of mass calculation

Conveyer:

\[ L_{track} = L_{above} + L_{down} + L_{side} \]
\[ L_{track} = 190 + 190 + \pi \times d_{pulley} \]
\[ L_{track} = 190 + 190 + 70.68 = 450.68 \text{ cm} \]
Volume
\[ V = L \times W \times t \]
\[ V = 4.51 \times 0.14 \times 0.001 \]
\[ V = 6.31 \times 10^{-4} m^3 \]

Mass
\[ m = V \times \rho \]
\[ m = 6.31 \times 10^{-4} \times 7500 \]
\[ m = 4.73 kg \]

\[ I_{\text{coneyer}} = m \times r_{\text{pulley}}^2 \]
\[ I_{\text{coneyer}} = 4.73 \times \left( \frac{22.5}{2} \times 10^{-2} \right)^2 \]
\[ I_{\text{coneyer}} = 0.06 kg.m^2 \]

Pulley (solid):
\[ I_{\text{pulley}} = \frac{1}{2} m \times r^2 \]
\[ I_{\text{pulley}} = \frac{1}{2} \pi \times \rho \times W \times r^4 \]
\[ I_{\text{pulley}} = \frac{1}{2} \pi \times 1200 \times 0.14 \times \left( \frac{22.5}{2} \times 10^{-2} \right)^4 \]
\[ I_{\text{pulley}} = 0.04 kg.m^2 \]

Since the conveyer have two pulleys at each side, \( I_{\text{pulley}} = 0.08 kg.m^2 \).

Empty bottles:
\[ m = 12 \, g \]

For each bottle, then for 12 bottles \( m = 12 \times 0.012 = 0.144 kg \)

\[ I_{\text{empty bottles}} = m \times r_{\text{pulley}}^2 \]
\[ I_{\text{empty bottles}} = 0.144 \times \left( \frac{22.5}{2} \times 10^{-2} \right)^2 \]
\[ I_{\text{empty bottles}} = 1.82 \times 10^{-3} kg.m^2 \]

Filled bottles:

Density for milk is 1035 kg/m^3
\[ m_{\text{bottle}} = 1.2 \times 1035 \times 10^{-3} = 1.24 kg \]
\[ m_{12\text{bottles}} = 12 \times 1.24 = 14.90 \text{ kg} \]

\[ I_{\text{filled bottles}} = I_{\text{empty bottle}} + m_{12\text{Liter}} \times r_{\text{pulley}} \]

\[ I_{\text{filled bottles}} = 1.82 \times 10^{-3} + 14.90 \times \left( \frac{22.5}{2} \times 10^{-2} \right)^2 \]

\[ I_{\text{filled bottles}} = 0.19 \text{ kg.m}^2 \]

\[ I_{\text{total infeed belt}} = I_{\text{coneyer}} + I_{\text{pulley}} + I_{\text{empty bottle}} \]

\[ I_{\text{total infeed belt}} = 0.06 + 0.08 + 1.82 \times 10^{-3} \]

\[ I_{\text{total infeed belt}} = 0.14 \text{ kg.m}^2 \]

\[ I_{\text{total outfeed belt}} = I_{\text{coneyer}} + I_{\text{pulley}} + I_{\text{filled bottles}} \]

\[ I_{\text{total outfeed belt}} = 0.06 + 0.08 + 0.19 \]

\[ I_{\text{total outfeed belt}} = 0.33 \text{ kg.m}^2 \]

Torque calculation

Velocity

\[ 2000 \text{ bottle} \rightarrow 3600 \text{ sec} \]

\[ 12 \text{ bottle} \rightarrow x \text{ sec} \]

\[ x = 21.6 \text{ sec} \]

\[ 21.6 = \frac{L_{\text{coneyer}}}{v_{\text{coneyer}}} \]

\[ 21.6 = \frac{190 \times 10^{-2}}{v_{\text{coneyer}}} \]

Solving equation:

\[ v_{\text{coneyer}} = 88 \text{ mm/sec} \]

\[ v_{\text{screw}} = v_{\text{coneyer}} \]

These values of velocity are constants since the conveyor will move continuously, so translation acceleration and angular acceleration equal zero. But at the beginning of the operation the conveyor needs to accelerate. To reach this velocity 1 sec is needed, then acceleration will be \(0.088 \text{ m/sec}^2\) then \( \alpha = 0.78 \text{ rad/sec} \).

In addition to that, the conveyor needs to work in another mode for maintenance, you need to move the conveyor 5 cm in 1 sec with triangular profile speed, then velocity will be \(0.1 \text{ m/sec}\) and acceleration \(0.2 \text{ m/sec}^2\) then \( \alpha \) will be \(1.78 \text{ rad/sec}^2\).
In Feed conveyer (depending on starting mode)
\[ \tau_{\text{infeed}} = \alpha \times I_{\text{total infeed belt}} \]
\[ \tau_{\text{infeed}} = 0.78 \times 0.1418 \]
\[ \tau_{\text{infeed}} = 0.11 \, N \cdot M \]

In Feed conveyer (depending on maintenance mode)
\[ \tau_{\text{infeed}} = \alpha \times I_{\text{total infeed belt}} \]
\[ \tau_{\text{infeed}} = 1.78 \times 0.1418 \]
\[ \tau_{\text{infeed}} = 0.25 \, N \cdot M \]

The selection will be according to the maintenance mode since the torque needed is larger than the torque at the beginning. Also, variable speed drive will be there to allow the conveyer to work in two modes.
Out Feed conveyer (depending on starting mode)
\[ \tau_{outfeed} = \alpha \cdot I_{total \ outfeed \ belt} \]
\[ \tau_{outfeed} = 0.78 \times 0.3305 \]
\[ \tau_{outfeed} = 0.26 \, N.M \]

Out Feed conveyer (depending on maintenance mode)
\[ \tau_{outfeed} = \alpha \cdot I_{total \ outfeed \ belt} \]
\[ \tau_{outfeed} = 1.78 \times 0.3305 \]
\[ \tau_{outfeed} = 0.59 \, N.M \]

Screw Feeder
Screw feeder uses a rotating helical screw blade to move the bottles and makes synchronization between in feed conveyer and filler machine. Another option was two doors which lock a bottle to move to the filler, but in this method hard controlling procedure, linear actuator which will work for some time and stop for another and a sensor will be added. So the screw feeder will accomplish this mission.
The angular velocity for screw feeder depends on the linear velocity which calculated in the conveyor belt design and on the geometry of the screw.

\[ \text{Diameter} = (L_{\text{bottle}} + \text{clearance}) + \text{solid part} = (8 + 1) + 3 \]

\[ \text{Diameter} = 12 \text{ cm} \]

\[ \text{helix angle} = 45^\circ \]

\[ v = \frac{t \times n}{60} \]

This equation for screw with \(45^\circ\) helix angle

Where:

\(v\): linear velocity

\(t\): screw diameter

\(n\): angular velocity

\[ n = \frac{60 \times 88 \times 10^{-3}}{12 \times 10^{-2}} \]

\[ n = 44 \text{ rpm} \]

All the next speeds will depend on this speed, also pitch and thickness will affect the synchronization for the whole machine, so let pitch equal 11 cm and the thickness 2 cm.

- Motor selection
  Second mass moment of inertia calculation

\[ m = 5 \times V_s \times \rho \]

\[ m = 5 \times \left( \frac{\pi}{4} \times (d_{\text{full}}^2 - d_{\text{empty}}^2) \right) \times t \times \rho \]
\[ m = 5 \times \left(\frac{\pi}{4} \times 10^{-4}\times (12^2 - 6^2)\right) \times 2 \times 10^{-2} \times 7500 \]

\[ m = 6.362 \, kg \]

Let \( r_{shaft} = 6 \, cm \)

\[ l = m \times r^2 \]

\[ l = 6.362 \times 6^2 \times 10^{-4} \]

\[ l = 0.023 \, kg.m^2 \]

Torque calculation:

\[ \alpha = 38.78 \, rpm \]

\[ T = \alpha \times l \]

\[ T = 44 \times \frac{2 \times \pi}{60} \times 0.023 \]

\[ T = 0.106 \, N.m \]

Figure 7 motor for screw feeder
A star wheel will move the bottle from the screw feeder to rotary disk at the in feed stage and vice versa at the out feed stage. The bottle will enter the star wheel in the empty space. All the design for the star wheel base on the design of screw feeder, so the empty space must be 9 cm and the solid part 2 cm and this is for synchronization between each stage. To get these dimensions with this shape a circle with diameter 28.5 cm and another circle with 46.5 cm diameter, first one to get the empty space and the second for the solid part. As shown in the schematic diagram.

- Motor selection
  Second moment of mass calculation:
  Cylinder with 6 cm diameter
  \[ m = V \cdot \rho \]
  \[ m = \frac{\pi}{4} \cdot d^2 \cdot t \cdot \rho \]
  \[ m = \frac{\pi}{4} \cdot 5.5^2 \cdot 10^{-4} \cdot 125.25 \cdot 10^{-2} \cdot 7500 \]
  \[ m = 22.32 \text{ kg} \]
  \[ I = \frac{1}{2} \cdot m \cdot r^2 \]
\[ I = \frac{1}{2} \times 26.56 \times 2.75^2 \times 10^{-4} \]
\[ I = 8.44 \times 10^{-3} \text{kg.m}^2 \]

Cylinder with 28.5cm diameter

\[ m = V \times \rho \]
\[ m = \frac{\pi}{4} \times d^2 \times t \times \rho \]
\[ m = \frac{\pi}{4} \times 28.5^2 \times 10^{-4} \times 2 \times 10^{-2} \times 7500 \]
\[ m = 9.57 \text{kg} \]
\[ I = \frac{1}{2} \times m \times r^2 \]
\[ I = \frac{1}{2} \times 9.57 \times 14.25^2 \times 10^{-4} \]
\[ I = 0.19 \text{kg.m}^2 \]

Rectangles

\[ m_{\text{one rectangle}} = a \times b \times t \times \rho \]
\[ m_{\text{one rectangle}} = 9 \times 2 \times 2 \times 10^{-6} \times 7500 \]
\[ m_{\text{one rectangle}} = 0.27 \text{kg} \]
\[ m_{\text{all rectangles}} = 0.27 \times 8 \]
\[ m_{\text{all rectangles}} = 2.16 \text{kg} \]
\[ I_{\text{original center}} = \frac{m}{12} \left( a^2 + b^2 \right) \]
\[ I_{\text{original center}} = \frac{2.16}{12} \times (9^2 + 2^2) \times 10^{-4} \]
\[ I_{\text{original center}} = 1.53 \times 10^{-3} \text{kg.m}^2 \]

Depending on parallel axis theorem:

\[ I = I_{\text{original center}} + m \times d^2 \]
\[ I = 1.53 \times 10^{-4} + 2.16 \times 18.75^2 \times 10^{-4} \]
\[ I = 0.077 \text{kg.m}^2 \]
\[ I_{\text{total}} = 0.275 \text{kg.m}^2 \]

Angular velocity:

\[ w = \frac{v_{\text{screw}}}{r} \]
\[ w = \frac{88 \times 10^{-3}}{46.5 \times 10^{-2}} \]
\[ w = 0.19 \text{ rad/sec} \]

This angular speed will be reached in 1 sec then \[ \alpha = 0.19 \text{rad/sec}^2. \]
\[ T = \alpha * I \]
\[ T = 0.19 * 0.275 \]
\[ T = 0.05N.m \]

**Filling machine**

All the design for the star wheel base on the design of screw feeder, so the empty space must be 9 cm and the solid part 2 cm and this is for synchronization between each stage. To get these dimensions with this shape a circle with diameter 56 cm and another circle with 74 cm diameter, first one to get the empty space and the second for the solid part. As shown in the schematic diagram.

- **Motor selection**
  
  **Second moment of mass calculation:**
  
  Cylinder with 6 cm diameter
  \[ m = V * \rho \]
  \[ m = \frac{\pi}{4} * d^2 * t * \rho \]
  \[ m = \frac{\pi}{4} * 8^2 * 10^{-4} * 129.25 * 10^{-2} * 7500 \]
  \[ m = 48.73kg \]
  \[ I = \frac{1}{2} * m * r^2 \]
  \[ I = \frac{1}{2} * 48.73 * 4^2 * 10^{-4} \]
  \[ I = 0.04kg.m^2 \]

  Cylinder with 56 cm diameter
  \[ m = V * \rho \]
  \[ m = \frac{\pi}{4} * d^2 * t * \rho \]
  \[ m = \frac{\pi}{4} * 56^2 * 10^{-4} * 2 * 10^{-2} * 7500 \]
  \[ m = 36.95kg \]
\[ I = \frac{1}{2} m r^2 \]
\[ I = \frac{1}{2} \times 36.95 \times 28^2 \times 10^{-4} \]
\[ I = 1.45 \text{kg.m}^2 \]

Rectangles
\[ m_{\text{one rectangle}} = a \times b \times t \times \rho \]
\[ m_{\text{one rectangle}} = 9 \times 2 \times 2 \times 10^{-6} \times 7500 \]
\[ m_{\text{one rectangle}} = 0.27 \text{kg} \]
\[ m_{\text{all rectangles}} = 0.27 \times 16 \]
\[ m_{\text{all rectangles}} = 4.32 \text{kg} \]
\[ I_{\text{original center}} = \frac{m}{12} (a^2 + b^2) \]
\[ I_{\text{original center}} = \frac{4.32}{12} \times (9^2 + 2^2) \times 10^{-4} \]
\[ I_{\text{original center}} = 3.06 \times 10^{-3} \text{kg.m}^2 \]

Depending on parallel axis theorem:
\[ I = I_{\text{original center}} + m \times d^2 \]
\[ I = 3.06 \times 10^{-3} + 4.32 \times 32.5^2 \times 10^{-4} \]
\[ I = 0.23 \text{kg.m}^2 \]

The tank will be stands on the filler machine with mass of 30kg, which is the double of the mass 12 bottle need.
\[ I_{\text{total}} = 1.72 + 30 \times 16 \times 10^{-4} \text{kg.m}^2 \]
\[ I_{\text{total}} = 1.77 \text{kg.m}^2 \]

Angular velocity
\[ w = w_{\text{starwheel}} \times \frac{r_{\text{starwheel}}}{r_{\text{filling machine}}} \]
\[ w = 0.19 \times \frac{46.5}{74} \]
\[ w = 0.12 \text{rad/sec} \]

This angular speed will be reached in 1 sec then \( \alpha = 0.12 \text{rad/sec}^2 \).
\[ T = \alpha \times I \]
\[ T = 0.12 \times 1.77 \]

\[ T = 0.21N.m \]

One motor for two star wheels and filling machine with VSD to change speed depending on the tank weight and gear box will be there; this will help the synchronization for the system.

Step down gear box with ratio of 60 is added before star wheel shaft.

Figure 9 motor for filling machine and two star wheels

Brief description of the AC brake and clutch motor

Figure 10 AC clutch and brake motor
AC motor's output shaft runs and stops by being controlled through the clutch and brake while the motor is running continuously. Output shaft rotation is controlled through the use of the clutch and brake mechanism. The load is stopped by disengaging the clutch and applying the brake. The motor is always affected by the rotor inertia. However, with a clutch and brake unit, the load is not affected by the rotor inertia.

Features:

- Suitable for High-frequency operation.
- Compact and Easy to handle the compact design simplifies handling and enables the drive unit of the machine to be mounted into a small area.
- Highly Reliable Gear head Employed.

Filling procedure

The milk is in tank, the bottle will filled by milk using solenoid valves which connected to positive displacement pump through distributor to give constant flow to twelve nozzle, there is a need to relief valve to protect against excessive pressures.

![Figure 11 filling schematic diagram](image)
**Pump selection:**

In this design the positive displacement pump is chosen because constant flow rate is required regardless with pressure changing in addition to this it is cheaper than centrifugal pump.

**Coarse filling:**

*Time calculation*

\[ R_{\text{filling star}} = 28 \text{ cm} \]

\[ \text{Distance}_{\text{traveled by bottle}} = \frac{3}{4} \times (2 \times \pi \times 0.28) \]

Distance_{traveled by bottle} = 1.319 m

Linear velocity = angular velocity \times R_{filling star}

Linear velocity = 0.12 \times 0.28

Linear velocity = 0.0336 m/sec

\[ \text{Time}_{\text{filling}} = \frac{\text{Distance}_{\text{traveled by bottle}}}{\text{Linear velocity}} \]

\[ \text{Time}_{\text{filling}} = \frac{1.319}{0.0336} \]

\[ \text{Time}_{\text{filling}} = 39.25 \text{ sec} \]

In coarse filling 1L required to fill in half of the Time_{filling}

\[ \text{Mass}_{\text{Coarse}} = 1 \times 10^{-3} \times 1.035 \text{ kg} \]

\[ \text{Mass flow rate}_{\text{coarse}} = \frac{\text{Mass}_{\text{Coarse}}}{0.5 \times \text{Time}_{\text{filling}}} \]

\[ \text{Mass flow rate}_{\text{coarse}} = \frac{10^{-3} \times 1.035}{0.5 \times 39.25} \]

\[ \text{Mass flow rate}_{\text{coarse}} = 5.279 \times 10^{-5} \text{ kg/sec} \]
Mass flow rate_{coarse} = 3.06 L/min

But the pump will feed 12 nozzles at same time

flow\_rate_{pump} = 12 \times \text{Mass flow rate}_{coarse}

flow\_rate_{pump} = 36.7 \text{ L/min}

Fine filling:

In fine filling 0.2 L required to fill in \frac{1}{7} of the Time_{filling}

\text{Mass}_{Coarse} = 0.2 \times 10^{-3} \times 1.035 \text{ kg}

\text{Mass flow rate}_{fine} = \frac{\text{Mass}_{fine}}{\frac{1}{7} \times \text{Time}_{filling}}

\text{Mass flow rate}_{fine} = \frac{0.2 \times 10^{-3} \times 1.035}{\frac{1}{7} \times 39.25}

\text{Mass flow rate}_{fine} = 3.691 \times 10^{-5} \text{ Kg/sec}

\text{Mass flow rate}_{fine} = 2.14 \text{ L/min}

But the pump will feed 12 nozzles at same time

flow\_rate_{pump} = 12 \times \text{Mass flow rate}_{fine}

flow\_rate_{pump} = 25.68 \text{ L/min}

This model has been chosen because it has integral relief valve.

<table>
<thead>
<tr>
<th>Coarse filling</th>
</tr>
</thead>
<tbody>
<tr>
<td>GG-190-10</td>
</tr>
<tr>
<td>Nominal pump rating</td>
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<tr>
<td>Maximum pressure</td>
</tr>
<tr>
<td>Maximum recommended temperature</td>
</tr>
</tbody>
</table>
Capper

Single inclined capper at filling stage will drop a plastic cap with tin above the bottle depending on gravity. Another capper will rotate the cap to be tight this is done on the second star wheel. Depending on the diameter of the neck which is 28mm and the material of the bottle and the cap which is carton for bottle and plastic for cap, according to standard guide the torque required for tighten is 1.1Nm.

When detection bottle the capper will come down, this operation is done using linear actuator with feedback to turn on the rotary actuator.

Since there are linear and rotary piece there is a danger on the worker, so there is a need to put a protection around it, plastic cover with two gaps to enter and exit the bottle.
Figure 13 linear actuator

<table>
<thead>
<tr>
<th>Linear motor specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Gear ratio</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
</tbody>
</table>

**Sensors and feedback devices**

**Load cell:**

A load cell is a device that is used to convert force into electrical signal. Strain gauge load cells are the most common types of load cells. There are other types of load cells such as hydraulic (or hydrostatic) load cells, Piezoelectric load cells, Capacitive load cells, Piezoresistive load cells...etc.

Load cells are used for quick and precise measurements. Compared with other sensors, load cells are relatively more affordable and have a longer life span, in this application the strain gauge load cell is suitable since precise measurement is needed.

The principle of operation of the Strain Gauge load cell is based on the fact that the resistance of the electrical conductor changes when its length changes due to stress. Copper and Nickel alloys are commonly used in strain gauge construction as the resistance change of the foil is virtually proportional to the applied strain. The change in resistance of the strain gauge can be utilized to measure strain accurately when connected to an appropriate measuring circuit. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. The electrical signal output is typically very small in the order of a few milli
volts. It is amplified by an instrumentation amplifier before sending it to the measurement system.

Sixteen load cells will be installed under the filling machine and rotate with the bottle using the conveyor belt. The aim is to use them to detect the bottle to start the filling process. It will start with coarse filling, after one liter it will convert to fine filling, after 0.2 liter the filling will stop. The starting, converting between coarse and fine filling and ending of the process will be controlled using signals from load cells.

<table>
<thead>
<tr>
<th>Model 1004-HW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated capacities (Emax)</strong></td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
</tr>
<tr>
<td><strong>Output at rated load (ORL)</strong></td>
</tr>
<tr>
<td><strong>Output at rated load tolerance</strong></td>
</tr>
<tr>
<td><strong>Zero balance</strong></td>
</tr>
<tr>
<td><strong>Recommended supply voltage</strong></td>
</tr>
<tr>
<td><strong>Operating temp. range</strong></td>
</tr>
<tr>
<td><strong>Safe overload</strong></td>
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<tr>
<td><strong>Ultimate overload</strong></td>
</tr>
<tr>
<td><strong>Ingress protection</strong></td>
</tr>
</tbody>
</table>

\[ sensitivity = \frac{\text{full range output}}{\text{transducer range}} \]

\[ \text{full range output} = \text{Full scale output} \times \text{Excitation Voltage} \]

\[ \text{full range output} = 0.9\text{mV/V} \times 10 \text{V} \]

\[ \text{full range output} = 9\text{mV} \]

\[ \text{transducer range} = 3000\text{g} \]

\[ sensitivity = \frac{9\text{mV}}{3000\text{g}} \]

\[ sensitivity = 3\text{microV/g} \]

**Proximity sensors:**

Proximity sensors detect the presence of objects without physical contact. Typical applications include the detection, position, inspection and counting on automated machines and manufacturing systems. They
are also used in the following machinery: packaging, production, printing, plastic molding, metal working, food processes, etc. In this system capacitive Proximity Sensors are used.

Capacitive Proximity Sensors

Capacitive proximity sensors work on the principle of the capacitor. The main components of the sensor are the plate, oscillator, threshold detector and an output circuit. The plate and object act as plates and air as the dielectric. As an object comes close to the plate, the capacitance increases which triggers the detector circuit, based on the amplitude output from the oscillator. An advantage with these sensors is that they are capable of detecting both metallic and non-metallic targets whose dielectric constant is more than that of air. They are generally low cost and have good resolution, stability, high speed and low power usage.

Eight capacitive proximity sensors will installed in the star wheel at the out stage, the purpose to use them is to detect if there is a bottle or not to start tighten for the cap. The sensing distance is choosing according to the clearance in the star wheel which is 1cm.

<table>
<thead>
<tr>
<th>Model : E2Q5-N20</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing distance</td>
<td>20mm</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 10%</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Sensing object</td>
<td>Non-metallic</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>10 to 30 VDC</td>
</tr>
<tr>
<td>Current consumption</td>
<td>20 mA max</td>
</tr>
<tr>
<td>Circuit protection</td>
<td>Reverse polarity, output short circuit</td>
</tr>
<tr>
<td>Indicator</td>
<td>Operating indicator (yellow LED)</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>Operating: -25 to 85 °C</td>
</tr>
<tr>
<td>Ambient humidity</td>
<td>35 to 95% RH</td>
</tr>
<tr>
<td>Vibration resistance</td>
<td>10 to 55 Hz</td>
</tr>
<tr>
<td>Protection degree</td>
<td>IP67 IEC 60529</td>
</tr>
</tbody>
</table>
Flow Chart

Bottle Transportation

Press start button

Empty bottle

+ 

In feed

Conveyer belt

Screw Feeder

Star Wheel

In

Filling Machine

Filled bottle with untied cap

Empty bottle

Delivered

Filling Stage

Empty bottle Detected

Load Cell

Controlling valve state in PLC

Starting Filling Operation

Coarse Filling

Fine Filling

End Filling Operation

Filled bottle with untied cap

Capping Stage

Filled bottle with untied cap

Star Wheel Out

Proximity Sensor

Linear actuator

Rotary actuator

Out feed Conveyer

Magnetic Capper

Filled bottle with tied cap
**Physical and algorithm controller**

**Physical controller**
The requirements must be in the physical controller for the system will explain in this section, then a physical controller will be selected according to these requirements.

The system need to be fully automated or manual executed, the system components are combination of mechanical and electrical. Electromechanical components like motors produce an electromagnet noise which can affect the response of controller so it’s better to be isolated.

Many inputs and outputs are required to control so the controller must be able to deal with their number. Also, some of inputs are analog so the controller better to have analog inputs.

The system include many devices with motion and torque so it has to be able to deal with them, also the synchronization in this system is very important then the response must be fast and critical.

Finally, this product must act with other systems like the bottle feeder and some responsible people needs to act with the machine without being at the site so it needs to be able to deal with SCADA system. Also, the machine will have human interface, then the controller must support this thing.

The physical controller which can deal with these requirements is Programmable Logic Controller, the type of PLC will be chosen according to the inputs and outputs features since many of PLCs share a lot of rest features.

**Control algorithm**
The control of the system will be sequential control, simple but critical to get required synchronization only ON/OFF operation is needed and it can deal with human interface.

The person will deal with this machine is technicians so the control algorithm must be understandable for them if a crash occurs. Also, if engineer want to develop the software it’s easy to develop the software and it’s easy to deal with the program.

Then ladder diagram is the suitable controller.
List of inputs and outputs

<table>
<thead>
<tr>
<th>Outputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Quantity</td>
</tr>
<tr>
<td>Conveyer belt motor</td>
<td>2</td>
</tr>
<tr>
<td>Star wheel and filling machine motor</td>
<td>1</td>
</tr>
<tr>
<td>Capping rotary motor</td>
<td>8</td>
</tr>
<tr>
<td>Capping linear motor</td>
<td>8</td>
</tr>
<tr>
<td>Robot arm start</td>
<td>1</td>
</tr>
<tr>
<td>Solenoid valve response</td>
<td>32</td>
</tr>
<tr>
<td>Pumps</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Quantity</td>
</tr>
<tr>
<td>Load cell</td>
<td>16</td>
</tr>
<tr>
<td>Proximity sensor on star wheel</td>
<td>8</td>
</tr>
<tr>
<td>Proximity sensor for caps</td>
<td>1</td>
</tr>
<tr>
<td>Proximity sensor for counter</td>
<td>1</td>
</tr>
</tbody>
</table>

The selection of PLC will depend on the number of inputs and outputs.

The selected PLC is GLOFA GM6

Figure 14 GLOFA GM6 PLC
### Specification of the GLOFA GM6

<table>
<thead>
<tr>
<th>Items</th>
<th>Models</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CPU module</strong></td>
<td>GM6-CPUA</td>
<td>Maximum I/O points: 256&lt;br&gt;Special functions: RS-232 communication</td>
</tr>
<tr>
<td><strong>Digital input module</strong></td>
<td>G6I-D24A</td>
<td>32-point 12/24 VDC input module (current source &amp; sink input)</td>
</tr>
<tr>
<td><strong>Digital output module</strong></td>
<td>G6Q-TR4A</td>
<td>2X32-point transistor output module (0.1A, sink output)</td>
</tr>
<tr>
<td></td>
<td>G6Q-TR2B</td>
<td>16-point transistor output module (0.5A, source output)</td>
</tr>
<tr>
<td><strong>Main base unit</strong></td>
<td>GM6-B06M</td>
<td>Up to 6 I/O modules can be mounted</td>
</tr>
<tr>
<td><strong>Power supply module</strong></td>
<td>GM6-PAFB</td>
<td>Free Voltage (100 ~ 240VAC)</td>
</tr>
<tr>
<td><strong>A/D conversion module</strong></td>
<td>G6F-AD2A</td>
<td>Voltage/current input: 4 channels&lt;br&gt;DC -15 to 15V / DC -20 to 20 mA</td>
</tr>
<tr>
<td><strong>Computer Link</strong></td>
<td>G6L-CUEB</td>
<td>RS-232C module</td>
</tr>
</tbody>
</table>

### Detailed electronic design

#### Motors connection

Controlling of motors will be on/off controlling using relays, since the motors need high power. When the relay is closed the motor will be on and vise versa.

#### Load cell connection

Two connections for load cell with PLC; one with digital input to send signal that there is a bottle there, the second with analog which is for the toggling between coarse and fine filling. This is done using two
amplifiers with two amplification amount because the difference between the empty bottle and the filled bottle is large.

Sensitivity of load cell = $3 \mu V/g$

Then, Output Voltage for 12g = $36 \mu V$

Since the input digital voltage for PLC is 12/24V, amplifier with gain of 500k will accomplish the mission.

For digital input:

\[
\frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_2}
\]

\[
V_{out} = V_{in} \times (1 + \frac{R_1}{R_2})
\]

\[
1 + \frac{R_1}{R_2} = 500001
\]

\[
\frac{R_1}{R_2} = 500000
\]

Let \( R_1 = 5 \, M\Omega \)

\[
R_2 = \frac{R_1}{500000}
\]

\[
R_2 = 10 \, \Omega
\]
For analog input:

Output Voltage for 0.21kg (0.2L)= 0.63mV

Output Voltage for 1.47kg (1.4L)= 4.42mV

\[
\text{Gain} = \frac{\text{input voltage for PLC when 0.2L is sensed}}{\text{output voltage from amplifier when 0.2L is sensed}}
\]

\[
\text{Gain} = \frac{2}{0.63 \times 10^{-3}} = 3175
\]

\[
1 + \frac{R_1}{R_2} = 3175
\]

\[
\frac{R_1}{R_2} = 3174
\]

Let \( R_1 = 100 \text{ k}\Omega \)

\[
R_2 = \frac{R_1}{3174}
\]

\[
R_2 = 30 \Omega
\]

The resolution of A/D converter that can deal with these values is with 8 bit.

Proximity sensor

This sensor can deal with PLC directly, and it is used as ON/OFF signal.
Detailed control code

Figure 17 detailed control code
**User Interface**

HMI which shows the status of the system, this screen is controlled using PLC which sends all signals. The user can deal with all operations of the system using program which easy to use.

The start and emergency stop buttons are used by the operator.

**Precision and accuracy**

These features of the system are mainly depending on the load cell accuracy, PLC time response and solenoid valve response. And, these parameters are suitable to get the desired precision and accuracy specified in user requirements.