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Design and Automation of Food Dispensing and Packaging Machinery using PLC

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Abstract: ***Food industry perpetually undergoes dynamic changes due to volatile markets. This is because, the processing and packaging technologies demand smarter and safer options with every passing day. A combination of industrial design and computer aided design assists in coping up with these challenges. The implementation of these technologies is very convenient in the large-scale industries due to the adequate availability of capital and resources. However, in case of the small-scale industries the scenario is completely different. It is more dependent on the manual efficiency, accuracy, and consistency. The ongoing pandemic is creating a market where contactless manufacturing is the demand, thus now there's a greater need than before for these small-scale industries to implement automation in order to survive and succeed. In this paper a compact and automated system for dispensing and packaging food is proposed. The aim of this paper is to develop a new system for optimum functionality by considering the availability of resources using existing literature. PLC programming is implemented to facilitate the automation. The proposed design is directed towards achieving output consistency and automation of the entire unit will as a result ensure safe and contactless production.***

Keywords: Process Automation, PLC, Food Packaging, Food Dispensing

1. Introduction

Improvements in the automation industry has an impact on other industries. Food industry is the immediate impacted industry which demands constant improvement and upgradation in the methods for processes like dispensing, sealing, packing, placing etc. Development of new and effective systems is a major part of machine design but modifying and adapting from the existing ones is vital too.
Small-scale industry such as local shops, home businesses, etc. that altogether dependent on manual efforts for their quality of output generally face issues like inconsistency, compromised hygiene, irregular labor and this in turn decreases their customer reliability thus affecting the business. A completely automated dispensing and packaging line can prove to be an effective solution to these issues.

2. Literature Survey

The dispensing element of the machine plays a vital role. The inculcation of appropriate and accurate mechanisms and control system in this dispensing element (hopper) can significantly improve the efficiency of unit. The patent mainly focuses on the alternative mechanisms that can be implemented for carrying out the required operations. It states that preferably the dispensing apparatus comprises a housing divided into two substantial equal halves; one half defines the candy receiving chamber while the other half which extends into the receiving chamber to act upon candies received therein. Such an arrangement is particularly convenient since it is compact and provides a high proportion of space for the candy receiving chamber. [1] To design an effective system the following points are incorporated:
a) Reusable system, automated mechanisms for dispensing, variable housings for dispensing candies, user dependent system are considered as important parameters.[1]
b) Transfer of candies from a loading container can be done through a valve into a dispensation magazine, additional candies can be loaded into the dispensation magazine by replacing the loading container [Interchangeability] such dispenser for candies would be economical and convenient to operate. [2]

Network analysis techniques such as event change methodology identifies and manages events and the relationship between them. It is used in dispensing apparatus for cued-food delivery task in which Event-Related Ppotentialsfor food-related images predict food delivery, images not predicting food delivery are also recorded. [3] Similarly, in this particular candy dispensing and packaging unit proximity sensors are incorporated to improve the accuracy of response recording. An algorithm is developed such that each working station can perform motion determination and provide feedback to generate the required output. It is observed that there's a greater need for highly flexible, cost effective, easy to maintain conveyor system. Intelligent control strategies provide accurate movements and feedback mechanisms assist in management of material flow. There are two widely used approaches for building an intelligent and accurate system. The first one is to equip each module with a sensor, the second approach is the use of vision systems for analyzing the on goings on the whole conveying surface. [4]

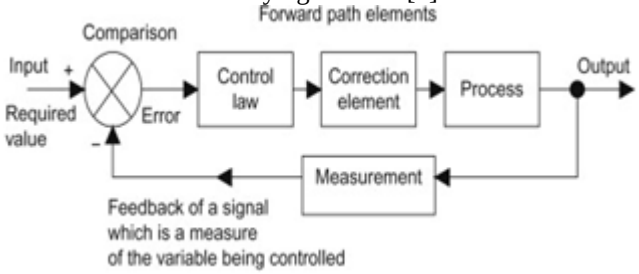

Figure 1 Control system [5]

Figure1 depicts the structure of a control system where a part of output is fed back to the input in order to increase stability.[5]. Focus is to be made on achieving complete control of the conveyor line, the proposed system allows optimization by trials and requirements. Thus, allowing easy manipulation & providing greater accuracy. The issue of complexity to incorporate complete controlled conveyor line can be tackled by increasing the number of stations as it is an easier approach to facilitate orderly process.[6]

An accurate and intelligent system can be built only if it is a perfect blend of Industrial design and Computer aided design. While Industrial design is governed by the production aspect, computer aided design depends upon the use of computer systems to assist in the creation, modification, analysis, and optimization of a design.[*7*]

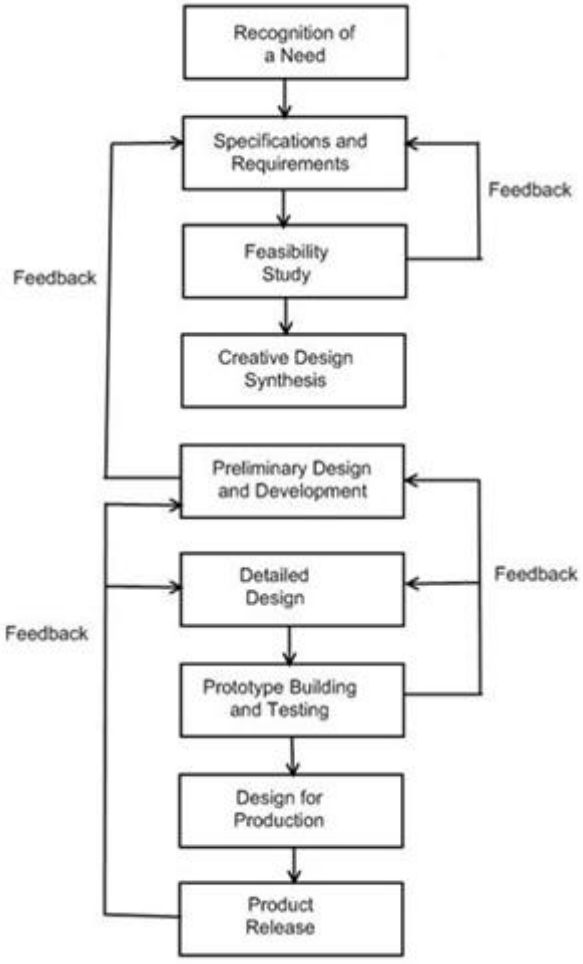

Figure 2 Design Cycle [7]

Figure 2 describes an interactive process that allows revisiting and improvisation of former actions, following the design cycle approach ensures a meticulous approach.

In the functioning of the documented unit the sensing and gripping process is vital. Thus, implementing an efficient sorting process is necessary. Though there are varied kinds of sorting processes the general framework consists of visualizing the object on moving belt, targeting a single item, recognizing the relevant parameters that make it acceptable or not and, if applicable, gripping it to perform the necessary separation. The optimum automation of sorting process can be done when the parameters are accurate i.e. the flow rate should be exactly known, the position should be accurate and the range of variation should be minimum. The identification of exact parameters is to be considered while selecting appropriate sensors to install. Vision sensors or 3D sensor can be used in more advanced applications of sorting whereas Passive Infrared Sensors or proximity sensors can be used for basic purposes. [8]

Another vital part is automation of opening of the plastic pouch without any damage. One approach for this could be using three symmetrical opening rods, which initially gather around the center of the guiding rod and then move away thus opening the bag. Although for this approach the load applied shouldn't exceed the elastic limit of plastic bag else it will cause damage and would be problematic during sealing procedure. Hence taking into consideration this critical parameter another approach of suction cup can be considered where the pressure applied for suction can be governed according to the quality of the pouch.[9]–[10]

Aim of the proposed design is to formulate a plan in order to satisfy the market requirements along with taking in account the technological advancements, ease of operation, availability of capital and limitation of resources. Industry requirement, synthesis of mechanism, analysis of components and potential layout design of the candy dispensing, and packaging conveyor line is discussed in this paper.

3. Methodology

To dispense single packed piece candies and seal them into large packets by no external manual effort, the methodology that is designed keeping in mind the fabrication of an easy to model prototype is elaborated in Figure 3.

1) The conveyor and bag magazine mechanism begin simultaneously.
2) The opened bag then is sensed by proximity sensor and the hopper mechanism is initiated.
3) Hopper is selected such that it is shaped to have a decreasing cross section, a vibration is induced such that it facilitates easy dispensing of single candies.
4) The PLC controlled counter inside the hopper assists in maintaining the output consistency.
5) The specific number of counted candies are then filled in the bag and the conveyor starts.
6) The filled packet is then passed through sealing mold for ease of sealing.
7) Heat rollers are installed at the end of the conveyor line and they finish the process by sealing the bag and give a feedback to repeat the entire process.
8) The process repeats until the hopper is either empty or the number of remaining candies is less than the number of candies to be filled.

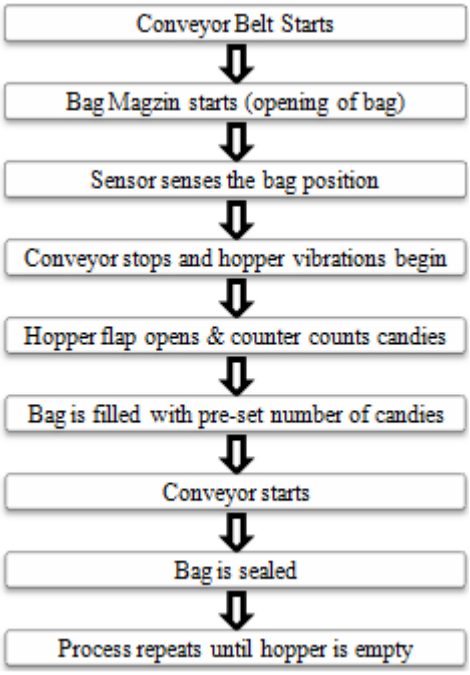

Figure 3 Working Methodology (Flow Chart)

Table 1: Pre-set values

Pre-set Value from HMI / SCADA	*Set Value*
PIR sensor(counter) inside hopper counts	20 candies
Set time for stopping conveyor in between	[15-20 sec]

The pre-set values are user dependent; the proposed model uses a count of 20 candies and accordingly the time required for entire process of candy filling is set in the range of 15-20 sec. These values can be changed by the consumer as per requirements accordingly.

Table 2: Interlock

	Interlock
1	Emergency Stop - Stop Conveyor
2	Sealing Station Proxy

In case of emergency the two functions: stopping the entire conveyor or switching off the heating rollers are given manual control. This can overlap any other ongoing process when assumed to be absolutely necessary by the user.

Table 3: Input / Output command

Digital Input	*Input Type*
System Start	Push Button
System Stop	Push Button
Position of Bag	Proximity Sensor
PIR Sensor (feedback Mechanism)	Proximity Sensor
Sealing Station IN	Proximity Sensor
Digital Output	*Output Type*
Bag Sealing Start	Heater
Analogue Input	
Belt Conveyor Speed	

3.1Layout, Design and Mechanism

The proposed layout of system and some of its elements is elaborated as below. Required components and their dimension range are as follows:

1) Hopper: Hoppers are available in various sizes and shapes and have varied discharge rates. Truncated Conical hopper is suitable for this purpose where dimensions can be manipulated depending on user requirement. However, for this particular prototype the height ranges from 140mm - 150mm, inlet diameter ranges from 135mm – 150mm and outlet diameter ranges from 25mm – 35mm. These dimensions however depend upon the volume of hopper required and can be calculated using the appropriate computations. For truncated conical hopper:

$$Volume = \frac{1}{3} \times \pi \times depth \times r^2 \quad (1)$$

$$Depth = \frac{volume}{\frac{1}{3} \times (r^2 + (r \times R) + R^2)} \quad (2)$$

where, r = top radius
R = base radius

2) Proximity sensors
3) Siemens S7 PLC
4) Heat sealing rollers
5) Metal Strips
6) Candies (as per consumer demands): Here the candy dimensions range from (30mm x 20mm x 3mm) to (45mm x 30mm x 4mm)
7) Plastic Pouches: The dimension of these pouches depends on the packaging requirement. Accordingly, standard available pouches of the required volume can be selected.
8) Bag Magazine: It is designed by taking in consideration two important parameters. Firstly, the position in which the bags are going to be placed (here they are supposed to be oriented from surface to surface) and second the number of bags to be packed in a single run.
9) Vacuum suction cups: preferably piab or festo suction cups are used.
10) DC motor
11) Standard Compression Spring: (nickel-titanium spring would be the best option as they generate continuous light forces along a wide range).

Table 4: Spring Data

Parameters	*Value (range)*
Wire Diameter	1.5mm to 2mm
Number of coils	6 to 8 coils
Free Length	50% of bag magazine length

The layout shown in **Figure 4** shows the placement of stations those are implemented keeping in mind the basic prototype. Variations are possible depending on the consumer requirement.

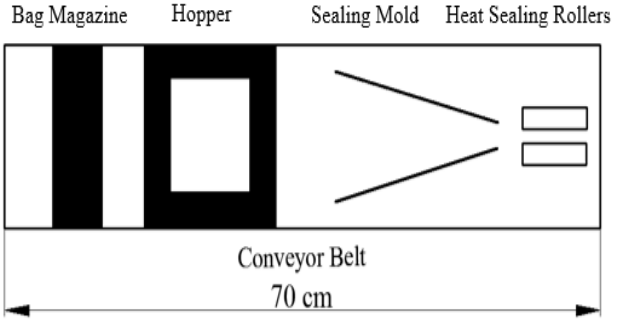

Figure 4: Top View of Unit Layout

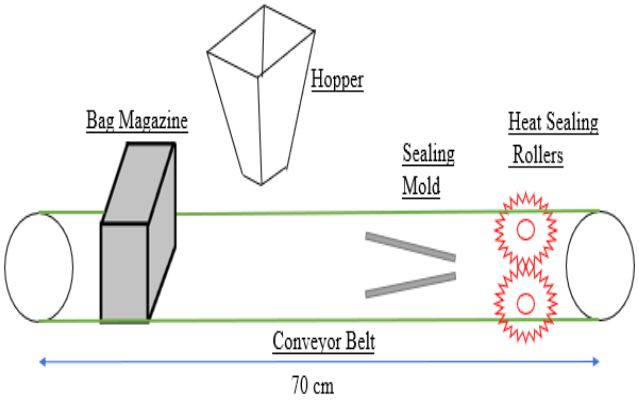

Figure 5: Symbolic representation of Unit Layout

There are 4 stations viz bag magazine, hopper, sealing mold and sealing rollers, these perform 4 major operations. These stations are oriented in the given fashion for the ease of controlling and interchangeability of the components as and when required.

1) Bag Magazine Station: The size of the bag magazine can be changed depending upon the size of the bag selected (here standard plastic pouch is considered). The rectangular bag magazine has a light spring flap attached so that it can generate the slight push required. The bag magazine will have flexible finger like structure to hold it and restrict it from leaving the magazine while the suction cups open the bag.

2) Hopper Station: There is a need to vibrate the hopper in order to facilitate the continuous dispensing of candies. The decreasing cross-section will ensure that candies are dispensed in a particular organized manner so that the proximity sensor can accurately register the count which thus improves the efficiency of the unit. The entire mechanism will stay at halt while the candies are being filled. The mechanism will resume only when the pre-set count & interval is completed. In **Figure 6** the working flowchart of hopper mechanism is shown.

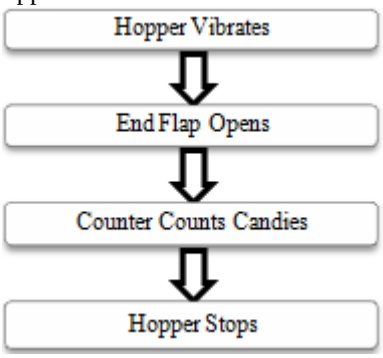

Figure 6: Hopper Mechanism

4. Result & Discussion

The automation of the unit is done using ladder programming thus every major operation has an individual network. The entire system is programmed on about 10 to 12 networks. Few major networks are as below:

1) Network 1- Start Conveyor: A push button starts the conveyor and simultaneously it initiates the suction stroke of suction cups installed in the bag magazine. At the same time a third operation of opening hopper flap is also carried out. All of these processes set the station 1 and station 2 in action.

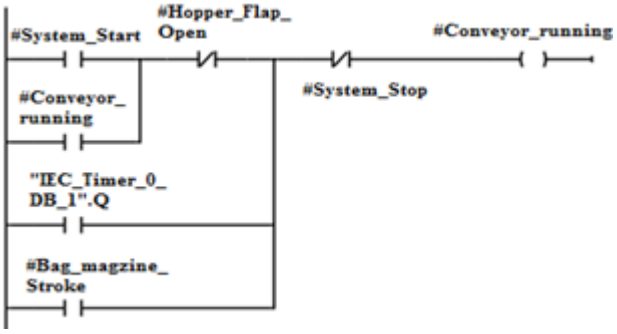

Figure 7 Network 1 – Starting the Conveyor

2) Network 2 - Start Hopper Cylinder: When the conveyor starts operating it also initiates the hopper cylinder.
3) Network 3 – Initiate suction cup stroke: Once the hopper cylinder is initiated a pulse is given to the suction mechanism hence the suction stroke begins and the bag is opened.
4) Network 4 – Execute the pre-set interval time for conveyor: The proximity sensor under the hopper station senses the bag and gives a feedback to the system to stop the conveyor for a pre-set time so that the bag doesn't move while dispensing is in progress.
5) Network 5- Hopper Mechanism: The proximity sensor placed right below the hopper cylinder detects the position of the bag, gives the feedback about bag being at its required position and the conveyor belt stops. Simultaneously the dispensing and bag filling starts, the conveyor is at a halt during the entire process.

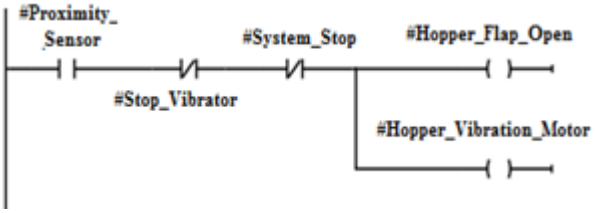

Figure 8: Network 5 – Hopper Mechanism

6) Network 6 – Candy Count: The counter inside the hopper counts the candies as they are dispensed due to the continuous vibration.
7) Network 7 – Stop Hopper Vibration: Once the candy count satisfies the set count the hopper stops vibration thus maintaining the required consistency of the packet.
8) Network 8 – Bag Sealing: At the sealing station the bag is sealed due to the temperature and pressure maintained by heat rollers.
9) Network 9 – Bag sealing time: The heat rollers cannot keep operating perpetually as it's not efficient and thus have to be given a pulse to switch them on for a fixed time until the bag is sealed.
10) Network 10 – Repeat process until all the candies in the hopper are packed in required quantity. Thus, all processes will repeat after the sealed bag is detected at the end.

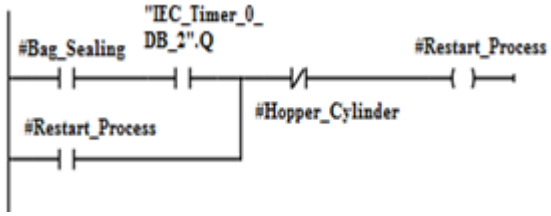

Figure 9: Network 10 – Repeat Process

5. Conclusion

This design is aimed towards achieving output consistency and safer processing and production. The purpose of this proposed system is to adapt from heavy industry machinery design and implement the inspired ideas to design an automated unit with minimum resources, optimum results and versatility of applications. Since the proximity sensors are installed at appropriate stations and their feedback governs the further operation, the dependency on manual interference will be reduced and it will save the extra time that is usually invested in monitoring and verifying the output of these processes. Generally, a completely automated system demands huge space but the proposed unit is designed such that it's compact and handy even for the corner outlets. Moreover, it is user friendly as the dispensing container can be upgraded according to the consumer requirement without replacing the entire system. Since different stations have been installed for different processes, operation of each set up is independent. Thus, it provides a greater scope for interchangeability. Furthermore, as PLC governs the system, the values of number of pieces to be dispensed, time taken to complete the entire process can be varied as and when required. All of these changes can be made and yet the end product will remain unhampered and the flow of process will remain undisturbed. Taking a step further for greater applications, advanced PLC's like S7 1500 can be used to achieve better user friendliness. Similarly, this type of mechanism can be applied in places like fast food outlets, grocery shops, vegetable store, local cafes, tiffin services etc.

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