Semi-Automated Spice Packaging Machine for Middle Scale Business in Sri Lanka

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ABSTRACT

In Sri Lanka, small scale spice packaging businesses use traditional methods while middle scale spice packaging businesses use separate machineries for each individual tasks such as weighing, filling, and sealing processes. Comparatively, considering the higher demand for large-scale spice products in the market, they use highly expensive, technically improved, automated machinery. According to the researches and the site visits, it is observed that currently, there is no affordable packaging machine available in the local market for middle scale businessmen, which includes all weighing, filling and sealing processes in a single system. Therefore, it limits their profits and production. The current used methods in middle scale businesses cause high wastage of raw materials, less accuracy, less hygienic, higher labor costs, and low efficiency. This project proposes a semi-automated, Arduino based machinery for middle scale spice packaging business where a packet is fed manually to the system, while weighing, filling, and sealing processes are automated and sequentially completed. The operation of this machine can be carried out with an involvement of a single laborer. The designed product is pneumatic based and uses some sensors for position, weighing and level detection, heating element, stepper motors, pneumatic system components for smooth operation and Arduino as the micro controller to make it cost effective. With this innovative structure, three packets can be filled and sealed within fifteen seconds while the current used method takes fifteen seconds to complete this process for a single packet. Cost and time effectiveness, reducing ingredient wastage and labor cost are the main advantages of this project. Due to the COVID-19 health restrictions, the hardware implementation is partially completed but to illustrate the working principle and the design plan, a 3D animated model was implemented using SolidWorks, incorporated with electrical stimulation in the Proteus software package.

KEYWORDS: *Packaging-machine, Middle-scale, Pneumatics, Weighing, Sealing, Semi-Automated.*

1 INTRODUCTION

Spices are widely consumed in culinary and other food products which increases its demand day by day. Depending on the per capita income, most of Sri Lankans attract towards medium quality products. The ease in initiation and operation, less legal barriers also affect in people to choose small and medium scale businesses as their source of income.

Most of the middle scale and small-scale businesses do the spice packaging process by using time consuming and laborious conventional methods, since the fully autonomated machines used in large scale businesses are not at all affordable for the middle scale spice packaging businessmen.

The issues identified in the local middle scale chili powder packaging business are gathered through a local middle scale spice packaging business owner and the design is also manufactured considering his requirements. The identified issues are, ingredient wastage, inability and uncomfortable

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to attend in this process for long hours due to the burning nature of the chilli powder, inaccurate weight measurements etc. These reasons result in less productivity of the business.

According to the research carried out, it is identified that in most of the middle scale businesses the packet doesn't come in a printed roll instead it is purchased separately with the middle and the bottom borders sealed where only the top border is not sealed. The reason for this is that middle scale businesses don't have high profits. Therefore, it is difficult for them to invest in expensive machinery and if they go for a machine where a packet roll is fed, they have to change their entire system and also have to invest and bear expenses related to packet material, printing cost etc. at once. Furthermore, since middle scale spice products don't have a high demand in the market a high output is not required, therefore, a fully automated machine doesn't match their requirements.

Low-cost automation is a safe strategy to cope up with the market competition. The originality of this product is that currently, there's no machine available in the market for middle scale spice packaging business in the local market (in Sri Lanka) where separate packets are fed to the machine instead of a packet roll. The designed machine is a semi-automated machine, and it can be operated by either skilled or non-skilled single laborer.

The automated processes are,

- weighing the powder quantity
- filling the packet with powder
- sealing the packet
- moving the packet to each packet filling, sealing and packet feeding stations.

Arduino based automation is used to reduce the overall cost of the machine since PLC based automation is costlier. In-order to obtain a smooth operation and make the machine more efficient pneumatic systems, stepper motors are used.

This research is an attempt and an innovative approach to design and manufacture a packaging machine for middle scale businesses as an affordable and efficient alternative solution to currently used packaging machinery.

2 OBJECTIVE

The major Objectives of this project are,

- To make a machine which is time efficient compared to the current used solutions.
- To reduce the production of ingredient waste.
- To design a spice packaging machine which is cost effective to the middle scale businessmen, compared to the current used methods.
- To manufacture a machine requiring less space.
- To make the machine easy in handling, user-friendly.
- To measure the weight measurements of the powder accurately.

3 BACKGROUND READING

3.1 Packet feeding, holding, opening and moving mechanisms

In 2018, A rotary pouch packing machine is designed by Viking Masek (Leonhard, 2021) to move the packets along with the filling, sealing processes, using a vacuum suction cup mechanism moved by a robotic arm which would pass the bags to the grippers that are controlled by pneumatic systems or motors. The grippers hold the packet once the proximity sensor detects a packet. The speed of it is up to 200 bags per minute. The bag is also inflated by an air blower. These opening jaws (figure 1) moves separately outward in order to open the packet. The packet is filled only if a packet is detected, opened and placed correctly. Two rectangular suction cups are used in order to open the packet at the either side of the packet.

Figure 1. Packet Opening Jaws

3.2 Research on Load Cell

According (Schwartz, 2008), the load cell which is a force transducer converts an input mechanical force such as load, weight, tension, compression or pressure into an electrical output signal. Strain gauges are applied onto a mechanical spring that deform when a weight force is applied, and this deformation is detected by the strain gauges and converted into an electrical resistance change

The setup is in figure 2; The opposite force to the applied load is produced by the elastic deformation of the mechanical spring "1" which contains four strain gauges. Two strain gauges "2,3" are compressed (resistance lowering) and two "4,5" are stretched (resistance rising). The change of the total load-dependent resistance is detected as a voltage signal in the Wheatstone bridge circuit and electronically processed. The following figure is what was explained above on strain gauge load cell.

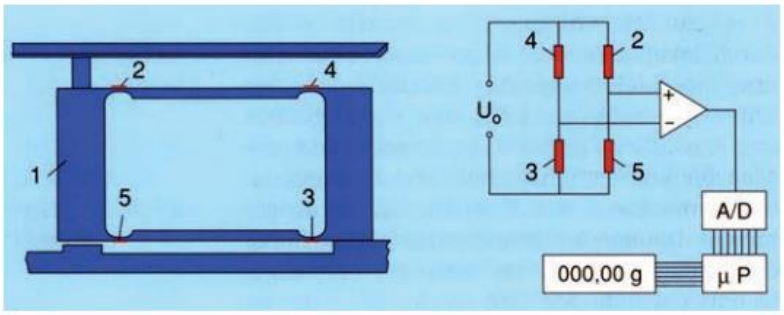

Figure 2. The set-up of a weighing instrument with a strain gauge load cell

HX711 module

The strain gauge in a load cell generates an electrical signal which has a few millivolts amplitude Therefore, it should be amplified by an amplifier. The most used amplifier is the HX711 weighing sensor module which is 24-bit analog to digital converter (ADC) and a simple digital pin-driven controlled system, so no programming is needed for the internal registers. The following features can be identified in the HX711 module.

- Two selectable differential input channels; gain of 128/64 for channel A and 32 for channel B, corresponding to a full-scale differential input voltage of ±20mV or ±40mV respectively.
- In built power supply regulator for load-cell and ADC analog power supply
- There is an on-chip oscillator, so an external clock source is not needed.

3.3 Different methods of sealing for food packaging.

- **Ultrasonic sealing**

Ultrasonic welding is an established and well-known method for joining polymers. This method of welding plastic parts has comparatively short welding times. During ultrasonic welding, the polymer parts or films get compressed and oscillated by longitudinal vibrations of the tool, the horn. A high frequency electrical field is converted into a mechanical oscillation within the so-called converter, typically made up of piezoelectric transducers (Sealing Technology, 2003).

- **Heat sealing**

Generally, heat seal technology is used in packaging made of thermoplastic material as this technology can easily produce bags used in packaging (Sealing Technology, 2020). Basis of heat sealing relies on the foundation of adhesion where a combination of heat, time and pressure create a seal with a set of crimp seal heating bars. When the jaws come together, this melts a layer of plastic and bonds the two layers of film together. Some mechanisms used in heat sealing include chain bonding, wedge bonding, vacuum bonding, intermolecular bonding, and static electric bonding.

Factors affecting heat seal quality:

- **Temperature effect**

The commonest shape of packaging materials utilizing laminate films is the bag or pouch. These are manufactured with different types of sealing technologies, such as chemical adhesives, ultrasonic welding, heat sealing, impulse heat sealing, hot air welding, etc. Heat seals are made by fusing the polymers to one another through the application of heat and pressure. The initial pressure enables intimate contact between the films. Adhesion is promoted by application of heat from the outside.

- **Wear resistance**

Electrical heating elements should have a high resistivity in order that the dimensions may be consistent with a compact design and mechanical strength while keeping the current to acceptable values; Heat sealing tapes consist of a substrate, which is the surface that comes into contact with the plastic, and an adhesive, which firmly bonds the substrate to the sealing machine. Fundamentally, heat sealing tapes must transfer thermal energy from the hot platen to the plastic without allowing the plastic to adhere to the tape.

- **Seal pressure**

Many studies indicate that any increase above the required level of sealing pressure, which is adequate to supply full contact between layers does not affect the sealing temperature and sealing strength significantly. Also, according to Najarzadeh and Ajji, increasing the seal pressure from at a very low level such as from 0.1 to 0.5 N/mm2 will decrease the seal initiation temperature. In that range, increased pressure provides better contact between two film layers. However, above that level, seal initiation temperature does not show any chance.

- **Cooling rate**

Controlling the cooling rate that influences crystal growth may help to enhance seal strength. Films showing a faster crystallization behavior had higher hot tack strength at temperatures lower than the temperature that supplies total melt of the crystals. This means that at the low temperatures, the seal strength will be enhanced by solidification due to quickly starting recrystallization.

3.4 Key attributes of the packing machines currently used in the spice packaging industry.

Table 1 Currently used machines for spice packaging

Company	Figure	Comment
Alibaba	 Figure 3. Chili powder packing machine	All the weighing, filling, sealing processes are included. Polythene rolls are used to form the packets. Rs.1, 375, 304.08

Dunuwila Traders	 Figure 4. Automatic powder filling machine	Filling process only Voltage 220V 50HZ Power 100w Filling Speed: 05 – 10bags per min (50g& 100g) Semi-Automatic
Dunuwila Traders	 Figure 5. Automatic powder packing machine	All the weighing, filling, sealing processes are included Voltage 220V 50HZ Power 500w Fully Automatic Filling Speed: 10 – 15bags per min (50g / 100g)

Most of the packaging machines used in the industry, uses the packing rollers to make the packets as shown in the above table and these machines are used for packaging businesses which carry out a bulk production. But since middle scale businesses do not require a bulk production, they always purchase separate equipment for each weighing, filling and sealing processes when doing packaging. Such machines which were observed during the site visits are listed below.

Table 2. Machines identified through site visit

Company	Figure	Comment
Sarupa Rasa Piyasa, Athurugiriya	 Figure 6- Intelligent Weighing Scale & Filling Machine	Filling process only Rs.110,000.00

Sarupa Rasa Piyasa, Athurugiriya	 Figure 7. Stainless Steel Band Sealer (Horizontal)	Sealing process only Rs.68,500.00

4 METHODOLGY

The project consists of two main parts, called hardware and software. The hardware part of the machine focused on three main sub-mechanisms, namely the packet moving mechanism, the powder filling mechanism, and the packet sealing mechanism. In all these mechanisms, pneumatics is the main controlling system used, since it has more reliable components and a long operating life, and is cheaper than hydraulics, especially since the required maintenance is less.

Moreover, most of the current autonomated machines use PLC as the programming board. In this project, the chosen programming board is the Arduino. More memory, as well as a large number of input and output pins, are required to process a large code. Considering the flesh memory, SRAM, and the number of input/output pins, the Arduino Mega is used to program the machine.

4.1 Overview of the project

The process flow of the designed machine is as below (figure 8).

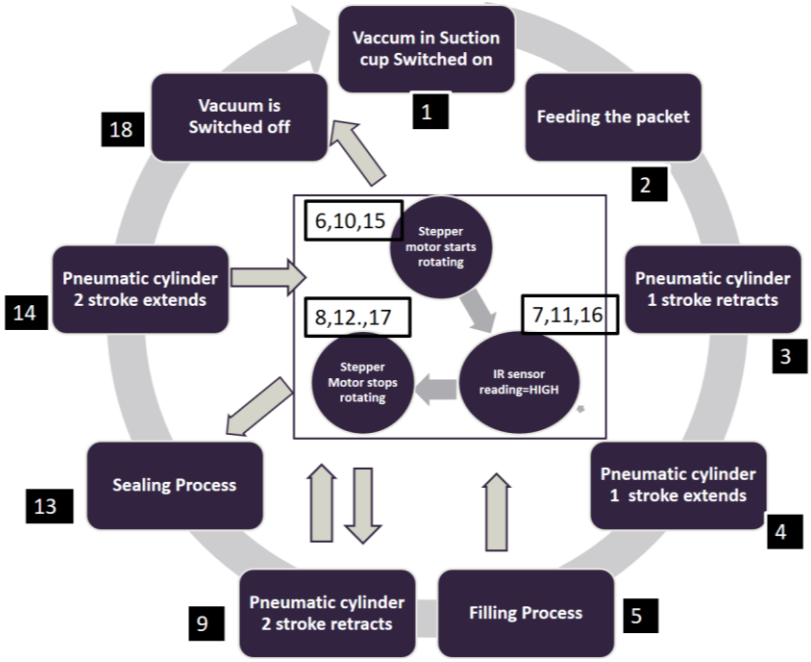

Figure 8. Complete process flow of the designed machine

Process happens as per the sequence - 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, and the same sequence repeats.

Initially, the vacuum is switched ON when the power is switched on and the suction is turned on as well. Then the process starts with an empty printed polythene packet being fed to the two stationary suction cups. The stroke of the pneumatic cylinder at the packet feeding station retracts, moving the vertical bar where the suction cup is attached forward to hold the packet. Next, the stroke of the

pneumatic cylinder extends, and the packet is opened due to the force generated by the tension of the spring draws back the vertical bar. Then the packet is moved to the filling section.

The storage tank, gutter, and vessel are the three basic parts of the powder filling structure. The storage tank is used to store the spices for the filling process, and the gutter is placed next to it to control the flow of the spices. Next to the gutter section is the vessel, which is the part that connects to the packet and fills it with powder. Side view of the powder filling section is shown in below figure 9 and figure 10.

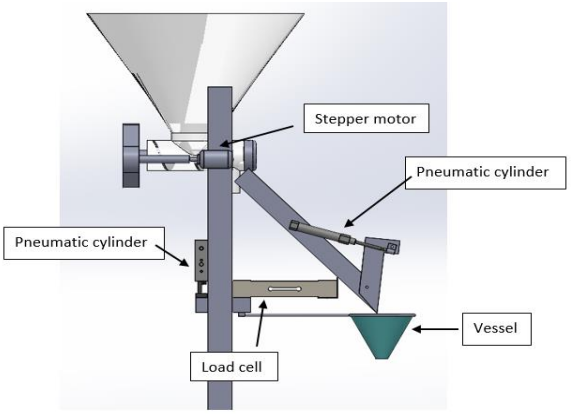

Figure 9. Solid works design for the powder weighing and filling processes

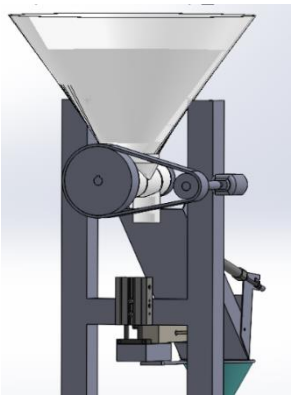

Figure 10. Gear system to connect screw to the stepper motor

The powder is first stored in the storage tank, and then when the machine is turned on, the screw rotates, moving the powder towards the gutter. The powder is then dumped into the gutter until the load cell reading reaches 100 grams (a pre-defined value). When that value is set, the IR sensor reading should be used to determine whether the packet has arrived at the filling region. As a result, if the packet has arrived, the twin-rod pneumatic cylinder should extend its stroke to the gutter. Because the entire gutter part is connected to the pneumatic cylinder, this is possible. Then the other pneumatic cylinder, which is the CDJ2D10-30 mini round cylinder, should extrude its stroke since the lid of the gutter is connected to it. As a result, when the packet is opened, the powder is loaded into the packet. Finally, when the load cell signal indicates that the load has been reset, the mini round cylinder extends the stroke to close the lid, and the TN 25X50 Twin rod cylinder extrudes the stroke to raise the entire gutter section. The process flow of the designed machine is as below figure 11.

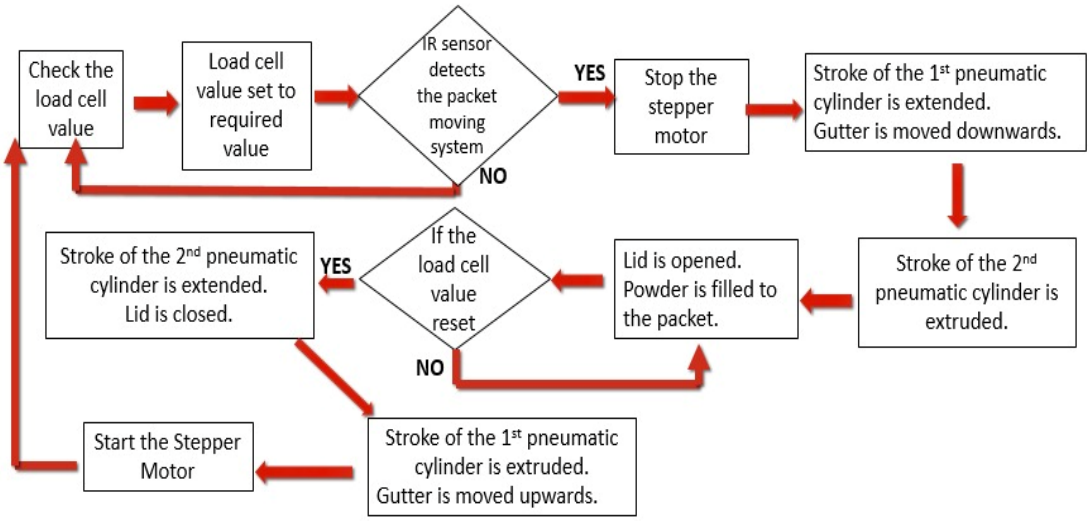

Figure 11. Process flow of the filling section

When the powder filling process done packet moves to the sealing station with stepper motor rotation. When the package arrives at the sealing station, the pneumatic cylinder mounted on the table retracts and ready to start sealing process.

Two pneumatic cylinders played the most important parts in the sealing process. Each pneumatic piston is connected with two separate metal plates. As shown in the below figure 12, the heating element is joined to the bottom pneumatic cylinder, and the other plate has silicon rubber connected to compress the packet. Finally, Teflon tape was covered both the silicon rubber and the element. Then the always packet should only be in contact with Teflon tape; as a result, the seal should be very smooth.

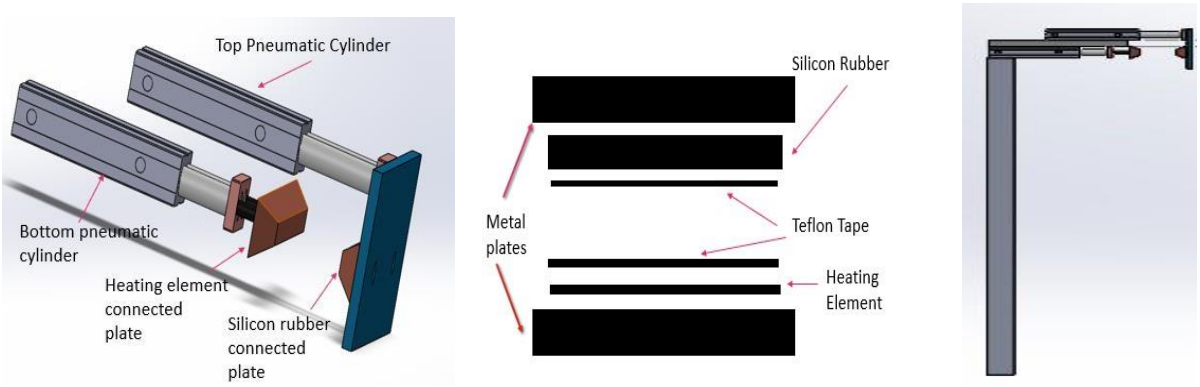

Figure 12. Cross sections of the sealing plate arrangements and the sealing station

The top piston is in the maximum stroke position at the start of the sealing process, while the bottom piston is in the minimum stroke position. The Arduino sends a signal to pneumatic valves when the packet arrives between two plates. The top pneumatic cylinder's piston moves backward, while the bottom pneumatic cylinder's piston goes forward, according to that signal. The element is then passed through a current, which heats up the heating element. As a result, the polythene layers softly melt, and the sealing process is completed once the packet is sealed. After the packet is sealed, the circuit from the relay is disconnected, and the pneumatics are allowed to cool for 1 second. Both pneumatics then returned to their original positions.

The vacuum is turned off once the packet is sealed. When the vacuum is turned off, the stationary pneumatic cylinder at the base extends its stroke, and the packet is discharged to the gutter slope, where it falls into the box that collects the completed packets

When the hardware implementation was decided, it was decided to remove the outer ring from the hardware element in order to reduce production costs. Solid work design for the proposed machine shown in below figure 13.

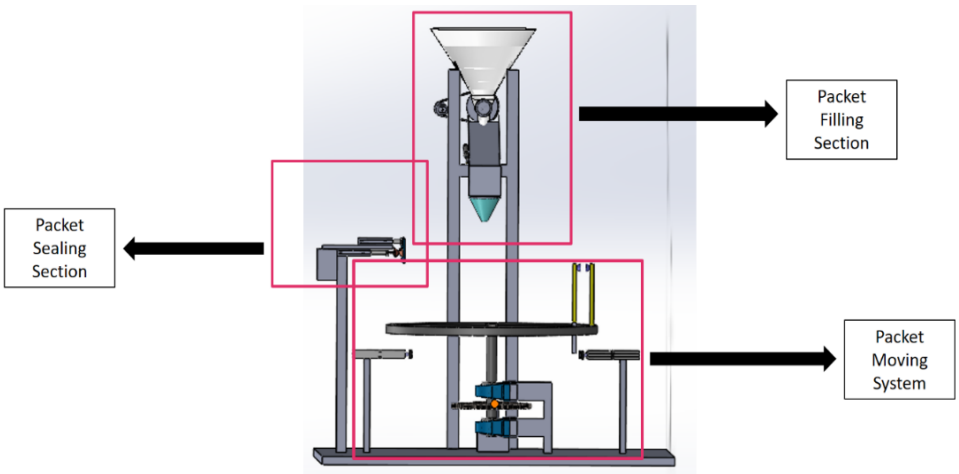

Figure 13. Finalized Solid work design of the machine

The method of powering up the sealing element is shown below figure 14.

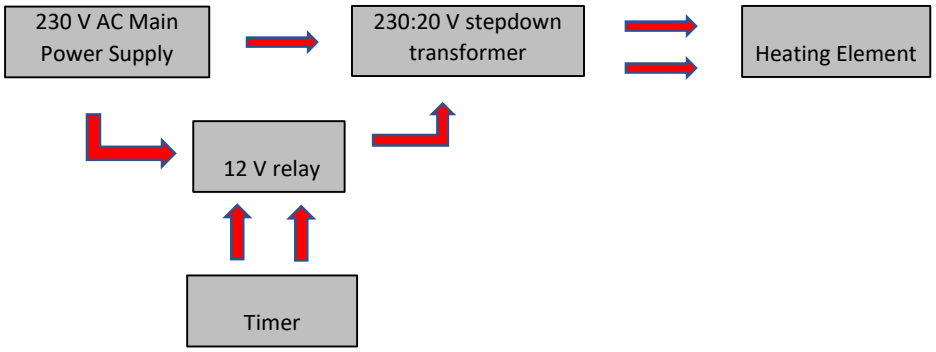

Figure 14. Sealing element power-up mechanism machine

Parameters of the selected heating element are as follows.

- Material of the element: Nichrome
- Element dimentions:15 cm* 1.5 cm
- Power requirement:133.33 W
- sealing time: 12 seconds

5 RESULTS AND DISCUSSION

An innovative design based on the requirements of a local middle scale spice packaging business could be designed which can be operated by only an involvement of a single laborer. The complete mechanical hardware part could be completed in a cost-effective manner where all the packet moving, filling and sealing parts are included in a single machine. The components were selected based on calculations and the requirements of the customer.

As a whole machine all the three individual parts were successfully completed by the three members, but the trial-and-error process has to be carried out with the actual machine and should check whether these simulation processes work align to the actual procedure and have to do the trouble shooting with the programming parts with the actual machine since this is a real product that we manufacture as per a customer requirement. The complete mechanical structure of the machine is shown in figure 15.

Figure 15. Complete mechanical packaging machine

5.1 Packet Moving System

The Mechanical Hardware of the Packet moving system shown in below figure 16.

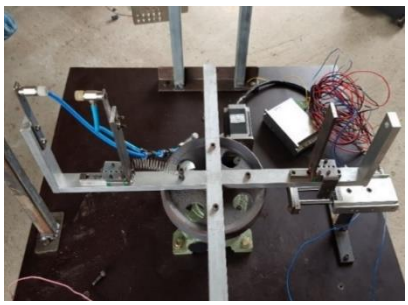

Figure 16. Mechanical structure of the packet moving system

The Solid work design for the system designed to discharge the packet is as below figure 17.

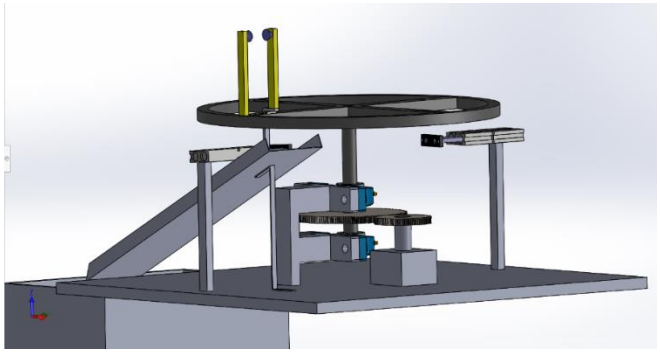

Figure 17. Designed system for packet discharging

5.2 Filling Section

The completed Mechanical Hardware of the filling section shown in below figure 18.

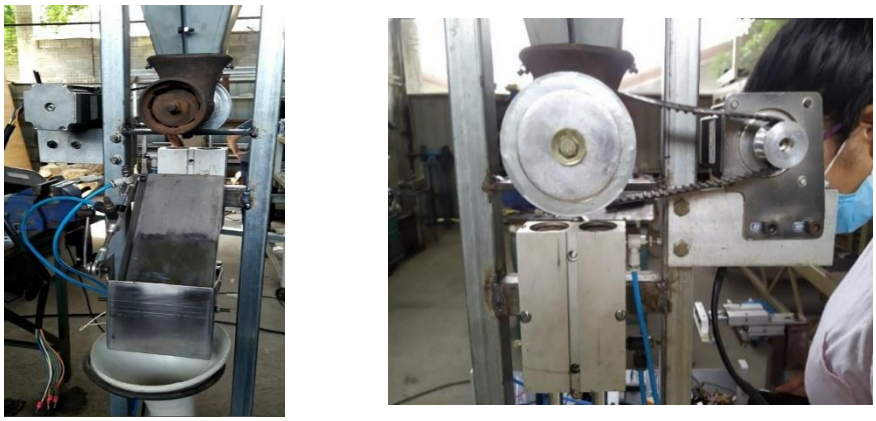

Figure 18. Mechanical structure of the filling section

5.3 Sealing Section

The completed mechanical hardware of the sealing section is shown in figure 19.

Once the filled packet reaches the heating element, packet is sealed finishing the packing cycle. When sealing the packet, the element passes a higher current load, and it should pass when the packet is at the proper orientation. Otherwise, the packet melts and cause damages to the machine. A timer circuit has been designed, to keep a constant time taken to seal a bag at the required temperature. To determine this pre-defined time a potentiometer was used and to make the machine user-friendly, a nob was used so that the operator is given the opportunity to adjust the sealing time depending on the type of polythene and the temperature of the system. Timer circuit was introduced to this system by considering all above factors.

Normally one RCCB and several MCB are used in machines. When using MCB, one main MCB and several other MCBs are used section wise. Since the target customer group is small and medium scale businesses and they usually operate in domestic entities we assumed they already have MCB and RCCB protection.

Figure 19. Mechanical structure of the sealing section

Very expensive and complicated mechanisms and methods have been used in local and global large-scale businesses such as grippers, robotic arms, actuators, conveyor belts. Because of high cost and more space middle scale businesses are not interest with above mechanisms. So, in this innovative design, following are the highlighted components used in all three processes which are packet moving mechanism, filling section, and sealing section. Pneumatic cylinders, vacuum suction cups, linear bearings, stepper motors, solenoids, venturi meters are used.

Pneumatics is used as the main implementation technology since it is cheaper than hydraulics, smooth operation, ease to obtain and store, components are reliable, has a long operating life and the required maintenance is less. In all of these 3 main sections pneumatic components such as twin rod and single rod pneumatic cylinders have been used. So, when selecting the pneumatic components specifically the pneumatic cylinders in the application, following factors should be considered.

- Stroke length
- Stroke moving distance
- Size and other physical characteristic
- Pressure that can be applied
- User friendliness

As an example, at the sealing point the two sides of the polythene bag should come closer to each other to create a seal. So TN10*25 double acting cylinder was used to move the sealing plates where the heating element and silicon rubber is attached, in order to close the opening of the bag.

5.4 Results analysis: -

Highlighted key points of the machine shown in below table 3.

Table 3: Specifications of the manufactured packaging machine

Current requirement	8.46 A
Power requirement	203.04W
Total height	1.2m
Total length	1m
Total width	1m
Cost estimation	Rs.110,000 (approx..)

Mainly, our packaging machine is more cost effective as it consists of all the weighing, filling, and sealing processes in itself and worth Rs.110,000.00 approximately while all other packaging machines which consists of all the three processes worth above Rs.1,000,000.00. If the equipment for each process is bought separately, that can cost about Rs.170,000.00) which will also increase the labor force needed.

As well as this project needs three type of power requirements and the selected SMPS power ratings shown in below table 4.

- To operate sealing process -230 V AC
- To operate compressor- 230 V AC
- To operate other DC components – Used switch mode power supply

Table 4. Total power requirement of the SMPS

Output DC current values	24 V	7.4 A
	12 V	1.06 A
Total output current	24 V +12 V	8.46 A

When comparing the power requirement, most of the machines which consists of all the three processes have about 500W consumption, but this machine require 200W amount approximately. Moreover, the special feature of this machine is the portability as it is made as a desktop version.

Comparing all of these aspects, this manufactured machine is more suitable for middle scale spice packaging businesses

6 CONCLUSION

The designed machine is constructed according to the requirements of a local middle scale spice production business. The design is an innovative approach which is not currently available in the market. This machine can be operated using domestic single phase AC power and doesn't need three phase AC power. The labor involvement of the designed machine is less since it is a semi-automated machine. The components used can be easily found in the market, therefore, the maintenance and repairs are easy and high skilled laborers are not required for the operation. The design is carried out considering the safety of the operators by not including sharp attachments such as sharp edges or blades to cut packets etc. Middle scale spice production business owners can purchase this product considering the affordability, efficiency, reduced ingredient wastage compared to the current available packaging machines in the market. This can be made available for different weight ranges.

Further research on this product can lead to many more developments such as making it available for several packets to be filled at the same time and improve it to pack a range of weights and testing the code with the actual mechanical hardware structure.

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