Design and Fabrication of Vertical Form Fill and Seal Machine (VFFS)

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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ABSTRACT

The aforementioned team chose the design and fabrication of Vertical Form Fill and Seal (VFFS) machine as its final year project. Packaging is one of the main concerns of manufacturing industry in Pakistan. The existing machines that are manufactured locally have shortcomings like low speed, seal leakage, paper wastage and design out.

The project aimed at design and fabrication of such a packing machine that will solve the problems faced by our industry. The machine designed by us seals the film in two parts, first it forms the longitudinal sealing seam and then it forms the horizontal sealing seam. The longitudinal seam is formed with the help of fin seal rollers that form the vertical seal as the film rolls past the minute gap between the fin seal rollers. The horizontal seam is formed by the reciprocatory type sealing jaws. The seams are sealed by briefly heating the sealing medium (usually polythene) which melts. The seams are sealed as soon as the sealing medium cools down and this cooling occurs in milliseconds.

The project involved the application of knowledge of quite a few subjects which we had studied in our bachelor’s program such as Instrumentation, Electrical Systems, Automation, Control Systems, Machine Design, Mechanical Vibrations, Mechanics of Machines.

ACKNOWLEDGMENTS

First of all, we are very thankful to our Creator and Sustainer Allah Almighty, The Most Beneficent, The Most Merciful, Who helped us through each and every step of this project. Indeed nothing is possible without His divine decree. We owe a great debt of gratitude to our parents who have always lent us their valuable support through all the ups and downs of our life. We would like to thank our project supervisor Dr. Jawad Aslam for being a great supervisor and for helping and supporting us through all the phases of this project. Sir, we appreciate your patience and believe that you are the perfect embodiment of an honest and inspiring teacher. We are also profoundly grateful to our advisors Dr. Aamir Mubashar and Dr. Samiur Rahman Shah for their generous support and guidance. Our Principal Dr. Shahid Ikram-Ullah Butt as well as HOD Dr. Emad-ud-Din are also be thanked for all the support we got from the school and department.

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ABBREVIATIONS

VFFS	Vertical Form Fill and Seal
DOF	Degree of Freedom
VFD	Variable Frequency Drive
PLC	Programmable Logic Controller
SSR	Solid State Relay
AC	Alternating Current
DC	Direct Current

NOMENCLATURE

F	Force
$\ddot{x}$	Acceleration
P	Pressure
W	Power
τ	Torque
w	Angular Frequency
m	Meter
Pa	Pascal
s	Second
kg	Kilogram
W	Watt
N	newton

CHAPTER 1: INTRODUCTION

1.1 Motivation

Vertical Form Fill and Seal VFFS machine is being used in many industries including multinational companies like Nestle, Unilever, P&G, Lays and the list goes on. In fact it is used for packing in all the industries producing eatables like packing of snacks, packing of liquids such as milk and juices in pouch and other daily use products like powders such as masala packing, detergent packing, tea packing and so on. The large scale use of this machine is from where we drive our motivation of undertaking this project. There are huge market opportunities for our project because the production of this machine at local level is still in emerging phase and we find it a great opportunity to play our role in this regard. There are very advanced packing machines being used in our industry but they are imported due to which they are very expensive and are out of the range of small scale industry. So our project will help small scale industry in solving its packing problems.

1.2 Problem Statement

Design and Fabrication of Vertical Form Fill and Seal Machine (VFFS) to solve the problems of slow speed, seal leakage, air leakage, paper wastage and high cost.

1.3 Objectives

The objectives of our project are derived from the problem statement. These objectives are Designing and Fabricating Vertical Form Fill and Seal Machine with following features:

- Continuous Motion instead of Intermittent Motion to solve problem of slow speed.
- 2 DOF Sealing Jaws to solve the problem of slow speed.
- Variable displacement sealer for various packet sizes.
- Proper control system design including feedback system to solve the problem of design out and paper wastage.

CHAPTER 2: LITERATURE REVIEW

2.1 VFFS Machine

Vertical form, fill, seal machines are very flexible machines. Widely ranging products can be packed efficiently and effectively, from our daily coffee to fresh vegetables to frozen meat. Also the insecticides, detergents and marbles are packed in bags. The first VFFS machines were built in the mid of the last century. Today thousands of them are in use. The wide use of VFFS machines is because one single machine can be used to produce variety of bag shapes. This is possible due to a large variety of simple-to-exchange parts such as forming shoulders and forming tubes. For example, chips are usually packed in a simple pillow shaped bag, while breakable cookies are packed in a bag with block bottom. Both of these bags can be produced by the same machine.

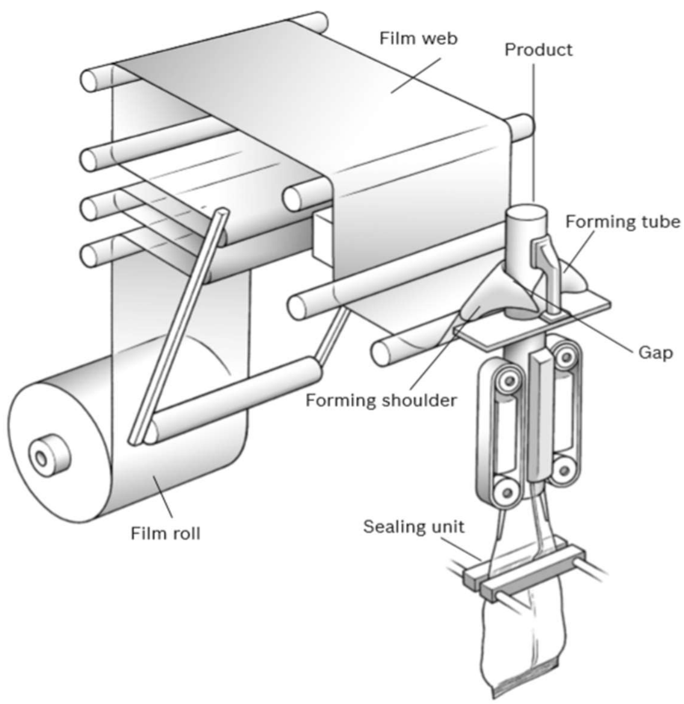


Figure 1: Vertical Packing Machine

A second factor is the low price of this type of packing machine. The machines allow for high packaging speeds and operate uninterrupted for a long time. They are reliable and give efficient output even at a high speed.

2.2 Packaging Product Types

VFFS machines are suitable for a wide range of products that can be divided into the following four main groups:

- Bulk goods varying from nuts and cookies to bolts and screws.
- Powders such as ground coffee and dehydrated milk.
- Grains or granulate such as detergent.
- Liquids such as ketchup, mayonnaise, salad dressing or bath gel.

2.3 Bag Making

A flat web of film from a large roll of film at the start of the machine is shaped into a tube. This tube is closed at the bottom. This is the bottom of the new bag. As soon as the product is dispensed into the bag, the top side is also closed. The time and steps that are needed to make one bag are collectively called a machine cycle.

2.4 Sealing

A bag has three seams. The longitudinal seam is the seam that runs down the length of the bag. The left and right side of the flat film join together to form it. The bottom seam closes the bottom of the bag, the top seam closes the top. Both of these are called cross seams. The seams are closed by sealing. To do this the packaging material is compressed and heated and the sealing medium (usually polyethylene) melts. As soon as the sealing medium is cooled enough, the seams are formed. This happens in milliseconds.

2.5 Sealing Jaws

The sealing unit at the bottom of the forming tube contains four sealing bars. The lower two sealing jaws form the top seam of the bag that has just been filled. At the same time the upper two jaws form the bottom seam of the next bag. The blade that cuts and separates both the bags is located between the two sets of sealing jaws. The film material is compressed together and heated by the sealing jaws.

2.5.1 Horizontal Sealing Jaws Types

- Reciprocating type. They have single DOF.
- Rotary type. They have 2 DOF.

Figure 2: Horizontal Sealing Jaws

2.5.2 Vertical Sealing Jaws Types

- Fin Seal Roller
- Flat Seal Type

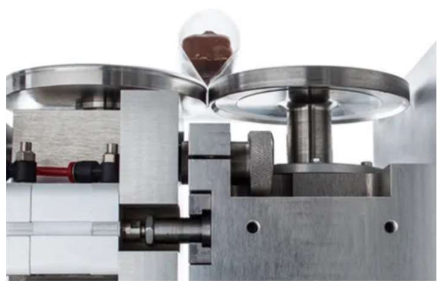


Figure 3: Vertical Sealing Jaws

2.6 Forming Tube and Forming Shoulder

Every packaging machine can form different bag sizes, fill them and seal them. The size and shape of the bag are determined by two important components, the forming tube and the forming shoulder. The web of film is pulled over the forming shoulder, so that the material around the forming tube is shaped from a flat film to a tube. The shoulder and tube are collectively called the forming parts. Every bag width requires its own forming parts.

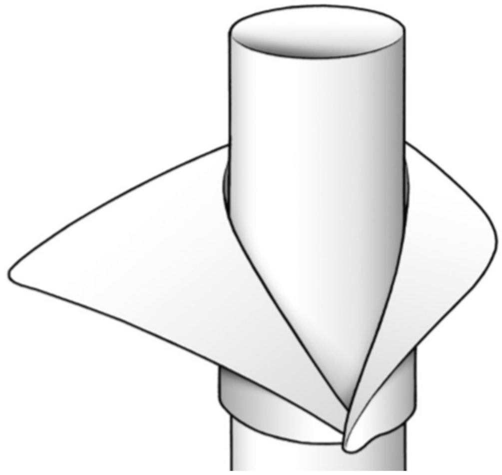


Figure 4:Forming Shoulder and Forming Tube

2.7 Overlap and Fold-over Seam

There are two types of longitudinal seams. In the overlap seam or lap seal one edge of the web of film is placed over the other edge, so that the material overlaps. In this way, the inside of the first edge is sealed to the outside of the other edge. With a fold-over seam or fin seal, one edge of the web of film is folded over, so the inside of the one edge is sealed to the inside of the other edge.

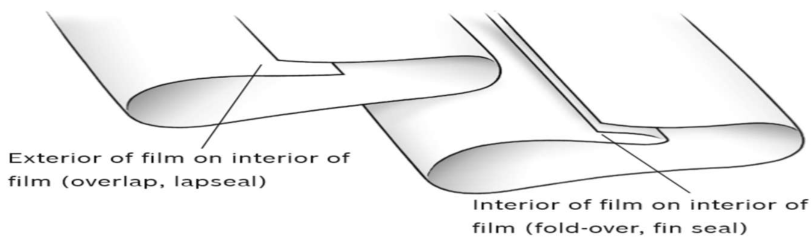


Figure 5: Types of Seams

2.8 Dispensing

In order to ensure that the correct quantity of product is always packaged, a doser is required. Depending on the product, the doser works on the basis of the filling weight or volume per bag. For liquids, a special pump is used that dispenses a certain amount of liquid for each package. When packaging a certain number of product units per bag a counting machine is used.

2.9 Dosing Systems Types

- Auger filler
- Volumetric cup filler
- Multi-head weighing filler

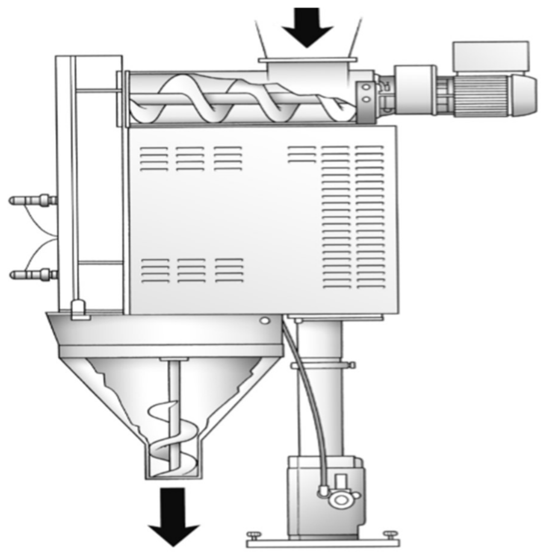


Figure 6: Auger Filler

2.9.1 Auger Filler

With auger dosings the often “dusty” product is found in a supply hopper. Under the hopper is a dispensing tube in which the auger filler rotates. An agitator causes the product to move from the supply hopper to the auger filler. The auger rotates the powder downwards. An amount of product is transported during every revolution of the auger and transfers a certain amount of product with each revolution. By setting how many revolutions the auger makes per dispensing, one can determine how much product volume will end up in each bag.

2.9.2 Volumetric Cup Filler

Volumetric cup filler has cups of certain volume. When the cup is filled the filler dispenses the product."

Figure 7: Volumetric Cup Filler

2.9.3 Multi-head Weighing Filler

The most common filling scale, called multihead weigher, has its popularity to its speed, precision and broad applications. As the name suggests, the multihead weigher uses multiple weighing hoppers at the same time. Each of the eight to thirty-six weighing hoppers is filled, then the multihead weigher determines at a high rate which combination of the hoppers contains the desired amount so as to dispense it.

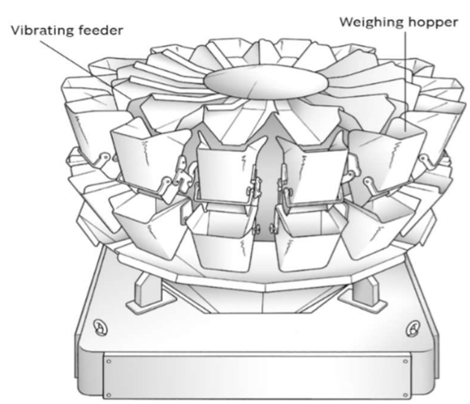


Figure 8: Weighing Filler

2.10 Bag Types

VFFS machines produce four types of bags.

- Pillow bag
- Gusset bag
- Flat bottom bag
- Doy bag"

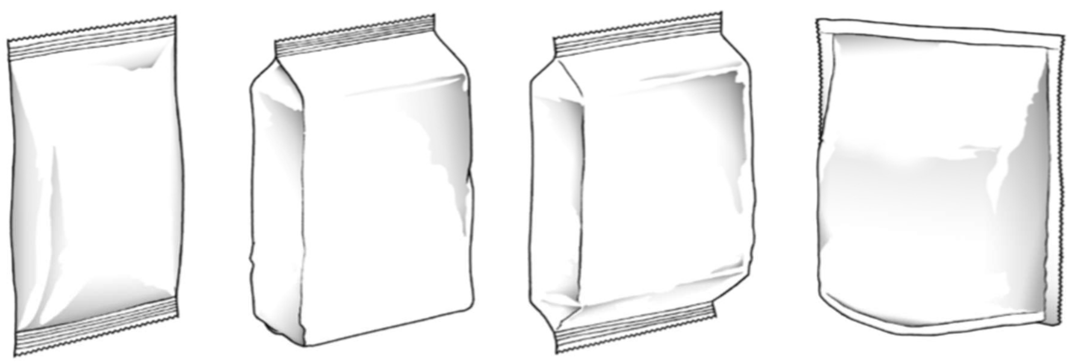


Figure 9: Bag Types

CHAPTER 3: METHODOLOGY

The design and fabrication of our Vertical Form Fill and Seal Machine required us to take on various steps. Following are those steps:

3.1 CAD Model

The first step was to draw an appropriate CAD model of VFFS. For that purpose we used SOLIDWORKS software and drew a CAD model of VFFS. After various meetings with our supervisor we made changes in the model to achieve an appropriate design with the passage of time. Following is the final CAD model of our VFFS machine:

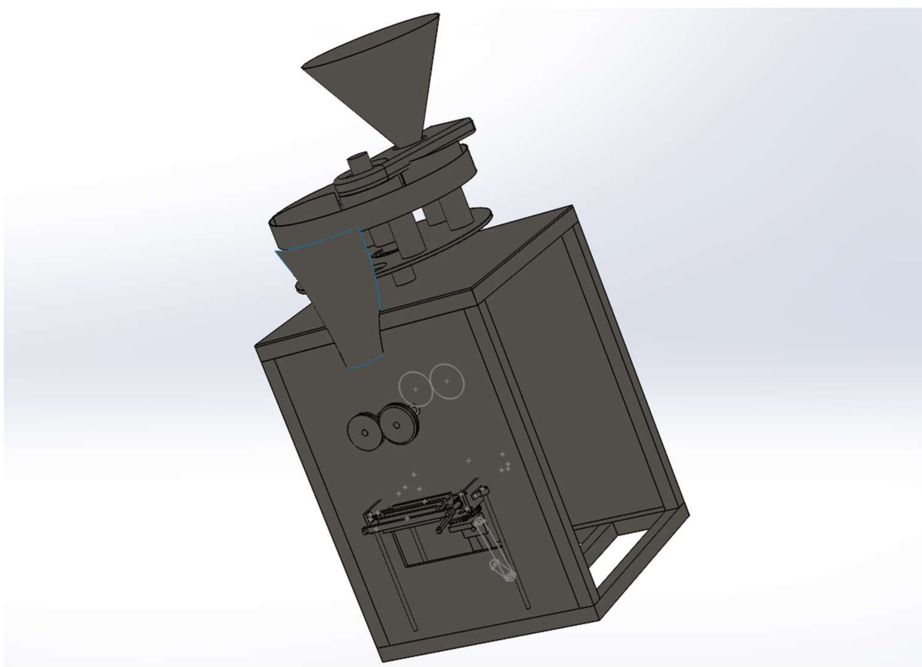


Figure 10: Final CAD Model

3.2 Design Calculations

The next step was to carry out the design calculations. To make the choice of various things such as the appropriate material, motor size, size of sealers, heating element and pneumatic cylinder, following calculations were made. This also included the testing of structural strength of the machine such as Buckling test, stress and deflection calculations of the structure of machine.

3.2.1 Lifting Motor Power Calculations for Horizontal Sealer

Horizontal sealer forms the horizontal seal of the packet. Lifting motor gives it up and down motion that helps to keep the film unrolling and continue the process of packing. The to and fro acceleration of the horizontal sealer mechanism was calculated using following formula:

$$Acceleration\ \ddot{x} = R\omega^2 \left(cos\ \omega\ t + \frac{cos\ 2\ \omega t}{n} \right)$$

The force needed to keep the sealer mechanism moving up and down was calculated using following formula:

$$Force\ (F) = m \times \ddot{x}$$

The torque needed to keep the sealer mechanism moving up and down was calculated using following formula: $Torque\ (\tau) = r \times F$

The required motor power is calculated by the following formula:

$$P(W) = \tau(Nm) \times \omega(rad/s)$$

Lifting Motor Calculations	
Acceleration	24.2443639 cm/s^2
Mass Lifting	20 kg
Force	484.887279 N
Torque	21.8199275 Nm
Power	342.747422 Watt

Table 1: Lifting Motor Calculations

3.2.2 Calculations for Required Pneumatic Cylinder

Pneumatic cylinder serves two purposes. One is the opening and closing of horizontal sealing jaws and the second is the compression of gas for the purpose of modified atmosphere packaging. Following relations are used for calculating the air pressure provided by pneumatic cylinder of certain bore and stroke for operating the horizontal sealing mechanism:

$$Area\ (A) = \frac{\pi B^2}{4}, where\ B = bore$$

$$Pressure\ (P) = \frac{Force\ (F)}{Area\ (A)}$$

Following relations are used for calculating the air flow rate provided by pneumatic cylinder of certain bore and stroke for operating the horizontal sealing mechanism:

$$Velocity = \frac{2 \times No.of\ cycles\ per\ minute \times S}{60}, where\ S = stroke\ length$$

$$Volume\ flowrate\ =\ Velocity\ (v) \times Area\ (A)$$

Pneumatic Cylinder Calculations	
Bore	0.063 m
Stroke	0.075 m
Area	0.003117253 m^2
Gauge Pressure	73.22092704 kPa
Velocity	0.375 m/s
Volume Flow Rate	0.00116897 m^3/s

Table 2: Pneumatic Cylinder Calculations

3.2.3 Calculation for Frame Deflection

The calculation for frame deflection is performed to ensure that the system bears the stresses and deflection during its working. Following is the relation used for the calculation of plate deflection: $Deflection = \frac{0.0284 \times F \times L^2}{E \times t^3 (1.056 \left(\frac{L}{W}\right)^5 + 1)}$, $t = thickness$

Frame Strength Calculations	
Stress	18.88863216 MPa
Deflection	0.000383814 m

Table 3 : Frame Strength Calculations

3.2.4 Calculation for Buckling of Pipe Structure

The calculation for buckling of pipe components of the frame structure is performed to ensure that the pipe components do not buckle under the working conditions. Following is the relation used for the calculation of buckling force:

$Compressive\ Stress = \frac{Force\ (F)}{Area\ (A)}$; $Force\ (F) = \frac{\pi^2 EI}{l^2}$,

$where\ E = Elastic\ Modulus\ \ I = Moment\ of\ Inertia$

Buckling Test Calculations	
E	205 GPa
Moment of Inertia	$9.2681 \times 10^{-8}\ m^4$
Compression Stress in Column	2.761893143 MPa
Buckling ($F_{critical}$)	218.8013294 kN

Table 4: Buckling Test Calculations

3.3 CAD Analysis

After having done with design calculations, CAD analysis was carried out according to the requirements of the project. For this purpose we chose ANSYS software. Following are the results of these CAD analyses.

3.3.1 Deformation Analysis of Frame Structure

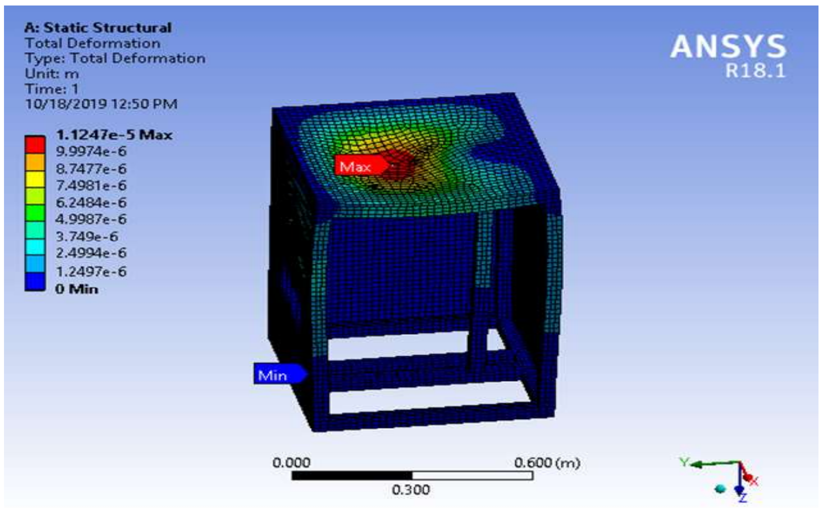


Figure 11: Deformation Analysis of Frame Structure

3.3.2 Stress Analysis of Frame Structure

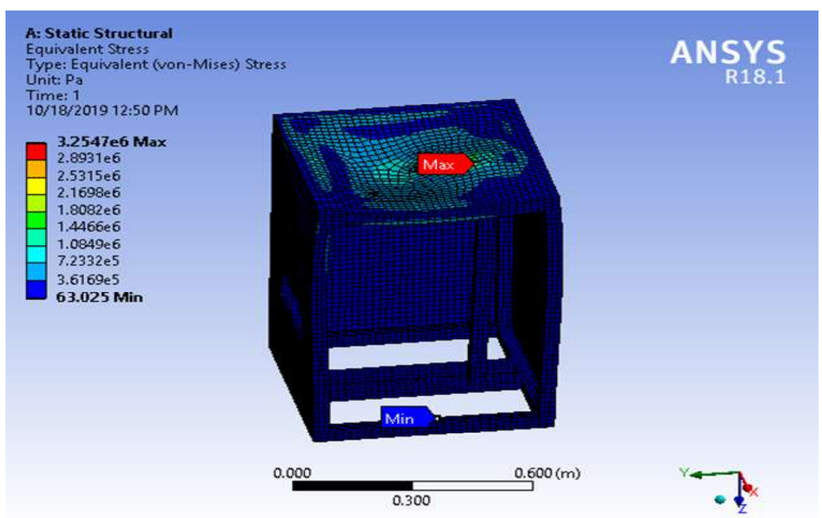


Figure 12: Stress Analysis of Frame Structure

3.3.3 Deformation Analysis of Horizontal Sealer:

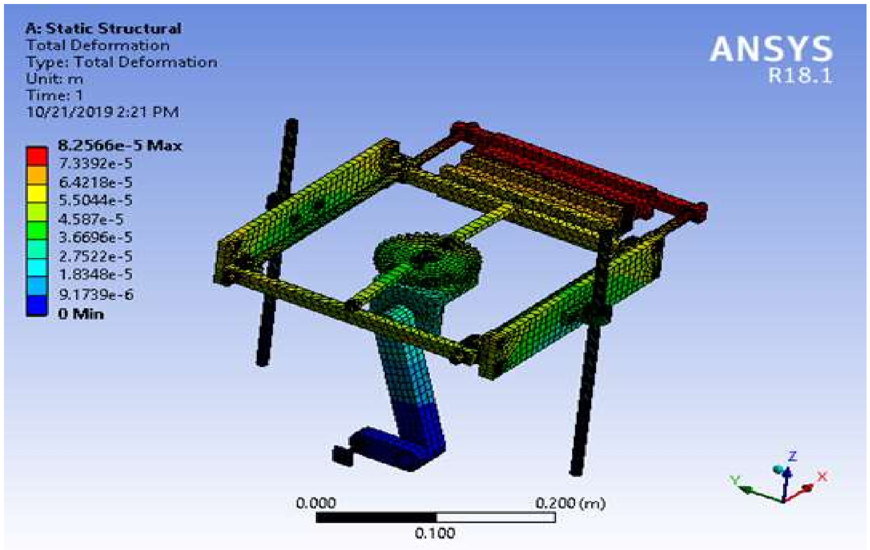


Figure 13: Deformation Analysis of Horizontal Sealer

3.3.4 Stress Analysis of Horizontal Sealer:

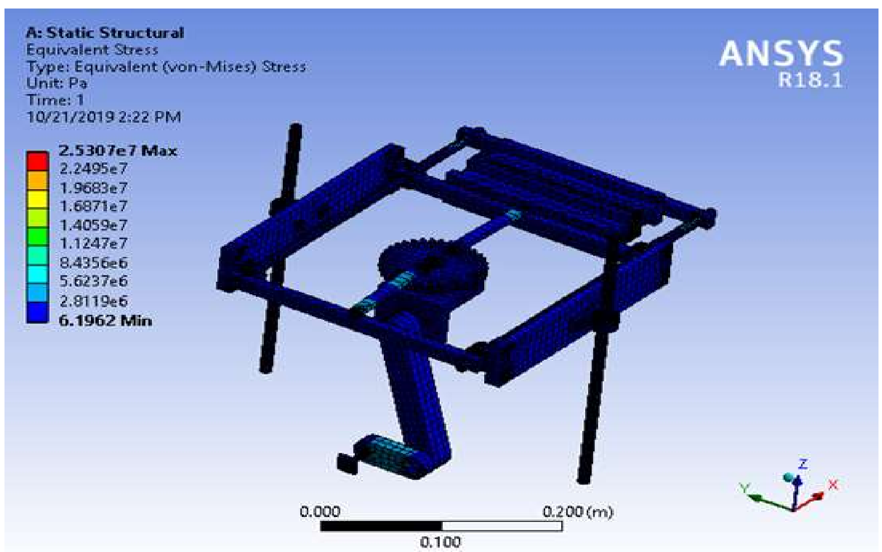


Figure 14: Stress Analysis of Horizontal Sealer

3.3.5 Deformation Analysis of Doser:

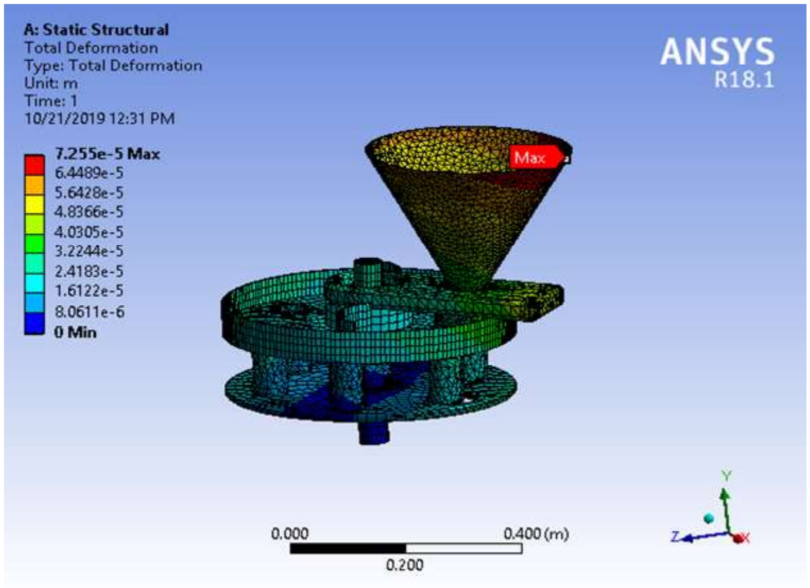


Figure 15: Deformation Analysis of Doser

3.3.6 Stress Analysis of Doser

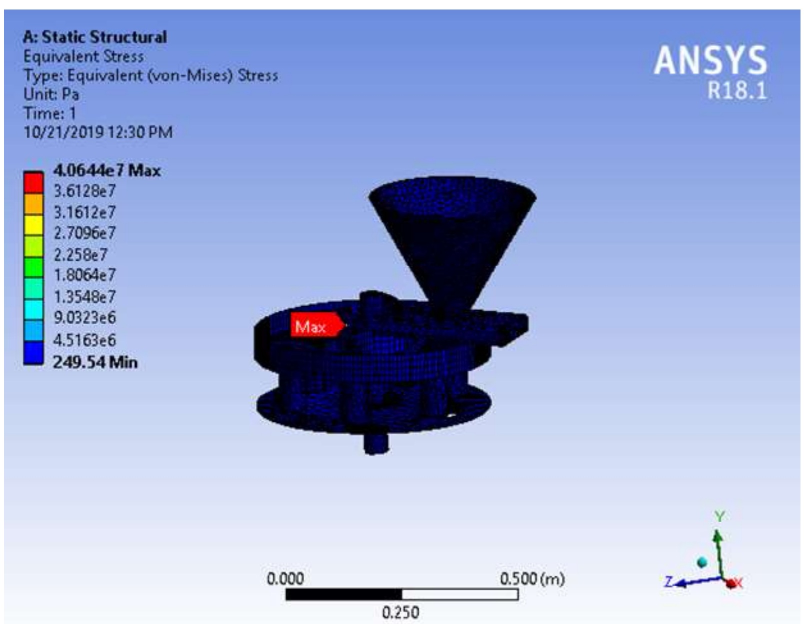


Figure 16: Stress Analysis of Doser

3.4 Material selection

Material selection is very critical part of every project. It requires a lot of care while selecting a material. For our machine we chose different materials for different components as described below:

3.4.1 Frame Material

The frame is made of mild steel. There are quite a few reasons listed below:

- High UTS and yield strength
- Weldability and machinability
- Nice finish and polishability
- Inexpensive

3.4.2 Doser Material

The doser is made of stainless steel. The main purpose of our machine is to pack the food items and thus food safety is an important factor to take care of. For food safety purposes stainless steel is the commonly used material. That is why we chose it for doser.

3.4.3 Volumetric Cup Filler Material

Volumetric cup filler is made of silver. Silver is highly resistant to corrosion. For food safety purposes, it is a perfect choice. That is why silver was chosen for cups.

3.4.4 Sealer Material

Horizontal and vertical sealers are made of mild steel. The reason being the low specific heat andhigh thermal conductivity of mild steel compared to the copper and aluminum.

3.5 Electronic System Design

There are various electronic and control components used to control the packaging process. These components help in better packaging by controlling temperature and avoiding packaging laminate design out by controlling the speed and position of motors and photocell sensors.

3.5.1 AC Motors

There is an AC motor on the upper side of machine which helps to loose the laminate and decrease the tension in the laminate, this motor does not run continuously, it runs only when there is need of laminate, two proximity sensors, 2 relays, DC supply and contactor are used to start and stop the motor. There is another AC motor which will rotate the doser and allow the product to fall which we want to pack.

Variable Frequency drive is used to control the motor speed.

3.5.2 Servo Motors

There is a servo motor for vertical sealers which works on speed control mode, it is controlled by pulses through PLC.

Photocell and **encoder** are used to determine packet length and motor speed accordingly.

There is another servo motor which moves the horizontal sealer up and down through crank slider mechanism. This motor runs in position control mode and it is controlled by pulses through PLC. Up and down motion of horizontal sealers depends on the packet length.

3.5.3 Solenoid Valves

For opening and closing of horizontal sealers, two pneumatic cylinders are used. To operate pneumatic cylinders, 5-ways solenoid valve is used. After the packet is sealed, the cutter is used to cut the packet, and this cutter is also operated by pneumatic cylinder through 5-ways solenoid valve. To fill the air in the packet to avoid product damage, 2-ways solenoid valve is used.

Solid State Relays are used to operate all of the above mentioned solenoid valves. All SSRs get the signal from PLC and operate the solenoid valves and then pneumatic cylinder accordingly. Solid State Relays also supply current to the cartridge and circular heaters according to the signals received from temperature controllers.

Cartridge heaters are used to heat the horizontal sealers.

Circular heaters are used to heat the vertical sealers.

Temperature controllers are used to control the temperature. Heaters get their current supply through SSRs and SSRs are operated by temperature controllers.

3.5.4 List of Electronic and Control System Components:

- Two servo motors
- Two AC motors
- Two pneumatic cylinders
- Three solenoid valves
- One photocell sensor
- Two proximity sensors
- One encoder
- One variable frequency drive (VFD)
- Two cartridge heaters
- Two circular heaters
- Six solid state relays
- Two 8-pins relays
- One DC supply
- One programmable logic controller (PLC)

3.6 Schematic Diagram of Machine Processes

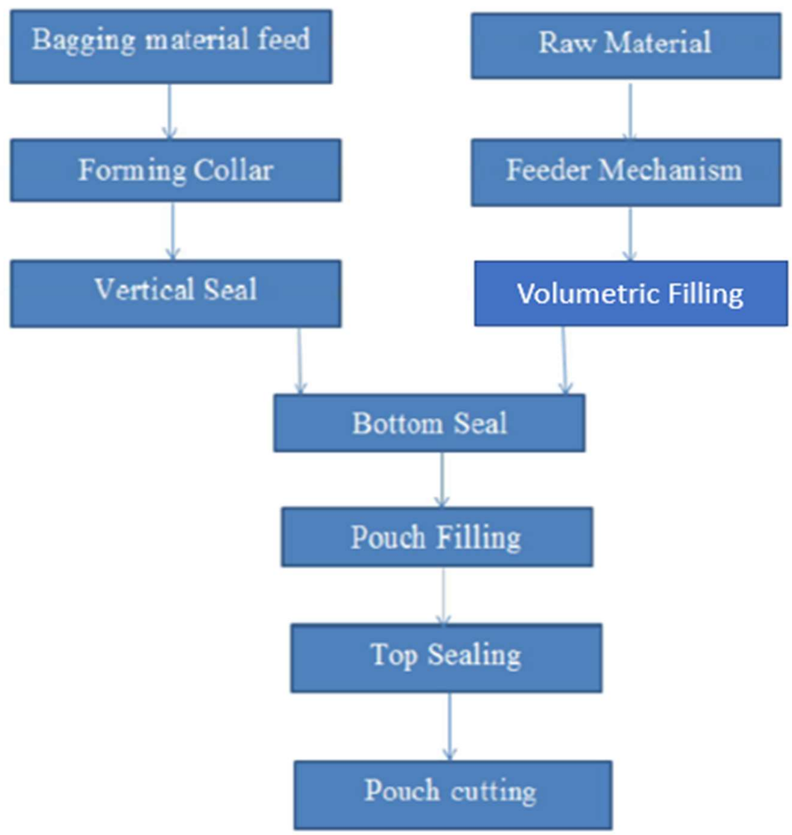
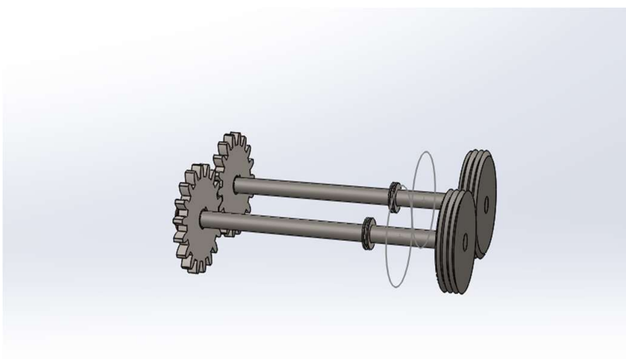


Figure 17: Schematic Diagram of Machine Processes

CHAPTER 4: RESULTS AND DISCUSSIONS

After having done with design calculations, CAD modelling and analysis, material and components selection and electronic control system design, the fabrication of the machine was started. The frame structure was manufactured to begin with. After that horizontal and vertical sealers were fabricated. Then the forming tube and forming shoulder were made. Then the doser system was fabricated. All these components were assembled to complete the machine structure. After this the pneumatic and electronic control system was installed including pneumatic cylinders, motors, PLC, solenoid valves, relays etc. The CAD design and actual manufactured components are compared below:



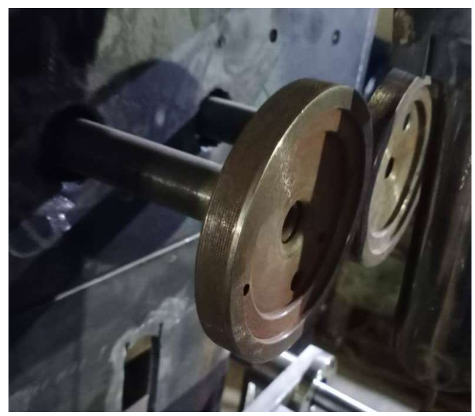


Figure 18: Vertical Sealer Comparison

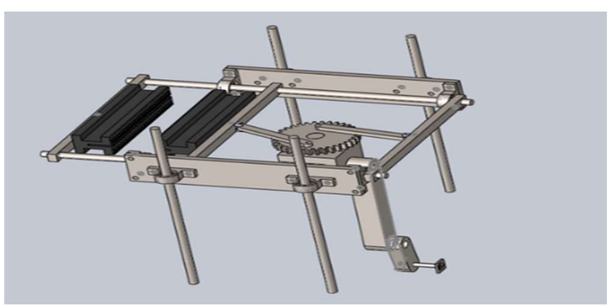


Figure 19: Horizontal Sealer Comparison

The final assembled structure of the machine looks like the following:

Figure 20: Final Fabricated Machine

The resulting fabricated machine is quite similar to the CAD model as can be seen from above shown pictures. The small differences are inevitable due to the gap between theoretical and practical world of things. The packing speed was found to be quite good that is more than 100 packets per minute which was our target as well. This is a huge success for us as the speed of packing was our priority. The strength and stability of various components came out to be perfect as expected from theoretical calculations and CAD Analysis. The working of electronic control system was also very much satisfactory.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In this project, the design of a vertical form fill and seal machine, commonly known as packing machine, has been presented. The project provided us with a great opportunity to apply our engineering knowledge and also to learn new things. It has helped us to understand how the things work in practical life and thus bridge the gap between theoretical and practical world of things. We undertook this project to help our small scale industry in the problems faced during the packing of their manufactured products. These problems are slow speed, seal leakage, air leakage, paper wastage and design out as well as high cost due to import duty. We solved the problem of slow speed by converting the intermittent motion into continuous motion by the use of 2 DOF horizontal sealing jaws. The problems of seal leakage and air leakage are solved by the proper design of sealers and their control system as discussed above.

The problems of paper wastage and design out have been solved by the use of encoder, photo sensor and proximity sensor but it can still be improved by the use of advanced control system consisting of feedback system. High cost will be reduced by establishing the industry of packing machines at the local level.

5.1 Future Scope

The Vertical Form Fill and Seal Machine designed by us has a bright future. The feature of continuous operation by the use of 2 DOF horizontal sealer is very attractive for the packing industry as it offers high packing speed and saves a lot of time as well as increases the earnings of the packing industry. We did this project to take the first step towards establishing an industry of manufacturing packing machines so that our small scale industry is able to get inexpensive packing machines. This will reduce our import bill as well and that will play a little but fruitful part in our country’s progress. The local jobs will be created as well.

REFERENCES

(https://literature.rockwellautomation.com/idc/groups/literature/documents/br/oem-br044_-en-p.pdf)

(https://resources.kinnek.com/media/gallery_images/pcvbsvonfuossuq.pdf)

(https://patents.google.com/patent/US4040237A/en)

(https://patents.google.com/patent/EP0296387B1)

(Hooper, Confectionery Packaging Equipment)