Low Cost Automation of FFS Powder Filling Machine with Dual Core Controller

Manikandan.N, Mathanesh.V.R, Pravin.S, Ravikumar.A, Sivashankaran.R

Abstract*: The manufacturing systems used to automatically fill seal and pack food products is referred as Form Fill Seal (FFS) technology. The FFS technology aims to reduce human intervention and thereby reducing contamination of the food products. This requirement is primarily found in Food and Pharmaceutical industries. The production rate in these machines is optimized through accurate time control of the packing process. The sequential steps involved are pack formation, content filling and pack sealing. The current system under study is not economical for short production, multi-ply packing and cannot self-adjust for different widths of bag. To overcome the above-mentioned disadvantages of the existing system, a low-cost automation system is proposed which uses standardized electrical, mechanical and pneumatic systems. Additional weigh and pour mechanisms were included to increase the accuracy of the system. A mechatronics system, developed for this machine is controlled by a Dual Core PIC Microcontroller, which is capable of receiving feedback from sensors and controlling the actuators accordingly. The low-cost automation system involved the mechanical system design, Finite Element Analysis of the mechanical system, electronic circuit design, control system design and HMI programming. The proposed system has increased the production rate at an optimum cost and also the machine size is reduced by five percent. With the increase in production rate and machine size, the developed machine can play a vital role in improving the outcome of a manufacturing system.

Key Words*: Dual Core PIC Microcontroller, Vertical Form fill and Seal (VFFS), Low Cost Automation, Optimum Production Rate.

I. INTRODUCTION

The global market demands any enterprise to provide products with better quality and low cost. In order to survive in the demanding market, automation with optimum cost is considered to be the safest strategy. This demands the use of standard components for mechanization or automation of the manufacturing systems. These systems can be operated even by semi-skilled or unskilled labors as there is a minimal requirement for human intervention. The packing machines are generally referred as Fill and Seal Machines (FFS). The currently available machines are highly sophisticated with control networks and computer interfaces. The machines have the capability of greater speed and versatility. The main classifications of these FFS machines are Vertical Form Fill and Seal Machines (VFFS) and Horizontal Form Fill and Seal Machines (HFFS). The VFFS machine was patented by Mr. Walter Zwoyer in 1936 while working with the Henry Heide Candy Company [1]. The VFFS machines primarily pack standard solid products and the HFFS machines can pack products of irregular shapes and sizes [2]. A computer controlled FFS machine was patented in 2004 where film sheets are made into pouches using a heat sealer and transverse sealer mechanism [3]. Instead of films, web shaped material was also used to produce pouches. The pouches were zipped using a slider operated string mechanism [4]. Also, a large pouch packing system was also developed with a capacity of 5 to 20 liters [5]. In order to hold the large pouches a cage system was also developed which prevents the pouch from ballooning out. Based on the overall literature review, in this paper we focus on the VFFS machines as it offers packaging of both solid and liquid packaging. The VFFS machines pack the products based on the weights. The VFFS machines makes packages vertically by forming a pack, filling the product and finally sealing the same. These machines find its place commonly in the consumer industry for packing various products like spices, snacks, candy, salt, sugar, etc. The VFFS machines relatively fast, economical and consume less floor space [6].

Besides providing many advantages, the current VFFS system suffers with the following disadvantages [7]:

a. Difficulty in handling multi-ply materials.
b. Cannot handle paper.
c. Not suitable for short production lines.
d. Cannot accommodate different widths of bag.

In order to overcome the above-mentioned disadvantages and improve the efficiency of the current system, a low-cost automation system was developed. A recently launched Dual Core Industrial microcontroller was chosen to control the overall system and to increase the efficiency in packaging process [8]. Pneumatic system plays a vital role in this packaging process and its actuation process is studied from [9]. The standard components for achieving low cost automation was understood from [10]. In the modified system the PLC is replaced with a PIC Microcontroller which drastically decreases the cost of the project and also the dual cores provide continuous working without any interruption or delay. The performance parameters of the existing system and the newly developed system were compared. The modified system is predicted to provide improvement in packing time.

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II. NEED FOR AUTOMATION

The steps involved in pouch packing are packet forming, weighing, filling and sealing the packets. Manual operation of these processes consumes time and the production rate will slow. Use of mechanized or automated systems are necessary to increase production rates thereby giving the entrepreneurs an edge over the competitors. The labors may suffer from fatigue as the process is repetitive and time consuming. Use of mechanization also reduces the labor reliance of the industry and improves the production quality and rate. Low Cost Automation is the considered to be the key to realize all the above stated advantages.

III. MECHANICAL SYSTEMS OF THE MODFIED VFFS MACHINE

A systematic engineering approach for the development of automated packing systems was discussed in [11]. Based on the approaches discussed the existing VFFS machine was modified. The key mechanical components of the modified VFFS machine is shown in Figure 1. The component analysis procedure was adapted from [12]. The system mainly consists of a frame, a material supply system and a sealing unit. The details of the mechanical system are discussed in the below sections.

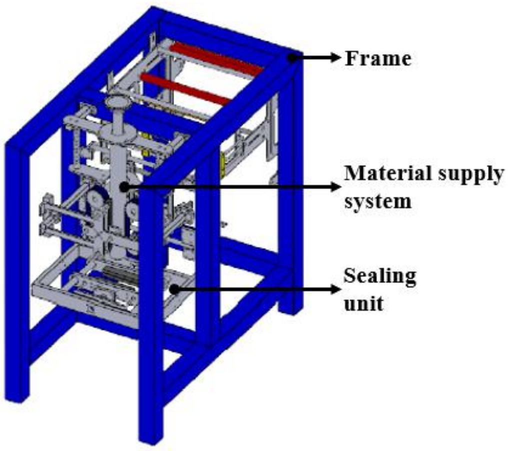

Figure 1. Key mechanical elements of the modified VFFS system

A. Frame

The frame is the main structural unit that carries the whole weight of the VFFS machine. Appropriate design calculations were made and it was decided to use rectangular mild steel tubes for the frame. Structural analysis of the frame was carried out in ANSYS R15.0 to verify the deformation and the value was found to be 0.054 mm which is negligible comparing the overall weight of the machine. The structural deformation is shown in Figure 2.

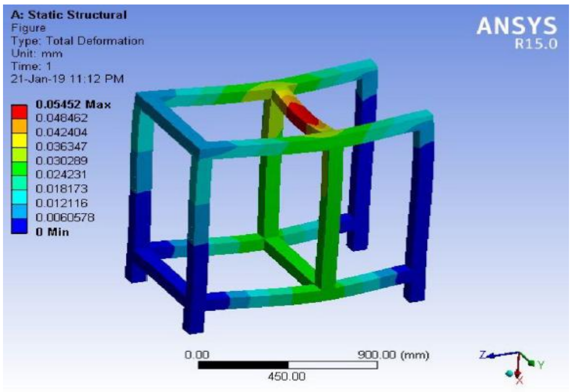

Figure 2. Structural deformation of the frame showing a maximum deformation of 0.054 mm

Another important mechanical component is the shaft holding the entire packing mechanism to the frame. Based on the other component weights, it was calculated that a cylindrical shaft of 30 mm diameter is required to hold the packing mechanism to the frame. Factors such as maximum bending stress and torsion were considered for the calculation as the packing system operates at very high speeds. The shaft design procedure is discussed below in detail.

Applying ASME code for shaft design to find:

Shear Stress (τ), $\tau = 0.18 * \boldsymbol{S_{ut}}$ (1)

Where: $\boldsymbol{S_{ut}}$ is the ultimate stress = 400 MPa

$\tau = 0.18 * 400$ $\tau = 72$ MPa

$\sigma = 0.3 * \boldsymbol{S_{yt}}$ (2)

Where: $\boldsymbol{S_{yt}}$ is the yield stress = 240 MPa

$\sigma = 0.3 * 240$ $\sigma = 72$ MPa

Also, Torque (M_t) = $(\boldsymbol{HP} * \mathbf{9550})/\boldsymbol{RPM}$ (3)

The torque from the motor is transmitted by a belt drive. So, the total tension can be calculated as follows.

Ratio of the belt tensions: $T_1/T_2 = e^{\mu\theta}$ (4)

Also, Torque = $(T_1 - T_2) * r$ (5)

Where:
T_1 - Tension of belt in pull side
T_2 - Tension of belt in push side
r – Radius of roller

From Equations (4) and (5), we get the total belt tension force of 466N. This force will act on the shaft that carries the whole packing unit and heater unit weight.

The equivalent bending moment equation for a shaft is given by,

$$M_{eq}=\boldsymbol{k_b M_b}\sqrt{}(\boldsymbol{k_t * M_t})^2 + (\boldsymbol{k_b * M_b})^2 \quad (6)$$

Where:
$\boldsymbol{k_b}$ - 1.5 (Shock & fatigue factor for bending moment)
$\boldsymbol{k_t}$ - 1.25 (Shock & fatigue factor for torsional moment)
$\boldsymbol{M_b}$ – Maximum bending moment calculated from bending moment diagram

Therefore, from Equation (6), we get the equivalent bending moment value as 368545N mm. With this the diameter of the shaft is calculated as follows:

$$\sigma = (\boldsymbol{16/\pi d^3}) * M_{eq} \quad (7)$$

On substituting the values in Equation (7), we get the shaft diameter as 30mm. Analysis was carried out in ANSYS R15.0 in order to evaluate the design and it was found that the maximum deformation and stress values to be 0.14 mm and 45.57 MPa. The design is predicted to be safe as the maximum stress values is within the yield stress. The structural deformation of the shaft is shown in Figure 3.

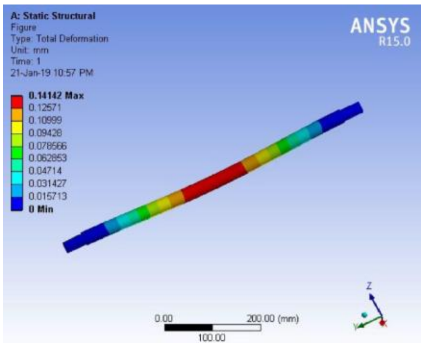

Figure 3. Structural deformation of the shaft showing a maximum deformation of 0.14 mm

B. Material Supply System

The material supply system mainly consists of the forming tube and the forming shoulder. The forming tube collects the powder or raw materials and it also referred to filling tube. Various sized and shapes of bags can be formed and filled by the machine. The shape of the forming shoulder and forming tube determines the size of the forming tube determines the width of the packing bags. The raw material film is driven by a mechanism over the forming shoulder to form the bags of different widths and shapes.

C. Sealing Unit

The VFSS machines are capable of only processing materials that will melt when temperature and pressure are applied. Most laminates fall under this category and for polyethylene special sealing systems are needed. The sealing system with the heater and cutter is shown in Figure 4.
Two pneumatic pistons are used to operate the heating unit along with the cutter. The pistons were selected based on the force and stroke required to cut the PE pouches. Commercially available pistons with part number "DSBC-32-500-PPVA-N3" was selected based on appropriate design calculations. The accurate control of the pneumatic actuators using micro controllers was adapted from [10].

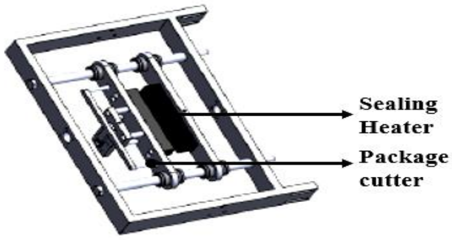

Figure 4. Sealing unit of the VFFS system

IV. ELECTRICAL SYSTEMS OF THE MODFIED VFFS MACHINE

The key electrical components for developing the VFFS machine are discussed below.

A. Sensors

The following sensors were employed in order to improve the production efficiency and operational control of the VFFS machine.

a. The film roll status is checked by a diffuse sensor.
b. Missing lugs and tension of the film is checked by an inductive sensor.
c. The synchronization of cutting and sealing is controlled by a registration sensor which confirms the registration marks in each pack.
d. The centering edge for sealing is detected using an optical sensor.

B. Microcontroller

The key differentiator from the existing VFFS system is the use of a dual core PIC microcontroller in place of the traditional PLC system. The microcontroller is smaller in size and can accommodate the required I/O pins for the automation process. A "dsPIC33CH128MP508" microcontroller was selected and programmed accordingly to receive information from the various sensors and to actuate the actuators at required intervals to achieve the packing process. The microcontroller consists of 80 pins which provides enough flexibility in connecting and controlling the sensors and actuators respectively.

C. Electric motors

Electric motors are employed to operate the auger for filling the pouches and to draw the laminates from rolls for packing. It was decided to draw the laminates for 160 mm in 0.1 sec in order to achieve improved production rate. It was calculated that a motor of 1.0 HP capacity is needed to operate the auger at 1400 rpm to fill the required amount of powder in the pouches. To draw the laminates at the required velocity, it was calculated that a motor of 1.0 HP capacity at 955 rpm is required. The speed of the available motor was increased with a gear ratio of three.

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V. PROCESS SIMULATION, MONITORING AND INTERFACING

The packing process is driven by feeding the raw material through the feeder mechanism and weighing the same. The packing pouch is formed from the material feeder by forming a collar, vertical sealing, bottom sealing, top sealing and finally cutting. The overall process flow of the modified VFFS machine is shown in Figure 5.The key control operations and programming of the machine is performed through MPLAB and DOP-Soft. DOP-B series HMI is adapted to achieve a stable and powerful programming platform.

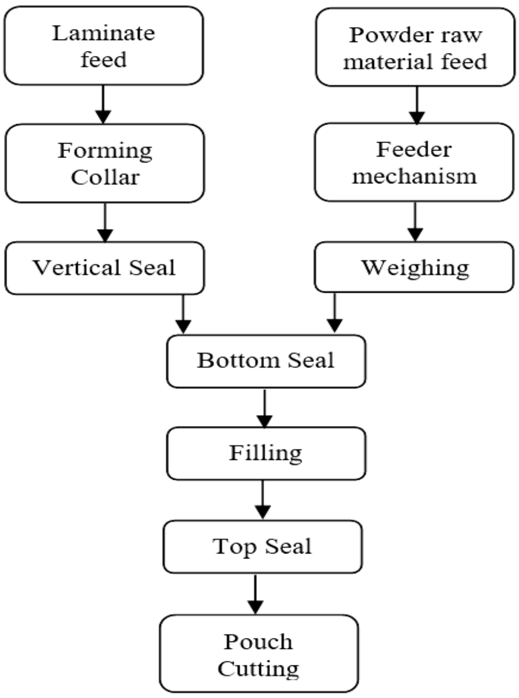

Figure 5. Overall process flow of the VFFS packing system

A user- friendly Screen Editor Software program for Windows platform was used to create the HMI. The machine run page for FFS Machine has been programmed. The HMI menu for monitoring the packing process is shown in Figure 6. Further the HMI system is capable of displaying the fill settings, calibration setting, start/stop/reset the machine and overall production rate.

Figure 6. HMI menu for monitoring the overall packing process

VI. RESULTS AND DISCUSSION

The modification of the existing VFFS system was carried out giving importance to the production output on demand. The concept of Mechatronics systems was implemented to develop this low-cost automated packing system. The future scope for developing the system includes the addition of machine vision systems to detect flaws in packing and introducing flexible low-cost automation systems for complete operation without human intervention.

VII. CONCLUSION

With the proposed design, it has been verified that the production rate is increased from 60 pouches per minute to 120 pouches per minute. Thus, the productivity rate has been increased around 50% when compared to the existing system. This allows us to achieve the production target with a low operational cost, high accuracy and less contamination. The comparison chart between the existing and modified system is shown in Figure 6. The key parameters under study were production rate, size of the machine and hopper capacity. The machine size was reduced about 5% and the overall hopper capacity was increased about 55%.

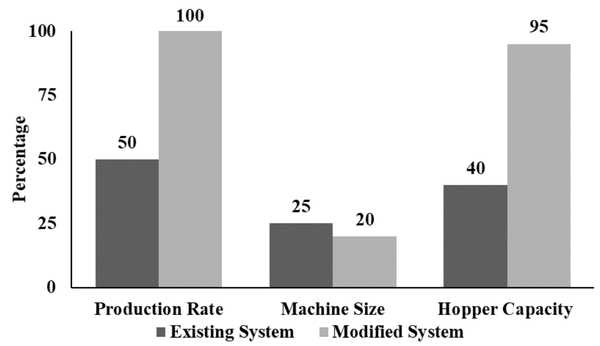

Figure 6. Comparison of existing and modified systems

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