

MECHATRONICS DESIGN OF A LOW-COST PACKAGING AND DOSING MACHINE FOR DOUGHY PRODUCTS

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Abstract. *The need to improve a packaging system of a company was the idea that impelled the realization of this mechatronics project. So taking into account the significance that represented for the company the acquiring of a mechanism that would allow the upgrading of the product, at a low cost, this research was developed; where, first of all, the type of machinery that would be able to take effect according to the characteristics of the substances to be packed was examined; then, the design parameters were analyzed in order to verify, that the machine complied with the specifications and rules established, and finally the construction of a prototype that described the different stages of the packaging process emphasizing the technical and economic solutions that were presented for the company, was developed. The machine uses two types of actuating system: electrical and pneumatic. The electric system controls the security of the machine, the temperature control of the sealing, and also actuates the pneumatic system which actuates the dosing valve and the horizontal seal. The interaction between these systems and also with a third component related with legal rules from a food engineering point of view allowed us to conceive the machine as a mechatronic design.*

Keywords: *Mechatronics Design, Industrial Mechatronics Project, Packing and Dosing Machine, Doughy Products, Check Valves, Sealing Bar.*

1. INTRODUCTION

In the present-day society, the commercialization of a product is not conceived, whichever its nature, without the use of any type of container or packing that contains it and protects it since its primary production until it reaches the consumer; this establishes the importance of alimentary technology (Tijskens, 2001). Along the years, thanks to the incursion of machinery in the packaging industry (Whelan, 1996); all types of containers, forms, and designs have been developed, using different materials, to answer the specific needs of the industry and the consumers (Dallyn, 1998). The technological development at a local level has been limited to big companies due to the investment that this implicates, denying the possibility to many businessmen to see packaging as a technical and economic function that would be able to minimize costs and maximize sales (Maroulis, 2003). In many places it is very common to find products packed manually by its employees without any type of sanitary control on who does this job, neglecting completely the quality of the product. This frequent situation makes the consumer the main victim. In addition, few companies know the advantages that they can to apply technology to tech the packing process of their products (quality and economy), since at glance the raised costs offered in the market are not reachable to many of the possible clients that do not have enough resources in their companies for such an investment (EHEDG, 2001).

For the realization of this project, one kept in mind the proposal of diverse companies of the sector of fast foods, which besides producing a special type of food also produce the sauces that accompany it. The packing managed by these companies for their sauces, is a completely manual system, which requires an employee in charge of filling each cup as they dispatch orders.

This is how this project evolved, looking for a design of a functional and economic machine, that may be manipulated by non-specialized labor force, bringing up together conditions of simplicity, quickly and quality, with the aim of making the companies begin to consider the different advantages, possibilities and facilities that can be acquired when they invest in new machinery and thus increasing the number of business that can be part of projects in search of technological development necessary for any company even more when they are focused into upgrading the quality of the products offered.

2. DESIGN OF A PACKING AND DOSING MACHINE FOR DOUGHY PRODUCTS.

A container or package obeys fundamental functions such as containing, protecting, communicating and differing; so, in order to accomplish them, the containers must respond strictly to the technical requirements of the products and the needs and demands of the market, taking into account that a bad or inadequate container can affect negatively and fail to deserve the quality of the packed food. The packing machine designed, besides producing a satisfactory packing, should have obeyed the established conditions of simplicity, efficiency, efficacy, dependability, but above all a solution for those companies that do not count with the adequate level of production and the enough capital to invest in new machinery. When examining the different parameters that should have been taken into account for food packing and the different forms in which this process could be done, an application where every concept could be deeply analyzed became indispensable. A company that wanted to improve the packing system for two types of sauces was taken as reference, for being an application suitable to describe the principal objective of the project and because their problem was representing the situation of many companies, that have wanted an opportunity to improve their packing systems, but the raised costs have made impossible such application. For the design and construction of the packing machine (Derby, 2005) it is important to know and to analyze each one of the stages that understand the dosage process and packing (Figure 1).

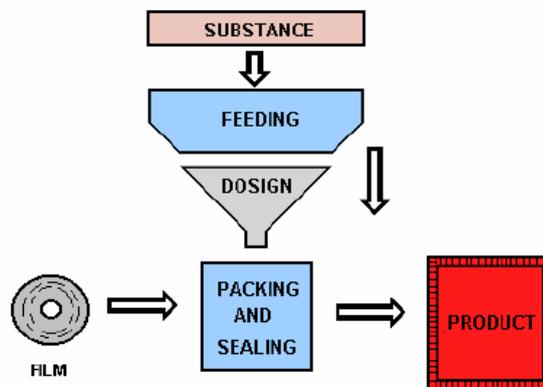


Figure 1. Packing process stages

As for the substance, sauces possess a high percentage of greases and oils, for such reason, phenomena such as self-oxidation and high temperatures oxidation should be analyzed; so, examining the light and temperature effects over the physical characteristics of the sauces (smell, taste, color), exposing them to different temperatures, it is possible to define a maximum time of conservation of 10 hours at room temperature (298 °K) and to know its behavior to each situation presented (high and low temperatures). The feeding system is in charge of supplying the substance that will be packed. This feeding is done through a conical hopper which was designed according to certain parameters that will make the product flow easily toward the dosing system. For this system's design, the density of the sauces was required to know its size.

3. MECHATRONIC DESIGN AND GENERAL OPERATION

For the construction and setting in operation of the packing machine, it is important to take account different aspects that will make of this, an economic, functional and versatile machine. For such a reason, the materials will be of easy acquisition and low cost those avoid any type of oxidation. Those parts that have direct contact with the material will be hygienic, of easy cleaning and disinfection to avoid the contamination of the product and the loss of its physical-chemical characteristics and organoleptic characteristics. As for the size; it will be designed with the purpose of facilitating their installation and location.

3.1. Feeding System

Keeping in mind that the biggest demand of sauces is (E); the hopper is designed so that it does not require product feedback; therefore its volume (V_{hopper}) is obtained in Equation (1).

$$V_{hopper} = \frac{m}{\rho} E \quad (1)$$

Where, m is the mass of sauce to pack and ρ is the density of the sauce. The volume (V) is defined taking into account the daily usage of a particular company with the purpose of avoiding the need to require a feedback of the substance. Another fundamental parameter for the hopper's design is the θ angle, which led to define height (H) (Equation (2) and Figure 2). The sauces are considered Non-Newtonian fluids (Rotstein, 1997), besides that, a simple experiment was made for their respective minimal angle of rest calculation; this angle is called the angle of rest, in which the substance flows. This depends on the type of fluid (Newtonian or Non-Newtonian) as well as on nature of the surface where it will move. Where each type of sauce was laid on a stainless steel plate (material that the hopper was built with) and then the plate was tilted in order to achieve a flow of the sauce.

$$V = \frac{\pi}{3} H (R^2 + r^2 + R \cdot r) \tag{2}$$

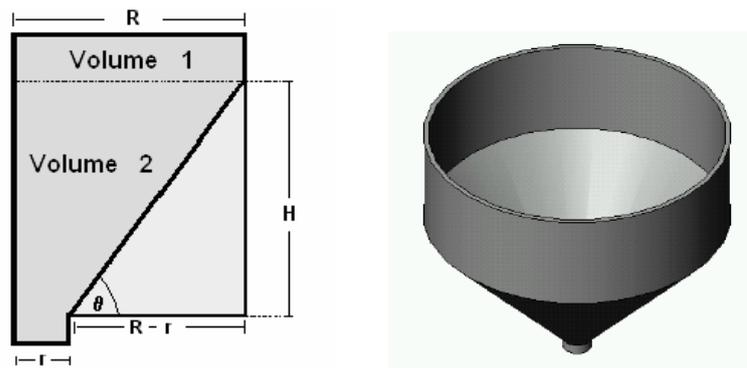


Figure 2. Rest Angle and hopper model

3.2. Dosing system

The dosing system is in charge of maintaining the weight and exact volume of the product in the packing. The sauces, being considered a doughy product, require a piston-type dosing. This type of dosing consists in suctioning and filling a container with an exact volume and discharging it some necessary times in order to complete the dosing quantity. For this labor, a dosing valve was designed (Figure 3).

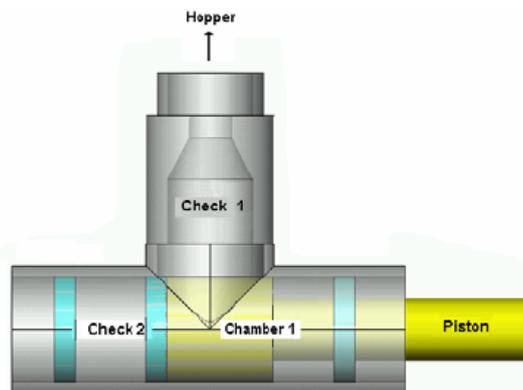


Figure 3. Dosing Valve

The four main elements of this valve were sized according to the quantity of sauce to dose per package. The check valves are the main elements in the valve, and are composed of three parts (Figure 4).

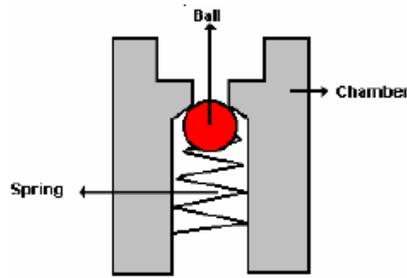


Figure 4. Check Valve elements

The chamber is the place where both the ball and the spring are situated; in its interior flows the dosing substance. The ball blocks the orifice both in and out, depending on the valve positioning, while the spring commutes the valve in the two possible positions (open or closed). It is important to take into account that these elements are in permanent contact with the substance; so according to legal existing rules for the food industry were designed in an easy dismantlable way for its cleaning and built in AISI 304 (Austenitic Stainless Steel – 18% Cr and 8% Ni). For the selection of the spring of the check valve 1, the maximum force that the spring must stand had to be calculated taking into account that this force depended on the substance's weight (Figure 5). So, the maximum force that the spring should hold was when the hopper would be completely filled, knowing the volume (V) of the hopper and the density of the substance (ρ), the force (F_1) can be calculated according with the Equation (3) and based upon this the right spring was selected.

$$F_1 = \rho \cdot V \cdot g \quad (3)$$

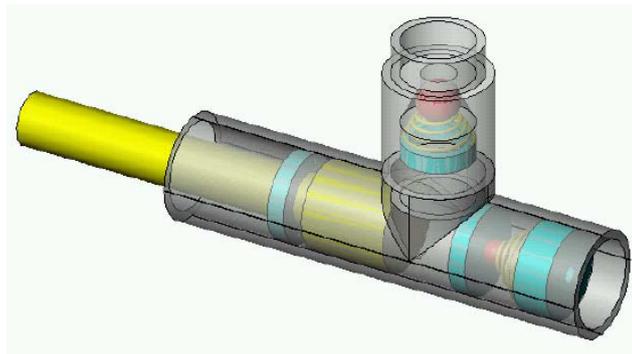


Figure 5. Dosing valve assembly

3.3 Packing and Sealing Systems

The feeding system and haulage of the material of packing of the machine, it is designed to pack a number of packages in a certain time. The minimum velocity to which the film of plastic will advance to fulfill the established quantity of packages to pack per hour is calculated as well as the ratio of the advance (r) wheels and the quantity of packages required by certain time, with this information are calculated the revolutions per minute of the axis of the advance wheel, where S is the perimeter of the wheels of advances in cm (Equation (4)).

$$S = 2 \cdot \pi \cdot r \quad (4)$$

The selection of the film or packing material depended on the time the substance and its composition wanted to be conserved and its composition. However, since the machine is designed for packing only the sauces that would be produced daily, it was not necessary to use multi-coat materials (because of their high cost and because that would require machines with specific sealing materials); for this reason, the packing material that has been used is low-density polyethylene since it provides an effective packing at an economic acceptable price. For the sealing of the polyethylene film, bars with resistances were added, which give the necessary heat for such seal; the heating system is done with a hot wire, placed between the sealing bars (Doherty, 1988). The horizontal sealing bar consists of six elements (Figure 6).

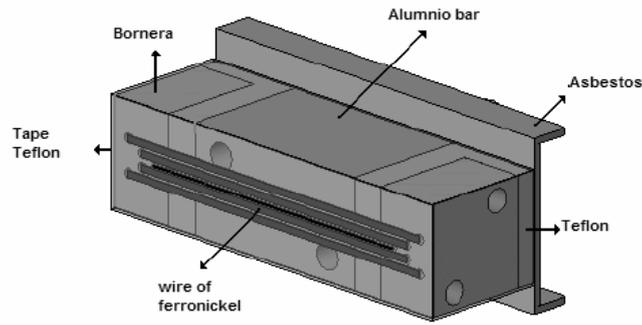


Figure 6. Sealing bar elements

For the selection of the resistances, the heat transfer that occurs from the resistance to the polyethylene film is analyzed (Figure 7). Since the only thing that separated them is a Teflon® (Bouquet, 1989) layer, only the heat transfer by conduction is considered. Keeping in mind that the power provided by the resistance should be enough to counteract the resistance imposed by the Teflon® (thermal conduction through the Teflon® film) film and that the temperature in the bar will have to vary from $\cong 298 \text{ °K}$ (ambient temperature) to the value of temperature at which the plastic film will be sealed, The Equation (5) that describe this process is (Kraus, 1995):

$$Q_{dissipated} = \frac{T}{R_{Thermal}} = \frac{T_{seal} - T_o}{T_{Thermal}} \quad (5)$$

Where, T_{seal} depends on the characteristics of the plastic film of plastic that it is used like packing and of the ambient temperature. In the case of the polyethylene of low density and with base in charts about the properties of this plastic, it is found that the temperature of hot sealing is between 393 °K and 673 °K (Peacock, 2000) T_o is the ambient temperature. The thermal resistance depends on the type of transfer of heat; in this case, as it was previously mentioned, transfer is about conduction through the Teflon® film that will recover the resistance and it will be in direct contact with the material to seal. The resistance for conduction ($R_{Thermal}$) is obtained from Equation (6).

$$R_{Thermal} = \frac{L}{Ak} \quad (6)$$

Where, A is the area of the traverse section of the material through which heat behaves; L , the longitude of the material among the points corresponding to the temperatures, and k the thermal conductivity of the material.

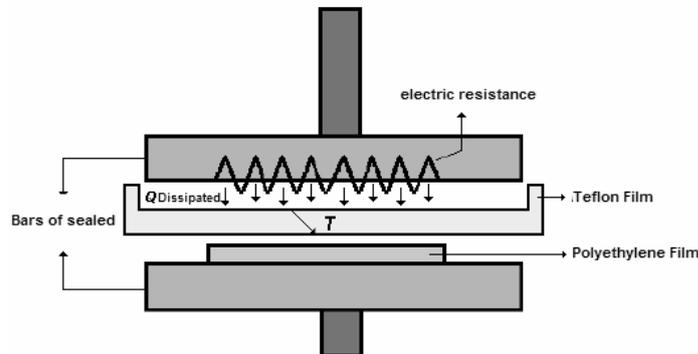


Figure 7. Conduction through the Teflon layer.

With the power, the electric resistance is selected and the current to get this power is calculated (Equation (7)).

$$P = I^2 R = \frac{V^2}{R} \quad (7)$$

This analysis allowed to know the necessary power needed to heat up the resistance to a temperature $T = 393 \text{ }^\circ\text{K}$; at which an appropriate sealing of the polyethylene film is achieved. Knowing each of the components of the machine, the next step was to analyze its operation.

3.4. Pneumatic Design

After defining each one of the mechanical components that conform the machine, it is important to define the type of work that will be implemented. For many years the pneumatic technology has played an important role in mechanics and in the development of automated applications. Additionally, pneumatic cylinders are being more used as elements of serial working, since it is about units of relatively low price, of easy installation, simple and available in diverse cylinder sizes. For such a reason the implementation of pneumatic actuators in the horizontal and vertical seals as well as in the dosing (lineal movement) were chosen in the machine's design. For the selection of the horizontal seal's cylinder it is important to keep in mind the aspects of the variables analyzed that are related to the process of sealing; three parameters that influence the process of sealing (pressure, temperature and time) made us decide to leave the value of pressure as a constant one, with the purpose of adjusting the time and temperature of sealing (Bhuyan, 2007). However, it is important to note that in practice this pressure value can be adjusted (regulators valves) with the purpose of diminishing the time of sealing and in order to increase the machines production (Bergstrasse, 1972 and Vicq, 1986).

Knowing area (A) (area that will have the seal or area of the bar calefactory where the resistances will be placed), and keeping in mind that polyethylene can be sealed with a pressure as low as 0.68 or 1.37 bar, it is possible to determine the value of necessary F to achieve a satisfactory sealing; in this sense, this will be the value that has to be exercised by the pneumatic cylinder to get the seal. To know the force (F) one has to know that $P = F/A$. Given the force value and of agreement the characteristics of the cylinder, push force (F_i) is given by Equation (8).

$$F_i = S_1 \cdot P_1 \cdot \eta \quad (8)$$

Where S_1 is the section area (cm^2), P_1 the pressure (bar) and η is the performance.

The automatic packing machine has three double effect pneumatic cylinders (Parr, 1999 and Krivts, 2006), in charge of carrying out the two types of stamps (horizontal and vertical) and the dosage (Figure 8a). The design of the pneumatic circuits in charge of coordinating the diverse movements of the machine, both automatic and semiautomatic are appreciated in the Fig. 8a and Fig. 8b.

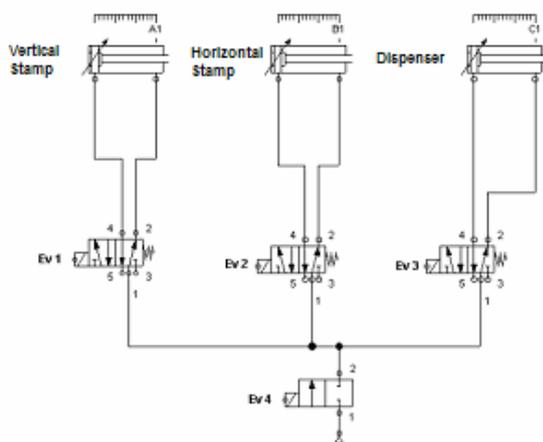


Figure 8a. Pneumatic circuit for the machine automatic packer.

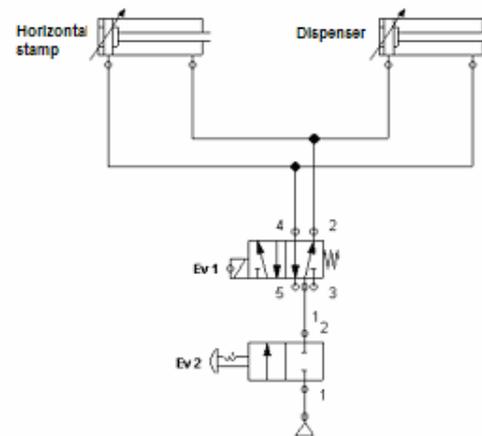


Figure 8b. Circuit pneumatic machine semiautomatic packer

The valve Ev4 could be activated in form manual or electric; its function is the supplying air to the system. The electro-valves Ev1, Ev2, Ev3, will be in charge of coordinating the movements of each cylinder; each one's sign of working comes directly from Programmable Logic Controller (PLC) (Hackworth, 2003 and Parr, 2003). The semiautomatic packing machine as shown in the Fig. 8b consists of two pneumatic cylinders of double effect in charge of the horizontal stamp and of the dosage. The valve Ev2 the same as the valve Ev4 of the automatic machine (Figure 8a), will be the one in charge of allowing the entrance of air to the system, while the electro-valve Ev1 will have the task of coordinating the two cylinder's advance and setback movements.

When valve EV2 is working, the dispenser cylinder goes out and the horizontal seal cylinder stays inside; this could be called “initial condition of the system”. Whenever electro-valve Ev1 is activated, the dispenser cylinder enters suctioning at the same time the substance that is in the hopper, while the horizontal seal cylinder goes out to seal the plastic film. To de-energize Ev1, the dispenser cylinder comes out again, dosing the substance inside the packing, and the horizontal seal cylinder is returns leaving the system in its initial condition once more. The cycle repeats according to the quantity of required bags

3.5. Mechatronic Integration

The machine uses two types of actuation; Electrical and pneumatic, the electric system controls the security of the machine and also activates the pneumatic system which actuates the dosing valve and the horizontal seal. This interaction allowed us to conceive the machine as a mechatronic system (Figure 9) in which electric engineering, mechanical engineering, pneumatics and an additional component related with legal norms that regulate the processes from a food engineering point of view allowed me to create a machine named from the beginning as a packing and dosing machine for doughy products.

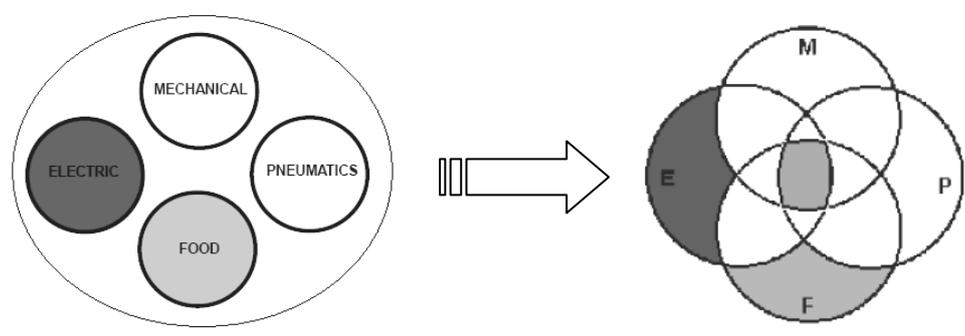


Figure 9. Mechatronic system components

However, to conceive the machine as a mechatronic system (Bishop, 2002 and Amerongen, 2003) a way to make each component interact with the others had to be found. Hence, taking into account that an economical solution had to be found, I decided that the machine had to be a semi-automatic one and that a pedal should be in charge of activating the sealing and dosing systems in a simultaneous way (Figure 10).

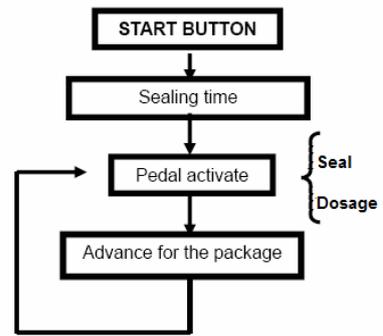


Figure 10. Semi-automatic process

4. CONCLUSIONS AND RESULTS

Knowing the rest angle is fundamental for the system’s feeding design, the results of the experiment were the following: for one type of sauce the angle was 30° and for the other the angle was 33°. The machine’s level of production was 20 packages per minute. One of the fundamental characteristics that the machine had to comply with was related with the economic aspects and its costs; a comparative analysis between traditional packing and the packing machine proves the accomplishment of this feature. The calculus of the main constituent parts of the packing machine was essential, in order to secure the realization of the prototype’s functions. Thanks to the technique that was applied it was possible to design a non-expensive, small, easy to place and use machine but, most important of all, even though it is not fully automatic, it can be considered a very efficient one if compared to machines previously available in the market, since it produces an average of 20 packages per minute. That makes it a very competitive machine in the market

it was designed for, taking into account that we are dealing with doughy products. The construction of the prototype confirmed the design parameters obtained on each stage of the packing process; the dosing system allowed the operator to increase the quantity of packed packages since his only work is to move the polyethylene film. Besides, it also assures the dosing quantity will always be the same one and will not vary. On the other hand, every part of the machine is easy to mount and dismount in order to ease its cleaning but, above all, to conserve the substance's characteristics and to comply with legal norms that regulate food dealing machines.

An economic analysis was carried out to give an idea on the economic advantages derived from the acquisition of the machine we designed. With a general analysis of the monthly costs of the packing materials, it can be observed that a company which owns our machine will save close to 75% of the money it would have spent with other packing systems. If this 75% is spent on the machine, in approximately 3 or 4 months its total cost can be paid off, allowing the company to save in packing material, which will be translated as an aggregate represented in quality, service, satisfaction and comfort to the consumer and employee when using this type of packing. The semi-automatic packing machine was an affordable simple, effective and efficient solution. A production level of 20 packages per minute makes it a really competent one in the market (Fig. 11).

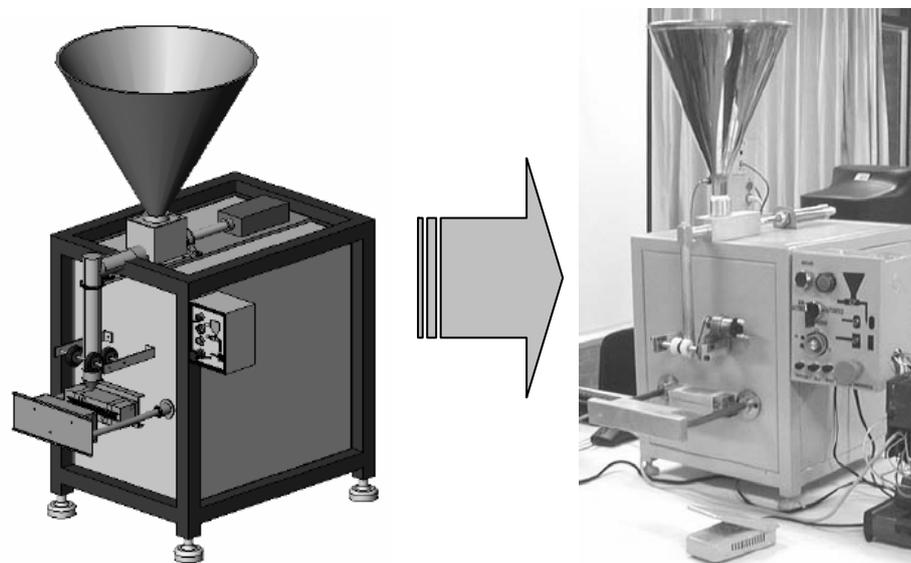


Figure 11. Packing and dosing machine for doughy products

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