Automatic Tablet Machine

G Aragón-Gonzáles*, I Barragán-Santiago, M Cano-Blanco, A León-Galicia and J R Morales-Gómez

Programa de Desarrollo Profesional en Automatización. Universidad Autónoma Metropolitana Unidad Azcapotzalco. Av. San Pablo # 180. Col. Reynosa Tamaulipas, 02200, Ciudad de México, México

E-mail*: gag@correo.azc.uam.mx

Abstract. A Mexican manufacturing plant, whose main product is deodorant tablets for domestic and commercial use, requested the design, construction, and start up of an automatic machine to make 3 600 deodorant tablets per hour of Paradichlorobenzene (PDB). The tablets should have a density no less than 1 400 [kg/m³] with a weight variation of 5% maximum. To design the machine, it was necessary, as a first step, to make an experimental study to determine the power needed to reach the required density and to determine the process characterization to obtain the general characteristics of the machine. Movements and compaction forces were performed by means of electro-pneumatic and electro-hydraulic technologies. The specification of the logic controller of the machine was realized by means of Grafcet to allow efficiency and accuracy. The result of the work generated a versatile, efficient machine with a robust control system.

1. Introduction

This work deals with the designing, construction and starting up of an automatic machine to make 3 600 deodorant tablets per hour of Paradichlorobenzene (PDB). In this work it is proposed to carry out an experimental study to obtain the process characterization, and the use of a mixed fluid power system (hydraulic and pneumatic), instead of a traditional mechanical system to give flexibility to the machine. Since the automatic machine is a discrete event system the use of Grafcet is adopted to specify the logic controller of the machine giving a way to analyse the automatic behaviour of the system off-line and to assure the dependability of the machine.

2. Methods

2.1. PDB deodorant tablets

The PDB is a granulated compound, looks like glass and has no colour. Its average particle diameter is about 4 mm, very volatile at room temperature and sublimates easily. It is used as a base material for fragrances and substances for moth control. Its chemical formula is C₆H₄Cl₂, its melting temperature is 53 ºC and its boiling temperature at normal pressure is 54 ºC. The approximated density of the granulated material is 610 kg/m³. Deodorant tablets required by the manufacturer should have a half-moon shape, approximate diameter of 95 mm, a wire loop for attaching, a density of 1 400 kg/m³ (± 5%) and a weight of 70, 80 or 110 gr depending on the production required.
2.2. Process characterization
To dimension the machine, it was necessary to determine the power needed to reach the required density for the tablets. For that purpose, the first step was to determine the energy to compress PDB. This energy was determined experimentally, using a universal testing machine and a test sample of the granulated material (70 gr). The test sample was placed in a cylindric container with a sliding piston (figure 1). Then, the material was compacted by applying a force ($F_c$) to the piston. This procedure was carried out for $F_c$ from 0 N to 15 000 N, for each value of $F_c$ the decrease in the height of the sample was measured and recorded. Then, volume reduction in the PDB testing sample, as well as the increase in its density, were correlated with the decrease in the height of the sample and the force applied. The pressure needed to compact PDB was calculated with force ($F_c$) and transversal area of the piston ($A_p$). The pressure was related to volume reduction and from this data the compaction energy can be determined (see graph in figure 2). The sample required 126.8 J to reach the density determined for the 70-gr tablet.

![Figure 1. Cylindric container with sliding piston.](image1.png)

![Figure 2. Pressure-Volume chart for 70 [gr] PDB tablet.](image2.png)

2.3. Power determination
It was needed 14 100 N to reach the compaction degree for a sample with an area of 1.1946 x $10^{-3}$ m$^2$. For a half moon shape tablet with the same mass but different shape the required work is the same, but since the tablet area is 3.41 times greater than the sample, the compacting force should be 3.41 times greater. Thus, the calculated compacting force is 48 081 N and the required energy is 126.8 J [1]. Since the automatic machine must produce 3 600 tablets per hour, the total time of the manufacturing process per tablet must take 1 s. The sequence of steps in the manufacturing process is as follows: locating the wire into the half-moon mould; dosing the material for the tablets in the mould; compacting process of the tablet; removing the finished product.

The compacting process was assigned with a time of 0.5 s, then the remaining steps must be carried out in the 0.5 s left. This apportioning of the time allowed to calculate an average power of 254 W for the compacting process.

3. General characteristics of the machine
3.1. Rotating table
The manufacturing of the tablets was organized by means of work stations around the perimeter of a rotating table (figure 3). Upon the rotating table (diameter of 845 mm) there are 15 interchangeable independent moulds which were designed to compact simultaneously two tablets. Thus, the process rate is maintained (3 600 tablets per hour) without high angular velocities of the rotating table. That is, the power will be given at a moderated speed but using a large force. Therefore, the design of the machine was directed to use hydraulic power. Each mould has two cavities with one actuator for each cavity (figure 4).
3.2. Feed of material
The material is loaded in a hopper (figure 5). Then, it is fed to the mould cavities by a worm conveyor driven by a pneumatic motor. The mass flow is regulated adjusting the angular velocity and a variable orifice valve. The maximum manufacture demand is 3 600 tablets/hr (396 kg/hr of material). The torque needed by the helical screw in the conveyor is function of the material properties, the helical geometry, the distance travelled by the material mass and the feeder filling percentage [2].

3.3. Angular displacement of table
The rotating motion is provided through a pneumatic rotatory actuator (figure 6) that supplies the power by a sprocket and chain arrangement [3]. With each step the table rotates an angle of 24° and then stops; each full turn covers the 15 moulds. One step takes 1.0 s and the time at rest is also 1.0 s.

3.4. Pneumatic system description
The pneumatic system is depicted in figure 7. The feeding of the granular material, from the hopper to the mould filling station, is carried out with a helical feeder which is driven by a variable speed
unidirectional pneumatic motor (2.0) which is started by a directional control valve (2.1). The rotary actuator comes with integrated regulating unidirectional flow valves [4].

3.5. Hydraulic power system
To design the hydraulic power system (figure 8) three parameters were considered: The calculated compacting force of 48 kN; The proposed time for compacting of 0.5 s; The actuator stroke to compact the material and to form the tablet. For 110 gr tablet the stroke is 25 mm; for the 80 gr, 18 mm and for the 70 gr, 16 mm. Required power results in 399 W, 290 W and 254 W respectively.

Figure 7. Pneumatic power system.

Figure 8. Hydraulic power system.

3.6. Electronic control system
The elements of the control system (figure 9) are positional sensors, push-buttons, a pressure switch, and an industrial Programmable Logic Controller (PLC) [5], which assure the positioning and synchronizing of the elements that carry on the compaction process. The instructions for the automatic operation of the machine are given by a program residing in the PLC memory.

Figure 9. Diagram with control and power elements.
3.7. Design of logic controller of the machine

The machine process is a Discrete Event System (DES). In this context, an essential task of the work was the design of the logic controller to command the automatic behavior of the system from the specifications of the machine operation. A useful graphic modelling language for the specification and analyse of logic controllers in discrete event systems is Grafcet [6] [7] which is the basis of the sequential function chart (SFC), an International Standard. In this work, the application of Grafcet was adopted allowing the study of the automatic machine process off-line (before the implantation in the PLC) and assuring the dependability of the system. Figure 10 shows the Grafcet of the process. The programming in the PLC is realized by the translation of Grafcet diagram into ladder diagrams (figure 11) [8].

![Grafcet of the machine logic controller.](image10)

![Part of the programming in ladder diagrams.](image11)

3.8. Structure and construction

The machine is built with construction materials easily found on the local market, such as steel plates, structural shapes, bearings, nuts, and bolts, etc (figure 12). Some parts do not carry significant load and were aesthetically designed; for the others the largest load was considered and designed by the resistance criterion [9]. The details are not included. Figure 13 shows part of the construction of the machine.

![Structure of the machine.](image12)

![Construction of the machine.](image13)
The complete machine cannot be showed due to a non-disclosure agreement with the manufacturing plant.

4. Conclusions
Fluid power systems have a notable advantage over the traditional mechanical systems since they allow increasing the global efficiency of the machine and offering possibilities for adapting to different working conditions. Although these systems require a thorough maintenance, their use is justified when their increasing lifetime is considered.

The proposal of a mixed fluid power system (hydraulic and pneumatic) offers the possibility of making the functioning of the several sub-systems in a way independent of each other. This allows adjusting variables such as feeding velocity; turning velocity of the table and compacting pressure, easily.

This flexibility in functioning makes possible the regulation of the material feed for each tablet, the density of the finished deodorant tablet and the no less important production flow. A machine provided with only one motor and restricted to mechanical transmissions would not have such flexibility.

The automatic behaviour of the machine was modelled and analysed with the graphic technique of Grafcet, an international standard and a very well-known tool for the specification of logic controllers. The adoption of this modelling tool responded to the technological interest for applying a methodological procedure in this essential part of the work to avoid errors in the specification and programming of the machine automatic process and to assure the dependability of the system. Once the specification of the logic controller was defined, the implantation was realized into the PLC which makes the system more versatile since it is possible to adapt it to different working conditions trough modifications in the program instructions residing in the PLC memory.

5. References
[1] Avallone E A and Baumeister T 2006 Marks’ Standard handbook for mechanical engineers. McGraw-Hill (USA).
[2] Mott R 2004 Machine Elements in Mechanical Design (New York: Ed. Merrill).
[3] Martin Sprocket & Gear, Inc 1995 Catalogue 1090 (USA).
[4] Parker Hannifin Corporation 1995 Actuator Products, catalog 0106-3 (USA).
[5] Petruzella F D 2005 Programmable Logic Controllers (USA Third Ed. McGraw-Hill).
[6] David R and Alla H 1992 Petri Nets and GRAFCET: Tools for Modelling Discrete Event Systems (New York: Prentice Hall Editions).
[7] Díez J L, Valera A, Navarro J L, Vallés M and Encinas A 2006 An interactive course on logic controllers design using Grafcet IFAC Proceedings Volumes 39. 135-140.
[8] Schumacher F and Schröck S 2013. Tool support for an automatic transformation of GRAFCET specifications into IEC 61131-3 control code IEEE Int. Conf. on Emerging Technologies and Factory Automation. 1-4.
[9] Feodosiev V I Resistencia de materiales 1985 (Moscow: Ed. Mir).