Automatic bottling Machine

G Aragón-Gonzáles1, I Barragán-Santiago, E Huerta-Rizo and A León-Galicia

1 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 bottled Pox (a traditional Mexican alcoholic beverage), requested the design and construction of an automatic bottling machine able to fill six bottles of 750 milliliters per minute and satisfy the exigencies of the Mexican regulation NOM-002-SCFI-2011. To develop this machine it was necessary, as a first step, to make an experimental study to determine the adequate dosage method to use, resulting in a dosage controlled with an electrical sensor that detects the free surface of the liquid inside the bottle. The automatic bottling machine is composed of four modules to fulfill the continuous supply of bottles and the liquid dosage. To command the complete control system and perform the automatic functions of the machine, an Arduino UNO board was adopted. The result of the work generated a versatile, efficient machine with a robust control system, able to dosage 250 to 4'000 ml volumes, not only for alcoholic beverages but for any liquid with viscosity and electrical conductivity similar to water, with an error not bigger than 15 ml.

1. Introduction
This work deals with the designing and construction of an automatic bottling machine to fill six bottles of 750 milliliters per minute of an alcoholic beverage named Pox, with an error not bigger than 15 milliliters. Pox is made from the sugar and corn distillation and contains 36% volume of alcohol. The work aims to replace and improve the original manual process used to manufacture the product, which induces a significant error in the bottled liquid of ±50 milliliters. The precision of the automatic machine is ±15 milliliters, to accomplish with the standard NOM-002-SCFI-2011 [1]. The machine design permits bottled up other liquids with viscosity and electric conductivity like drinking water to 20°C (μ = 1 mPa·s and κ = 5–50 mS/m).

2. Methods
2.1. Machine operation
The liquid dosage is controlled with an electrical sensor that detects the free surface of the liquid inside the bottle. The electric sensor is composed of two metallic electrodes. When the electrodes contact the liquid, a circuit is closed and disables the filling system. A centrifugal Jet type pump transfers the liquid from 50 L containers to a head with two dosing solenoid valves. Special nozzles were designed to discharge the liquid into the bottle. The sensor electrodes and a piece of a hose connected to the dosing solenoid valve are accommodated in the nozzles.

1 gag@correo.azc.uam.mx
The set is inserted into the neck of the bottle. The machine's control system allows one or two of the solenoid valves to be opened, to fill one or two bottles simultaneously (figure 1). The hoses, valves, connections, and the centrifugal pump are made of stainless steel and polymers that do not show chemical reactions with the drink. A rotating disk supply system displaces the empty bottles and places them in the filling area under the dosing solenoid valves. A roller conveyor belt removes the bottles that were filled. The machine control system is organized by an Arduino UNO board [2], which commands sequential instructions to the actuators to control the power devices.

2.2. Liquid dosage characterization

The electrical level sensor is composed of two metallic electrodes that register the rise of the liquid level. The conduction of electricity through the liquid closes a circuit when the electrodes make contact with the free surface of the fluid. The detection method viability was verified by the conduction of an electrical signal (5VDC, 12VDC, and 120VAC), introducing two metallic electrodes in 250 ml of Pox. Initially, the test was performed with two bare tipped, AWG 14 copper wires. The continuity in the circuit was established easily with 120VAC, but with the low voltage DC signals the wires must be 1 to 2 mm apart and deeply submerged to close the circuit.

The continuity of the circuit through the liquid mass was ensured by selecting electrodes with a larger surface area. The copper wires were replaced by rectangular aluminum sheets, making it possible to close the electrical circuit with 120VAC and a much smaller submerged distance than that necessary with the wires (figure 2).

3. General characteristics of the machine

The continuous bottle supply system is made up of four modules (figure 3). The first one is a flat inclined surface, which supplies the empty bottles. The second is a rotating disk, similar to a revolver, which places the bottles in the filling area. The third is a platform that raises the empty bottles, to bring them closer to the nozzles that supply the liquid and descends them when they have been filled. The final module is a conveyor belt that removes the filled bottles.

3.1. Inclined plane

The inclined plane consists of a smooth surface inclined 15° to the horizontal plane, as shown in figure 4.

The operator places the bottles on the surface, and they slide by gravity to the rotating revolver arranged in a single row. The capacity of the inclined table is 24 empty bottles. The structure that supports the inclined plane and the railing to guide the bottles are built with IPS aluminum profiles.
3.2. Rotating revolver
The bottles that advance by gravity on the inclined plane enter in a rotating mechanism, called revolver. It is a horizontal disc with an external diameter of 430 mm. It has four pairs of cavities to receive and angularly transfer the bottles to the filling area. The four pairs of cavities are angularly separated at every 90°; the angular separation between neighboring cavities is 30° (figure 5). The revolver must rotate two successive angular steps, 30° and then 60°, to receive two bottles and transfer them to the filling area. The revolver is mounted on a hollow steel shaft [3]. The system that drives the angular displacement of the revolver consists of a stepper motor, a pair of toothed pulleys [4], the hollow steel shaft, a shaft bearing, and the acrylic discs (figure 6).

3.3. Bottles elevation system
The filling stage starts until a couple of bottles are presented in the filling area. Then, bottles are elevated to the nozzle and the level sensors are inserted into the neck of the bottles. A double-acting pneumatic linear actuator [5] is used to lift the bottles. The revolver places the bottles on a pair of metal plates attached to a horizontal aluminum bar, using two vertical cylindrical bars threaded at the ends (figure 7). The horizontal bar is attached to the threaded end of the actuator rod. When ordering the actuator extension, the horizontal bar, the vertical cylindrical bars, and the metal plates with bottles rise. When liquid dosing is complete, the actuator rod retracts, and the bottles descend to the table surface.
3.4. Conveyor belt
The filled bottles are removed from the filling area with two successive turns of the revolver. The bottles enter in a conveyor belt, which transports them to a place where an operator can take them for storing. The entrance to the conveyor belt is using a 5° inclined plane. The speed at which the bottles can move without causing overturning was experimentally determined (0.3 m/s). The conveyor belt has a bed of rollers that rotate freely as the belt passes; figure 8. In addition to transfer bottles, the rollers support them through their displacement. The conveyor belt permits to transport up to 6 bottles on its rollers bed.

![Figure 8. Conveyor belt.](image)

3.5. Filling system
A Jet pump (¼ HP) is used to displace the Pox from the containers to the bottles. At the end of the pump suction line there is a non-return valve to prevent the pump from having to be primed repeatedly. The flow delivered by the pump arrives at an arrangement of three interconnected ball valves to control the flow accessing the dosing solenoid valves and to prevent excessive pressure from the pump. If there are no bottles in the filling area, the flow displaced by the pump will return to the container through a return line.

Conveniently, both bottles are filled at the same time; therefore, the liquid must travel the same path, with the same pressure drop and the same conduit length. The filling system must fill 2 bottles in no more than 16 seconds, to meet the goal of producing 6 full bottles per minute. The filling set is composed of the head, where the dosing solenoid valves are installed, the ball valves set to regulate the liquid flow, and the bottles’ elevation system. An electrical circuit made with two-pole relays was adopted to control the dosing solenoid valves (figure 9).

![Figure 7. Bottles elevation system.](image)
3.6. Electronic control system
The complete control system links the liquid dosage and the continuous bottle supply. For liquid dosage the machine control must meet this conditions: starting from a start signal, so that the dosing solenoid valves open and allow the liquid to pass through; inclusion of an emergency stop signal; each valve has a sensor that senses the level of the liquid inside the bottle, which gives the signal to stop the flow of liquid when the desired volume has accumulated; the presence of the bottles is detected with a sensor. An Arduino board is used to command the complete control system. It is responsible for managing all the actuators based on the external signals that it receives through sensors placed at specific points on the machine. A pulse on the start button is required to start the process, and the stop button is disabled; figure 10. At that moment, the pump begins to displace flow. Initially, the system disables the stepper motor of the revolver, the belt motor, the dosing solenoid valves, and the pneumatic valve. The revolver takes a bottle, turns 30° and pauses for 1 second, then takes another bottle and turns 60° more, to place both bottles on the platform where they will rise.

Figure 9. The filling system.

Figure 10. Diagram with control and power elements.
3.7. Structure
The Machine structure is divided into three main parts: the inclined plane, the revolver-filling area, and the conveyor belt, figure 11. Safety rails were placed to avoid bottles from going off the route. The force applied by the revolver and the reaction of the safety rails must act on the parallel plane to the bottle base where the center of mass is located, both when it is empty and when it is full, to prevent bottles from overturning. The bottle is a solid of revolution, and its center of mass is on the vertical axis that passes through the center of the base. The center of mass was determined experimentally, located on the parallel plane 8.5 cm from the base; in this way, the height of the rails (on the sides of the machine) and of the revolver were determined.

4. Conclusions
A system was designed to control the dosage of liquid using an electrical sensor with two electrodes that work as level detectors. These have a flat rectangular shape, with a wide contact surface with the liquid, which favors the conduction of the electrical signal that interrupts the filling of the bottle. The operation of this sensor was experimentally verified, with water and the alcoholic beverage, having an accuracy of ± 5 ml for every 750 ml. Special nozzles were designed to discharge the liquid into the bottle. The continuous supply of the bottles was solved with different subsystems: the inclined plane, the revolver, the elevation system, and the conveyor belt. Transfer and filling times allowed to fill up to 6 bottles per minute. The machine's power system was dimensioned using analytical methods, with which the power required to move the bottles and displace the liquid was calculated, and the adequate commercial devices were chosen for each application. All elements in contact with the product were selected based on the food product health regulation NOM-251-SSA1-2009 [6]. The machine operates automatically, is impulsed by stepper motors and its control system is based on an Arduino UNO board.

References
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