PCM-3500 Automated Powder Coating Machine

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ABSTRACT

Power coating is a dry finish process introduced in North America in 1960s. Since then, the field has rapidly grown. Nowadays, more and more companies or family businesses specify powder coatings for a high-quality, durable finish, allowing for maximized production, improved efficiencies, and simplified environmental compliance. However, a powder-coating machines is expensive, even a small one can cost upwards of €20,000. Besides, much of the design behind these machines involves containing the powder within the system to maintain a clean environment, which can cost more to build the machines. The objective of this project is to design a small, automatic, affordable and effective powder-coating machine. The product will not only promote more growth for the powder-coating industry, but secure its position as a market-leading method to serve small and family businesses. This paper details the advances that were made towards achieving the project's goal. The mechanical structure and electrical circuits have been developed and implemented. The program has been written to test the functionality of the product. Partial experiments have demonstrated the feasibility and effectiveness of the design. The next step is to test the whole system and write user instruction manual for customers to use it.

Keywords: powder-coating machine, structure design, computer control

1. INTRODUCTION

In the powder coating industry, work is either accomplished by manually painting the parts by hand or in an assembly line for large scale operations. For the manually painting, since the paint particles will be suspended in open air and the extra paint particles can't be recycled, many harmful, unhealthy, unsafe and costly effects ensue. To utilize a large scale automated powder coating machine to complete a work, the cost is very expensive due to the high price of the machine and/or labor of a shop. Hence, there is a need for an inexpensive small scale automated machine with safe and healthy working environment marketed towards small and family businesses.

2. BACKGROUND STUDY AND DESIGN OBJECTIVE

To begin the design, the powder-coating machines currently used in the industry have been investigated and compared. Figure 1 shows a hand held powder coating system [1][2]. To work using the tool can be very hazardous. Therefore, an applicant must wear the protective gear such as a respirator, painting jump suit, gloves, and boots. Furthermore, a powder coating spray booth, which contains the powder inside and properly ventilate the powder and air into the environment using different air filters, is needed to protect the environment from the powder.

The next level of powder coating is performed by an automated system as shown in Figure 2 [3][4]. The system consists of a set of hangers to hold the parts on a track system. When the part is mounted to the hanger it travels around the system. The first step is to start with a clean piece of metal. The part is automatically grounded in order to attract the powder particles. Then the track leads the part into the oven to be baked and finished. Since the machine is expensive for small-business customers and difficult to operate, this system may be perfect for mass production of a product. This system does not need much human interaction within the spaying area, making it less harmful for the workers. However, the same type of ventilation system is needed in order to properly release the powder and air mixture out of the spraying area.

Figure 1: Hand held powder coating gun

Figure 2: Track and spray system of an industrial automated powder coating machine

The advanced level of automatic power-coating machine [5] can be seen in Figure 3. It came when industrial sized powder coating machines were designed. The machine follows the same processes as the previous system, but more efficient and smaller in size. Therefore, it allows faster completion of the coating process. However, given the smaller size than the industrial factories that carry the automated lines, the powder coating machine is still too large and expensive for small or family businesses. Besides, most of these powder coating machines are designed to coat only one type of part, which allows the production to be extremely efficient.

Figure 3: Industrial powder coating machine

From the above study, it can be seen that the small automatic powder coating machine with necessary safety equipment is still not on the market. Based on the research, the objective of this project is to develop a user-friendly, automated, and cost-effective powder coating machine. The machine will be able to contain all the powder inside to allow recycling of the powder after spraying. It will also be able to fit in a small business or a consumer's garage easily. This machine will then be affordable for a small or family business owner to purchase. The basic features for the powder-coating machine are (1) three choices for the size of a part to be painted; (2) computer control of linear and rotating movement of the part during the painting process; (3) Plexiglas chamber for air pollution control and direct observation of the painting process.

3. HARDWARE DESIGN

Once the design objective for the powder coating chamber has been decided, we start to design the parts.

3.1 GLASS CHAMBER

There are two choices for the material to be used for the frame of the powder coating chamber, i.e. make it out angled aluminum or steel. Either of them needs to ensure that Plexiglas can be used for the walls and the motor and drive-train can be mounted to the top. If the frame is made out of angled aluminum it can be lighter, but the price will increase due to the cost of angled aluminum. Besides, since the angled aluminum has to be glued to the Plexiglas to form the structure of the chamber, the strength of the chamber would decrease due to the glue holding the whole weight. To develop a cheaper and durable product, we have decided to construct the frame out of steel. Figure 4 shows the designed and implemented chamber.

Figure 4: Plexiglas chamber of designed powder coating machine

The design has to be implemented through many detailed works. The angled iron needs to be cut into lengths of 2', then the pieces needs to be notched so they could fit together and make a perfect square. The pieces were cut to size so that the welding was performed at each corner of the frame. The section of the frame where the Plexiglas was going to be attached needed to be welded on the outside so the Plexiglas could sit flat to the frame. Since the welds were on the outside of the frame, they could be ground down and smoothed by using body filler.

The strongest part of the frame is the top plate where the drive train and motor will be attached. The sheet metal was cut to size and welded at each corner on the underside and on all four sides, top and bottom. A 1 3/4" hole was drilled in the center of the plate in order to mount the drive-train and a 1 1/2" x 1 1/2" square hole was cut into the top about six inches from the center of the 1 3/4" hole. To mount the motor, a 1 1/2" x 1 1/2" x 2" square of steel was welded on top of the sheet metal, so the mounting holes could be drilled to mount the motor to it. However, when mounting the motor, the drive-train must be lined up perfectly in order for it to work properly.

In order to satisfy our adjustable powder coating gun requirement, a system for making the position of the powder coating gun change was designed. The design consisted of a piece of steel welded across the right side of the chamber horizontally. Then, a piece of angled iron would be used as a tray to hold the powder coating gun. The angled iron is welded to the horizontal piece of steel and a v-shaped notch needed to be cut into it. In order to hold the gun in place, an adjustable hose clamp is attached around the shaft of the gun and the tray to keep the gun in the desired position.

Finally, the Plexiglas is attached inside the chamber using Velcro, so that the walls could be removed easily if needed. The door was attached using a piano hinge and sealed by using weather stripping. To make sure the door closes, three expanding rubber knobs were used.

3.2 MOTOR AND DRIVETRAIN

Selection of an efficient motor is a crucial step in the design. These calculations were derived off the motion of a power screw. The power screw is a device used in machinery to change angular motion into linear motion. It is usually to transmit power.

Figure 5: Chicago Powder Coating System

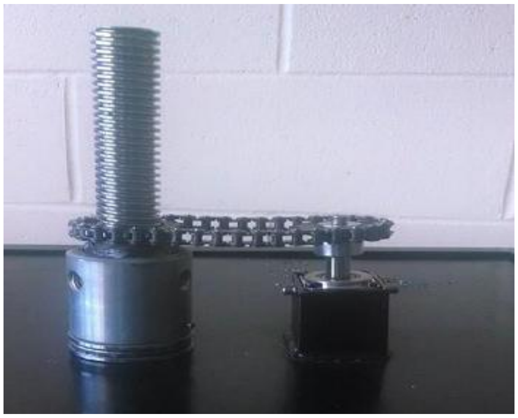

Figure 6: Motor Drive Train

Table 1: Motor Specifications

MOTOR SPECS	PDX104	PDX256
Type	Planetary	Planetary
No-Load Speed	230 rpm	90 rpm
Amps @ Nominal	1.5 Amps	3.8 Amps
Torque @ Nominal	0.5lb-ft	2.9lb-ft
Efficiency	45.33%	45.33%
Peak Power	0.55 hp	0.55 hp
Stall Current	148 Amps	148 Amps
Stall Torque	49.58lb-ft	116lb-ft
Weight	17.8 oz	17.8 oz

To get a motor that can provides the necessary torque to move the part, we have the following derivation. The normal thread area F is represented by the summation of all the unit axial forces. To raise the load, P_R acts to the right while to lower the load, P_L acts in the opposite direction. The friction force which acts to oppose the motion is equal to the product of the coefficient of friction f with the normal force N. The summations of forces in horizontal and vertical directions, respectively, are as follows.

For raising the load:

$$\Sigma F_H = P_R - N\sin\lambda - fN\cos\lambda = 0$$
$$\Sigma F_V = F + fN\sin\lambda - N\cos\lambda = 0 \quad (1)$$

For lowering the load:

$$\Sigma F_H = -P_L - N\sin\lambda + fN\cos\lambda = 0$$
$$\Sigma F_V = F - fN\sin\lambda - N\cos\lambda = 0 \quad (2)$$

where λ is the thread angle of the rod.

The normal force N can be eliminated from (1) and (2) so that P_R and P_L can be solved as follows:

$$P_R = \frac{F(\sin\lambda + f\cos\lambda)}{\cos\lambda - f\sin\lambda} \qquad (3)$$
$$P_L = \frac{F(\sin\lambda - f\cos\lambda)}{\cos\lambda + f\sin\lambda}$$

Then, the numerator and denominator of the equations were divided by cosλ. The relation tanλ=l/πdm was substituted into the equations with l as the distance between threads and dm as the mean diameter of the rod, respectively.

$$P_R = \frac{F[\left(\frac{l}{\pi d_m}\right) + f]}{1 - (\frac{fl}{\pi d_m})} \qquad (4)$$
$$P_L = \frac{F[f - \left(\frac{l}{\pi d_m}\right)]}{1 + (\frac{fl}{\pi d_m})}$$

The product of the forces P and the mean radius $d_m/2$ is equal to the torque therefore, the final equation for raising and lowing the load can be written as follows:

$$T_R = \frac{Fd_m}{2}(\frac{l + \pi f d_m}{\pi d_m - fl}) \qquad (5)$$
$$T_L = \frac{Fd_m}{2}(\frac{\pi f d_m - l}{\pi d_m + fl})$$

Substituting the specific values for our project into (5), i.e. F = 30lb, dm = 1.125 in, l=1/12 in, *f*=0.8 N, the torque required on the threaded acme rod is calculated.

$$T_R = \frac{30(1.125)}{2}(\frac{\left(\frac{1}{12}\right) + \pi(0.8)(1.125)}{\pi(1.125) - 0.8\left(\frac{1}{12}\right)}) = 1.18\text{ft}\cdot\text{lb} \qquad (6)$$
$$T_L = \frac{30(1.125)}{2}(\frac{\pi(0.8)(1.125) - \left(\frac{1}{12}\right)}{\pi(1.125) + (1.125)\left(\frac{1}{12}\right)}) = 1.06\text{ft}\cdot\text{lb}$$

Considering the electrical and mechanical energy loss during motion, the PDX256 DC motor has been chosen for the project.

For the drive-train system, there were two designs under investigation in order to bring the part into the chamber. Both systems needed to be able to lower the part into the chamber and rotate it on at least three possible axes. Our first choice was to use a worm gear mounted directly to the acme threaded rod. Both the worm gear and ACME threaded rod would need to mesh perfectly to satisfy our requirement of high efficiency and longevity of drive-train system parts. Since the ACME threaded rod and worm gear follow different specification standards, matching them as close as possible is not practical. Matching them as close as possible can work in real life applications. However, since our load was being fixed directly to the ACME threaded rod, it would create high stress on the worm gear-threaded rod interface. For this reason, we decided to design a system which required more man hours to build posing much higher risk for damage to our parts in the fabrication phase. Designing the drive-train in this way, the overall cost of building this system is much lower and not as complex.

We chose to use a collar-hub mechanism in which the ACME threaded rod would interact with. This system consists of an ACME threaded rod, gear, ball bearing, hub and collar. The collar and hub are fixed together via two spring pins. The gear was welded to the top of the collar which spins on a bearing on the top mounting plate of the chamber. When the motor is turned on and a part is mounted on the ACME threaded rod, the motor will turn the collar and threaded hub. Due to the ACME threaded rod being stationary and meshing with the hub, the threaded rod will be lowered into the chamber but will not rotate. In the programming portion of this project, the rod will stop at predetermined positions, depending on part size. At this position, the user will insert a bolt into the collar to exert pressure on the threaded rod. This will fix the rod to the collar and allow the threaded rod to rotate on its axis. Then the bolt can be removed and the rod will continue to be lowered into the chamber and the process can be repeated if necessary. Figure 6 shows the motor drive-train used in the project.

3.3 POWDER COATING GUN AND ELECTRIC SOLENOID VALVE

- Powder Coating gun

In Figure 7, the powder coating gun and powder supply as well as the powder coating paint to be used to coat the part are shown. Figure 8 displays the electric solenoid valve.

Figure 7: Chicago Powder Coating System

Figure 8: Electric solenoid valve

The electric solenoid valve chosen for the project matches with the 1/4" NPT airline fitting of the powder coating gun. The valve is used in place of the trigger of the gun so that the spraying of the valve could be controlled by the program.

3.4 MICROCONTROLLER AND MOTOR DRIVER

Two microcontrollers were seriously considered to be incorporated into the PCM-3500 automatic powder coating machine: the Arduino Uno and PIC18F4580. The features of both microcontrollers were compared in Table 2 in order to decide which one would fit better in our design. Similar to Arduino, PIC18F4580 microcontroller can be programmed in C language. However, it lacks many functions (in the library) that are provided by the Arduino software, which results in a more tedious programming process. PIC18F4580 MCU can use the oscillator frequency up to 20 MHz whereas the Arduino's is 16 MHz. However, 16 MHz is enough for the application. Also, the power consumption of the Arduino is lower than that of the PIC's. The Arduino features 6 PWM ports which can drive a small motor directly. Either microcontroller would have required a motor driver for the motor selected in the project. Given the PIC's higher cost, the Arduino Uno was a better board for our project. In the end, we selected Arduino Uno due to its simpler user interface and built-in software libraries.

The diagram in Figure 9 displays the pin layout of the Arduino Uno, as well as other features of the board. The six PWM pins are indicated on the right. The power connections are made up of the upper seven pins on the left-hand side.

The selection of the Arduino Uno as the microcontroller resulted in having to select a motor driver which would not only allow it to control the motor, but protect the board from high currents. The two drivers under consideration were VEX Victor Pro 888 (shown in Figure 10) and Pololu VNH5019. VEX Victor ended up being

Table 2: Microcontroller Specifications

Parameters	Arduino Uno	PIC18F4580
Flash Memory	32 KB	32 KB
RAM	2 KB	2 KB
EEPROM	1 KB	256 Bytes
Number of PWM output pins	6	2
Input Voltage	7 – 12 V	7 – 12 V
Crystal Frequency	16 MHz	20 MHz
Reset Button	Yes	Yes
Pin Count	20	40
Number of Timers	3 (One 8-bit, Two 16-bit)	4 (One 8-bit, Three 16-bit)

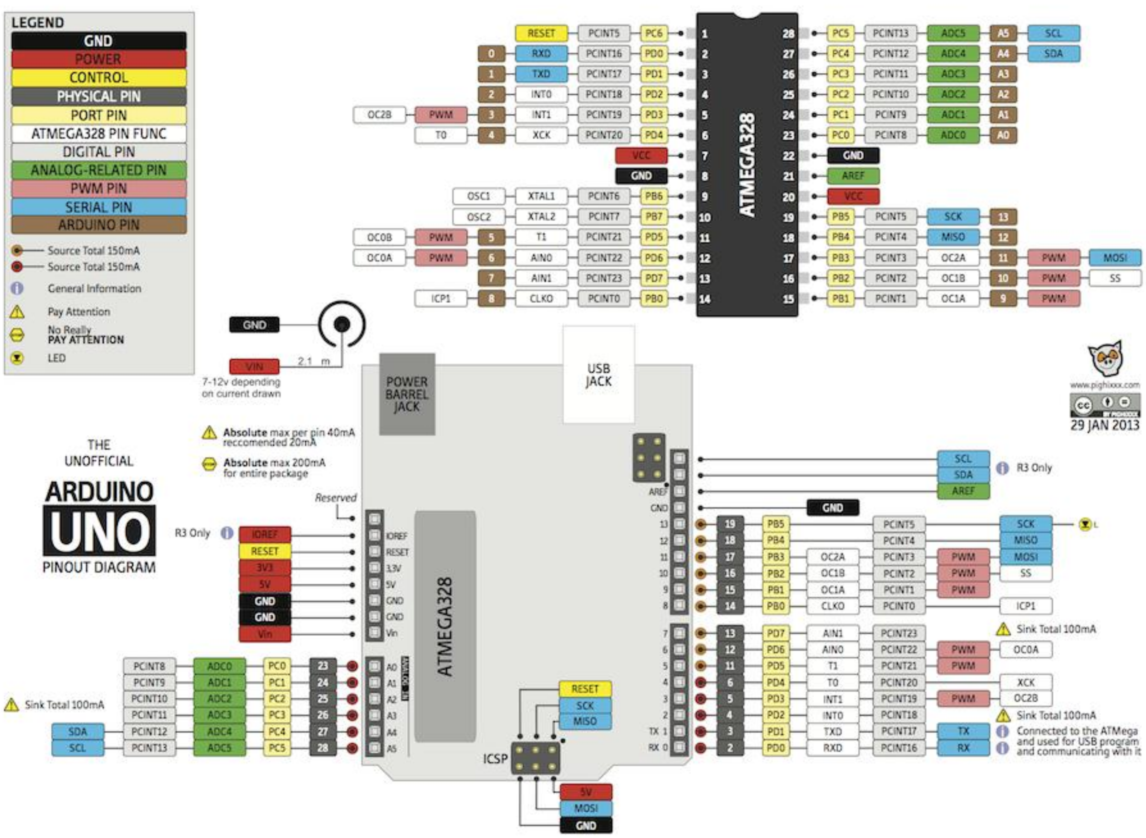

Figure 9: Pin Layout of Arduino Uno Microcontroller

chosen due to its high current capacity which satisfies the motor's needs. VEX Victor is more expensive than Pololu. However, the driver Pololu could only hit a peak current of 30 A, while VEX Victor can handle up to 50 A of continuous current. Selecting a motor driver that would work well with the Arduino and protect the motor was the top priority. The Pololu would also have required some soldering, complicating the integration process. Table3 lists the Victor's specifications.

Table 3: Motor Driver Specifications

VEX Pro Victor Specification	
Nominal Voltage	**12 V**
Minimum/Maximum Current	**6-15 V**
Continuous Current	**60 A**
Surge Current	**150 A**
Minimum Throttle	**5.4%**
Fan Voltage Range	**6-16 V**

3.5 Power Supply

Since the VEX Victor Motor Driver requires a 12 V power supply, the only options under consideration were two power supplies with varying currents. One provided 30 A, while the other provided 15 A. The second power supply's current was found to be insufficient after testing the motor and the driver with a power supply from the school. The 30 A regulated power supply has three outputs, all of which can provide 30 A. Its power consumption is 360 Watts, which was acceptable for our design. The power supply is shown in Figure 11.

Figure 10: VEX Victor Driver

Figure 11: Power Supply

2. Software Flow Chart

The flowchart for the program to control the PCM-3500 automatic powder coating machine is shown in Figure 12. Three part sizes for a user to select are small, medium, and large. The microcontroller will control the motor to send a part in one of three different sizes to a position in the chamber. The larger the part, the more positions it will be sprayed at. After moving a part to a position, the program waits for the user's input to continue. At the time, the user will insert a bolt to stop the rod from moving vertically and press the button to turn on the powder coating gun via the electric solenoid valve and the motor for angular movement. While the part is sprayed, the part will be controlled to rotate uniformly so that the painting particles can reach all surfaces of the part. After a specified amount of time for a part, the motor and powder coating gun will stop to wait the user's instruction. The user removes the bolt and continues the program. This is repeated until the part is thoroughly sprayed. At the.

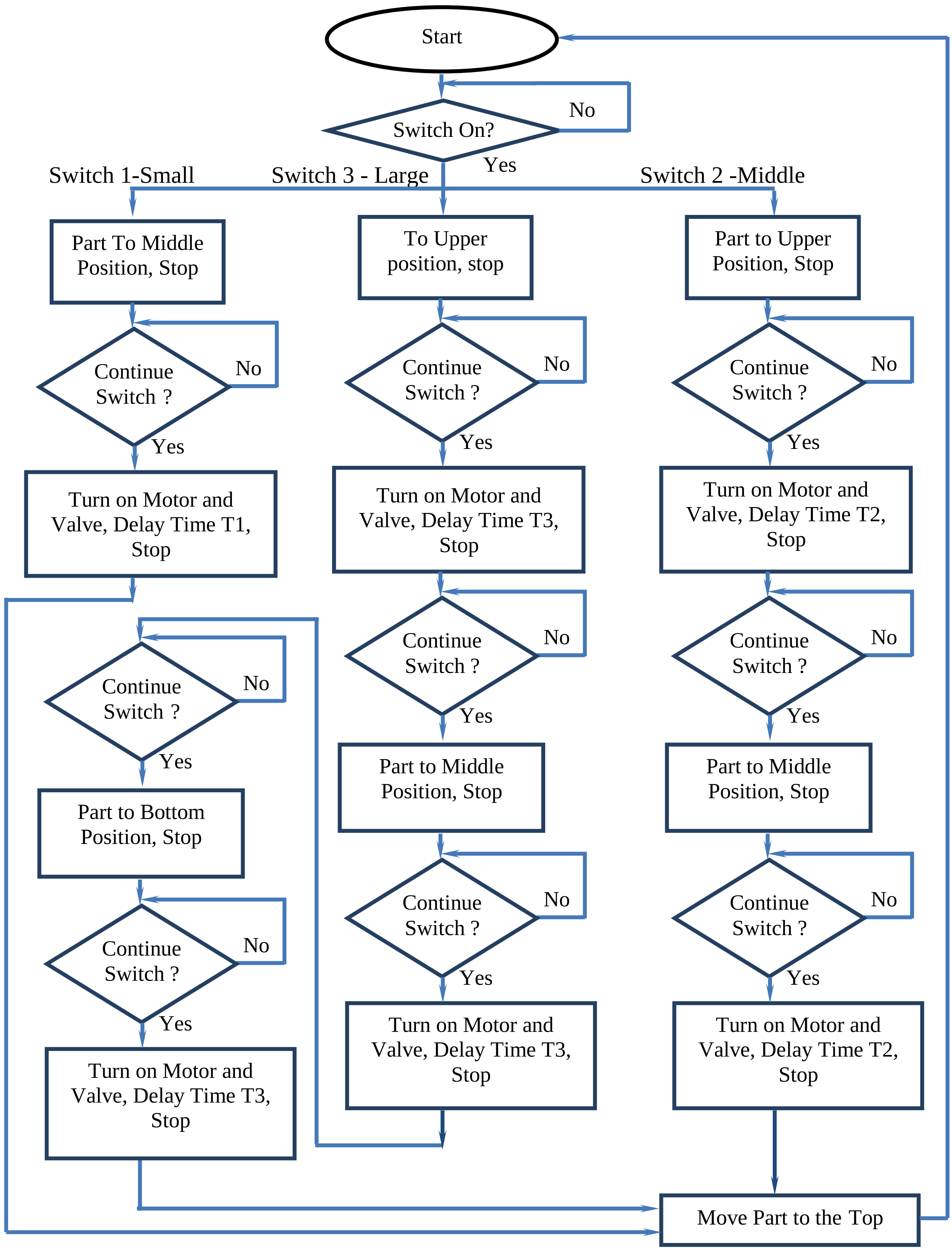

Figure 9: Flow Chart of the Program

end of the process, the part is raised to the top of the machine where it is removed. The program then waits for another input.

The program has been tested with the switch was fixed. The variables were initialized to the values they would obtain from a switch in order for the program to run. In the beginning, the pins' variables are declared, as well as the motor's PWM pin. This is followed by declaring variables to store the time. In the setup function, the pin variables are initialized to one and the motor's pin is set to output a signal. The loop function then stores the time at which the pins are set and provides the motor driver with the required duty cycle for a specific amount of time. The rest of the program follows the flowchart in Figure 12 for the part in small size.

3. CONCLUSION

The powder-coating industry has been increasing greatly in recent years. By performing some research, it is clear that the consumer market has not yet been influenced by a powder-coating machine designed for small and family businesses. All aspects of this project have focused on reducing the machine's cost as much as possible without sacrificing the reliability and effectiveness of the product. The designed automatic powder-coating machine costs about $670, which is affordable for small and family business owners. In addition, the machine is environment-friendly, healthy and produces the high-quality painted parts. The development of this machine will further expand the powder-coating industry by allowing small and family businesses, maybe hobbyists, to have access efficient powder coating without the high costs of industrial machines.

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