Design and fabrication of Automated mechanism for chemical pre-treatment process in Powder coating

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Abstract. The paper is intended to design and fabricate an automated mechanism for chemical pre-treatment process in powder coating for avoiding the manual handling of metal substrates in chemical pre-treatment processing in order to remove dust, to avoid corrosion and to provide good adhesion for powder coating. For this, a gantry crane structure is proposed where two vertical columns and a horizontal beam setup are designed to which a movable carriage is mounted across the horizontal beam. The movable carriage is fitted with a pulley mounted by a rope, the end of the rope is connected to a hanger which has a workpiece holder to which a metal substrate is hanged. The process is controlled by a programmable controller which is programmed with appropriate delays and according to the process designated, the hanged workpiece will move up and down and get dipped into the chemical tank. Once the delay was completed, the carriage automatically moves horizontally to the next tank. The gantry crane structure with movable carriage having pulley and programmable controller are well suited for automating pre-treatment process and it can safeguard manual workers' hands from hazardous chemicals in the tank and also achieving the exact delay operations of each tank process.

1 Introduction

Pre-treatment is the method of chemical processing of different forms of metal, before adding a powder-coated surface finish. Effective pre-treatment of the surface is important in all cases of powder coating to ensure long-lasting results [1]. Pre-treatment is crucial to consistency, just as important to the finished powder-coated product's efficiency as the materials used in its production, design, and the conditions in which it is used. It is absolutely important at Powder Coating Services that high pretreatment levels are maintained to ensure a consistently high-quality end product [2]. Pre-treatment is done to prepare the surface. Hereby pre-treatment means metal pre-treatment as the powder coating is predominantly applied to metals. Preparation of surfaces includes cleaning by mechanical or chemical ways. Mechanical cleaning consists of techniques such as scratch brushing and sandblasting. It not only removes the surface impurities but also cracks and surface defects by abrasive action. Cleaning is very good, but the coating must be done immediately because the cleaned surface is in a highly reactive state and corrosion occurs very fast[3,4]. Chemical cleaning includes the removal of dust, oil and grease and oxidation chemicals from the surface. The chemicals may be wiped, sprayed or dipped. Generally, chemical pre-treatment processing order to remove
dust, to avoid corrosion and to provide good adhesion for powder coating. The nature of the chemicals used depends on the base metal [5]. Conversion coating application is used for three purposes: 1) Providing temporary corrosion protection in the process before Powder coating 2) Encourage the proper adhesion of the powder coating to the substrate. 3) Deliver Corrosion under the paint and thus prolong the life of the powder coating [6].

2 Literature Review

A kind of durable powder coating without any solvent is a powder coating. It is commonly used in the metal industry because of its excellent application performance and eco-friendly usage. The use of powder coatings has been introduced very rapidly in recent years, and the criteria for practical powder coatings have also been continuously improved [7]. Pre-treatment prepares a component before powder coating is added to improve adhesion and corrosion resistance. Phosphating is a method of surface treatment by which the surface of virgin steel is converted into metallic phosphate and is commonly used before painting. Phosphate coatings are produced by the chemical reaction of base metal with an aqueous solution of phosphoric acid and phosphates (Ions of Bivalent metal Zn²⁺, Mn²⁺, Fe²⁺). Phosphating can be done popularly by manganese, iron and zinc phosphate [8]. In [9], authors described the coating of phosphates on stainless steel and mild steel by electrochemical method under galvanostatic conditions and the results showed that mild steel with phosphate coating had better corrosion resistance when compared to the mild steel without phosphate coating. Both traditional high zinc phosphating formulations and contemporary tricationic phosphating formulations on steel surfaces are contrasted with the characteristic features of phosphate coatings in [10]. This is suitable for the automobile finishing pretreatment process with cathodic electrodeposition primer. On analyzing, the corrosion protection of the phosphated and painted steel panels for automobiles by salt spray test and electrochemical impedance spectroscopy, the authors found that modern tricationic phosphating formulations had effective corrosion resistance. In [11], Zayed and et al. described the effect of zinc phosphating on the coating process and explained the importance of adjustment of phosphate, iron and zinc concentrations for improving the quality of phosphate coating. There are various pretreatment processes like sandblasting, grinding and polishing for applying phosphate coating on alloys. For the better formation of corrosion protective low surface roughness is needed which is not possible by sandblasting and superior in grinding and polishing [12]. Another important thing to notice about such coatings is, they do not offer complete resistance to atmosphere and are principally used as an adherent base/primer coat for paints. From a metal surface, the surface is cleaned with water for removing unreacted conversion coating chemicals and a post-treatment application. Post-treatment increases resistance to corrosion and humidity about two to tenfold when compared to conversion coatings without final rinses. Post-treatments are usually chromic acid-based. The following are the different steps involved in the process of chemical pre-treatment [13], [14].

1. Alkali degreasing
2. Cold swilling
3. De-rusting
4. Cold swilling
5. Hot phosphating
6. Cold swilling
7. Sealing/Passivation

The chemical composition and duration of each step is given Table 1.

| S.No. | Tank number | Process        | Tank Capacity (in Liters) | Chemical Composition           | Duration     |
|-------|-------------|----------------|---------------------------|--------------------------------|--------------|
| 1     | Tank 1     | Alkali degreasing | 7000                      | NaOH – 6-8% Tri sodium phosphate- 2 - 3% | 15-20 minutes |
| 2     | Tank 2     | Cold Swilling   | 7000                      | Static water                    | 2-3 times   |

Table 1. Standard Steps in Chemical Pre-treatment Process
3. Tank 3  De-rusting  7000  H₃PO₄ – 25 -30%  5-7 minutes
4. Tank 4  Cold Swilling  7000  Static water  2-3 times
5. Tank 5  Hot Phosphating  7000  H₃PO₄+Zn₁(PO₄)₁ – 30%  10-15 minutes
6. Tank 6  Cold Swilling  7000  Static water  2-3 times
7. Tank 7  Sealing (Passivation)  7000  Chromium tri oxide – 0.025 – 0.05%  25-30 seconds

3 Proposed method
This paper deals with the fabrication of automated material handling mechanism for chemical pre-treatment process in powder coating to avoid the manual handling of metal substrates in chemical pre-treatment processing. This intends to remove dust, to avoid corrosion and to provide good adhesion for powder coating. The gantry crane structure is proposed where the crane chassis has two vertical columns and a horizontal beam setup is designed which is a fixed structure placed on the floor to which a movable carriage is mounted across the horizontal beam. The movable carriage is attached with a pulley mounted by a rope, the end of the rope is connected to a hanger has a work piece holder to which the work piece (metal substrate) is hanged. The movable carriage is driven by a driver powered by D.C. motor using the power supply. The process is controlled by a programmable controller programmed with appropriate delays, and according to the process designated, the hanged work piece will move up and down and get dipped into the chemical tank, and once the delay was completed, the carriage automatically moves horizontally to the next respective tanks and the chemical process will take place inside the chemical tank. By doing so, it is possible to eliminate the manual pre-treatment process, and safeguard the manual workers hand from the chemicals in the tank and also achieving the exact delay operations of each tank process. The block diagram of proposed method is shown in Figure 1.

![Figure 1. Block Diagram of proposed method](image)

The various components used in the fabrication of prototype and their functions are discussed below.

3.1 Beam
While attached to a crane, the lifting beam is generally best suited for outdoor construction use, and the gantry crane is its standalone lifting device ideally suited for large warehouses or flat outdoor spaces.
3.2 Controller
The controller selected for fabricating prototype model is LilyPad Arduino. The ATmega168V (the low-power version of the ATmega168) or the ATmega328V are the basis of the LilyPad Arduino Main Board. Leah Buechley and SparkFun Electronics designed and built the LilyPad Arduino. By simply plugging the board into a USB port on the device or 5V wall charger, the built-in battery port makes it easy to choose a LiPo battery that fits the run time specifications and recharges the battery. It features include 5 Digital I/O pins, 4 Analog pins, ATMega32U4, Built-in ON/OFF switch, Built-in power supply socket (JST connector) for a 3.7V LiPo battery and charging circuit (no additional battery charger needed), Simplified layout with fewer pins, giving more space for sewing or less complex projects, Micro USB connection instead of FTDI header pins.

3.3 Motor
The movable carriage is driven by a driver powered by D.C. motor. Motor is one of a class of rotary electric motors that converts mechanical energy into direct current electrical energy. The forces generated by magnetic fields depend on the most common forms. Almost all types of DC motors have some internal function to regularly adjust the direction of current in a portion of the motor, either electromechanical or electrical. The first type of engine commonly used was DC motors, since they could be operated by existing direct-current lighting power distribution system. The speed of a DC motor can be regulated over a wide range, by using a variable input voltage or by adjusting the current strength of its field windings. In tools, toys, and equipment, small DC motors are used. The universal motor is a lightweight brushed motor used for compact power tools and equipment, but can run on direct current. Currently, larger DC motors are used in electric vehicle propulsion, elevator and hoist propulsion, and in steel rolling mill drives.

3.4 Crane Chassis
The crane chassis has a girder, pillars, braces and base. Some important considerations should be taken into account when designing the chassis for the gantry crane. It is important to note that the moment is usually spread evenly around the girder when the load is on the central axis of the crane and when the load is on the other side of the crane, the maximum on one side. Strong support at both legs is therefore required to keep the system in balance. In addition to braces at the top half and bottom half of the pillars, the lateral braces at the girder provide a solution to such a problem. On the other hand, the system's center of gravity should be positioned as near as possible to the bottom of the crane chassis structure, so that the center of mass allows the system to stay in balance, regardless of the size of the load, which needs to be less than the total mass of the crane. This can be achieved by designing the base of the chassis structure to cover an area that maintains an appropriate center of gravity position along the central axis of the chassis[15]. Other factors that need to be considered for the design of the crane are the resistance due to load swing, the influence of the wind and acceleration of the moving masses. Nevertheless, given the lack of wind impact due to indoor activity and the option of low speeds for load hoisting and travel, these factors can be ignored. Another important aspect is maintaining operational health, as a simple error can lead to catastrophic accidents, most of which are caused by unsecured load and exceeded load power. The various parts of the chassis are regular steel pieces that are joined to form the final chassis framework using welding and bolted joints. Using the required safety criteria, all structural components, welding and bolted joints are tested for shear stress, crushing stresses, and bending moment stresses.

3.5 Trolley Mechanism
The trolley mechanism has a wheeled carriage and hoisting mechanism. These are fitted with a ratchet wheel braking system for supporting the load placed at high places. The carriage drive mechanism consists of an electric motor, which drives an underhung wheeled carriage through a fixed coupling that moves on the rails that are attached to the girder. The mechanism of load raising and lowering
consists of a drum, pulley system, speed gear reduction and electric motor. It also contains a hook that is meant to be connected to the load and steel wire ropes. All parts and mechanisms are selected using load-based formulae so that they are selected to be consistent with the requirements recommended for manufacturing gantry cranes.

3.6 Crane Mobility System

The basic function of the mobility system is to allow the user to move the crane within the area of operation. The crane's mobility system consists of two main systems; the crane driving system which is used to drive the crane forward or backward and the crane steering system which is used to guide the crane movement. That system relies on two electric motors to accomplish its operation. Using the control unit, the mobility system is controlled via the electrical wire system and the control devices. A braking mechanism is used to slow the crane or lower its speed.

4 Design Calculation

Material choice for beam and column is Mild Steel.

Properties of Mild Steel to be used:
Density = 7850 kg/m³
Young’s Modulus = 2.08×10⁵ N/mm²
Poisson’s Ratio = 0.3

4.1 Weight acting on the Beam

One work piece dimension = 12.5 × 7.5 × 0.5 cm
One work piece Volume = 46.875×10⁻⁶ m³
For three work piece, V = 140.65×10⁻⁶ m³
Mass = Density × volume
= 7850×140.625×10⁻⁶
= 1.103 kg

For hanger,
Considering Golden Ratio for Rectangle, \( \frac{d}{b} = 1.6 \)
Here, \( b = 2 \) cm
\( \sqrt{1.24} = 1.24 \) cm
\( L \times b \times t = 11\times2\times1.24 \)
\( V = 27028\times10^{-6} m³ \)
Mass = 7850×27.28×10⁻⁶
= 0.21 kg

Total mass = 1.103+0.21+2
= 3.51 kg

Force = mass × gravity
= 3.5×9.81 \( \Rightarrow \) 35 N

∴ Total weight acting on beam = 35 N

4.2 To find whether the Beam Design is Safe/Not

Moment at A,
\( (R_b\times0.75) = (35\times0.375) \)
\( \therefore R_b = 17.5 \) N
\( R_A + R_b = 35 \)
\( R_A + 17.5 = 35 \)
To find Shear Force,

S.F at A, \( F_A = 17.5 \, \text{N} \) (5)

(Shear Force between A and C is constant and equal to 17.5N)

S.F at C, \( F_C = 17.5 - 35 = -17.5 \, \text{N} \)

S.F at B, \( F_B = -17.5 \, \text{N} \)

Shear Force between C and B is constant and equal to -17.5N

To find Bending Moment,

\[ M_A = 0 \]
\[ M_B = 0 \]
\[ M_C = 17.5 \times 0.375 \Rightarrow \text{Bending Moment, } M_C = 6.5625 \, \text{Nm} \] (6)

To find Maximum bending stress,

\[ \sigma = \frac{E}{y} \frac{MB}{I} \] (DDB. 7.1)

For rectangle, from Golden Ratio,

Here, \( b = 5 \, \text{cm}, \frac{b}{d} = 1.6 \)

\( b = 1.6 \times 5 = 0.08 \, \text{m} \)

\[ \therefore \sigma_b = \frac{MB \times y}{6.5625 \times 0.025} = \frac{8.3 \times 10^{-7}}{6.5625 \times 0.025} \]

\[ \therefore \sigma_b = 49.76 \, \text{N/mm}^2 \] (7)

Allowable bending stress = 200 N/mm\(^2\)

\[ \therefore \text{Calculated value} < \text{Allowable value} \]

Therefore, the beam design is safe.

4.3 To find whether the Column Design is Safe/Not

Here, b = 5cm

For Rectangle, considering the Golden ratio, \( \frac{b}{d} = 1.6 \)

\[ \text{Here, } L = 70 \, \text{cm} \]

\[ \therefore \text{Long column} \] (8)

Since it is long column, Euler’s formula is used.

Consider End condition = both ends are fixed.

Crippling load, \( P = \frac{4\pi^2 \times E 	imes I}{L^2} \times \left[ I_{bd} = 5 \times 1.325 \times 10^{-3} \, \text{mm}^4 \right] \)

\[ P = 2.12 \times 10^5 \, \text{N} \] (9)

Crippling Stress, \( \sigma = \frac{P}{A} = \frac{2.12 \times 10^5}{700 \times 50} \)

Crippling Stress, \( \sigma = 21.0571 \, \text{N/mm}^2 \) (10)

Allowable crippling stress, \( \sigma = 40 \, \text{N/mm}^2 \)

The calculated crippling stress is less than the allowable crippling stress. So, the Column Design is Safe.

4.4 Calculation of Motor selection for Carriage movement
Torque, $T = 2F \times R$

$F = \mu \times R_N$

$= 0.3 \times 17.5$  \hspace{1cm} \text{[Coefficient of friction, $\mu = 0.3$]}

$F = 5.25 \text{ N}$ \hspace{1cm} (11)

$T = 2 \times 5.25 \times 0.04$ \hspace{1cm} \text{[Radius of wheel = 0.04m, Standard trolley wheel radius which withstand 35N]}

$= 0.42 \text{ Nm}$ \hspace{1cm} (12)

Power, $P = T \times \omega$

$= 0.42 \times 2.5$

$= 3.5 \text{ W} \Rightarrow \frac{3.5}{0.8}$

Power, $P = 5 \text{ W}$ \hspace{1cm} \text{[Efficiency, $\eta = 0.8$]} \hspace{1cm} (13)

To find Speed in rpm, consider,

$\omega = \frac{2 \pi N}{60}$

$= \frac{\omega \times 60}{2 \pi}$

$\Rightarrow \text{Speed, } N = 23.87 \text{ rpm} \approx 30 \text{ rpm}$ \hspace{1cm} (14)

From the design calculation, weight acting on the beam is determined. Based on the bending stress, the beam design and based on crippling design column design are found safe. The specification of motor required for carriage movement is also found.

5 Results and Discussion

This paper deals with designing and implementing a light duty crane, which is used to handle materials operations within small workshops. All the drawings, design calculation reports presented in this paper have been used to develop a prototype (with beam dimensions 850x50mm and column dimensions 750x50mm) that envisages the actual working of a real time gantry crane where the authors bound to simulate the real time process in the sequence using the sample tanks two in number that shows the simulation of the pre-treatment process of the powder coating mechanism. This prototype when enlarged using the real time dimensions as specified can be used for the pre-treatment of the powder coating process that involves the sequence of all the seven processes. The 3D model of the proposed system is shown in Figure 2. The fabricated model of the automated mechanism for the chemical pretreatment process is depicted in Figure 3.
Figure 2. Three-Dimensional Visualization of Prototype

Figure 3. Fabricated model

6 Conclusion

The application of powder coating over the industry is very large. The effects of alkalies on the human during pre-treatment of powder coating are analyzed and came with a solution of automation. The goal of this paper is to increase the powder coating efficiency and protect the workers from harmful alkalies. The solution given here can be done in less time and it is implemented with required enhancements. Also, here the manual pre-treatment process is eliminated and it is helpful to safeguard the manual workers’ hand from the chemicals in the tank and also achieving the exact delay operations of each tank process.

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