Measurement of Electric Currents in Electrostatic Spray Painting System

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Abstract

Many parameters affect the electrostatic painting process. And numerical modeling provides an economical method to optimize the operating parameters in order to achieve maximum transfer efficiency and good paint finish quality. Due to the complexity of the electrostatic painting process, no complete theoretical model is available to predict the required parameters such as droplet size and charge-to-mass ratio distributions. Experimental data are needed in order to get more accurate modeling results. By measuring the electrical currents involved in the electrostatic painting process under different operating parameters, the droplet charge-to-mass ratios can be calculated. Using design of experiments (DOE) techniques, for each type of paint, the number of experiment can be reduced to 26 for 5 operating parameters of 3 levels while still generate enough data for this study. The experimental results showed that for both waterborne and solventborne paint, conduction charging is dominant for the applied voltage up to 80kV. For the same voltage and other parameters, waterborne paint has much larger total current and target current than solventborne paint. Target currents increase with paint flow rate, bell speed and shaping air flow rate, and decrease with bell-to-target distance. Since applied voltage and type of paint have the greatest effects on the current and thus the droplet charge-to-mass ratio, they need to be adjusted carefully during the painting process.

Introduction

Electrostatic spray painting with rotary bell atomizer is extensively used in the automotive painting industry for its high transfer efficiency and good paint finish quality. However, the present transfer efficiency is between 65% and 80%, varying from shop to shop. There are many operating parameters affecting the painting process such as the bell configuration, applied voltage, bell speed, shaping air velocity, paint flow rate, paint type and physical properties, bell-to-target distance and target geometry, etc. It is a real challenge to find the optimal operating parameters that can achieve maximum transfer efficiency and good paint finish quality under various working conditions. Numerical modeling provides an effective tool to meet this demand compared with traditional trial-and-error method in terms of time and cost savings.

Due to the complexity of the electrostatic painting process, especially paint atomization and charging, in which a spectrum of droplets with different sizes and charge-to-mass ratios are produced, there is no satisfactory way to predict the droplet size and charge distributions so far. Simplified models, empirical equations and experimental data are often used in computer simulations. For example, Elmoursi [1] first used a simple Laplace field model to study a bell type electrostatic painting system which showed the dependence of droplet trajectories to electrical parameters. Then the model was expanded to include the space charge of charged paint droplets [2]. The study showed that space charge tends to enhance particle deposition and also causes spray to expand. Ellwood and Braslaw [3] developed a finite-element model which includes the continuous phase of the shaping air, particle phase of the droplets and the electric field in which the droplet charge-to-mass ratio was assumed to be a constant. The results showed increase of electric field near the target which enhanced paint deposition. With the advance of computational fluid dynamics (CFD), more sophisticated models [4-6] are developed for electrostatic painting process with a bell atomizer which corporate shaping air flow, particle discrete phase and electric field. However, the charge-to-mass ratios of the paint droplets used assumed values, which do not reflect the fact that both conduction/induction and corona charging may be involved in the process.

Since droplet charge plays an important role in deciding droplet trajectories and the transfer efficiency, accurate values are vital for numerical modeling of the painting process so that good optimization can be achieved. Many researchers have carried out a number of experiments trying to figure out the relationship between droplet charge-to-mass ratios and operating parameters. For example, Anestos [7] measured the charge-to-mass distributions of a spray gun under different operating parameters such as atomizing air flow rate and liquid flow rate for both aqueous and organic solutions. The results showed that droplet charging is mainly due to breakup of a liquid surface; corona

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charging does not appear to play a significant role. Unfortunately, the conclusion is not convincing because he kept the voltage at 6kV without varying it within a certain range. McCarthy [8] did similar experiments in which the average droplet charge-to-mass ratio (or specific charge) increases with applied voltage until reaches a maximum then declines. He also tried to separate the droplet current and the ionic current but his method was not correct. Bell and Hockberg [9] did a lot of experiments on rotary bell atomizer and derived an empirical equation to calculate the droplet charge-to-mass ratio under different applied voltage, bell speed and paint resistivity. However, it may only valid to a specific type of bell, for example, when the diameter of the bell cup changes, the atomization of paint also changes, which may generate droplets of different diameters. Also, the droplet charge-to-mass ratio changes with size distributions and the equation did not show its relation to droplet size.

A thorough experimental study of the electrostatic painting process is possible which needs modern measuring equipment and careful design of the experiment and it is also costly and time consuming. An economical alternative is that we measure the global parameters involving in our bell atomizer system and capture the main characteristics so that we can derive out the required data for computer modeling of our painting systems. Based on the modeling results, these global parameters can be adjusted in our painting applications.

Our plan for the experiment is to measure the electric currents involved in the electrostatic painting process under different operating parameters in order to get the required input data for our simulation so that the results will be more close to our practical applications. Through the experiment, we may get some insight of the parameters that relate to the electric currents.

Electric Current Flow in a Painting System

A typical electrostatic liquid painting system with rotary bell atomizer is shown in Fig. 1. In this system, a high voltage of -50 to -80kV is applied to the bell cup. An electric field is established between bell cup and a grounded target. The paint flows along the inner surface of the high speed rotating bell. It breaks up at the edge of the bell and forms a cloud of charged paint droplets. These droplets are driven to the target by electric and aerodynamic forces. The electric forces are dependent on the space charge distribution of the charged paint particles and ions, and the aerodynamic force is primarily due to the shaping air introduced through the air shrouds behind the bell and downdraft air. Most of the charged paint droplets are driven to the target and the rest escapes due to overspray, downdraft air and leakage.

The electric currents in the electrostatic spray painting system can be identified into four types. The total current coming out of the voltage source (I_{to}), the target current from deposition of the charged paint droplets and ions (I_{tg}), the leakage current from off-target droplets (I_{L2}) and the leakage current through bell (I_{L1}). The relationship between the four currents can be expressed as

$$I_{to} = I_{tg} + I_{L1} + I_{L2} \tag{1}$$

Design of Experiments

As already mentioned above, there are many factors affecting the electrostatic rotary bell painting system, including the bell configuration, rotating speed, paint flow rate, shaping air flow rate, applied voltage, bell-to-target distance and paint type. The combination of these parameters could yield hundreds of test conditions. So design of experiments (DOE) is essential in order to obtain sufficient data at a minimal number of experiments. For the SAMES PPH707 bell, the tests will be carried out in two steps: preliminary tests and full tests.

<u>Preliminary tests:</u>

These tests aimed to test the currents without paint, from single parameter to multiple parameters in order to evaluate their effects to the currents. The test conditions are summarized in Table 1. For each tests, the total current is measured using the meter at the control panel. The target current is measured by connecting a microampere meter between the target and the ground. By still state tests, the leakage current of the power source can be determined. In other tests, the difference between the total current and the target current will be the total leakage current which includes the leakage current to the environment.

<u>Full tests:</u>

The full tests will be carried out with solventborne paint and waterborne paint. For each type of paint, there are five operating parameters that have to be adjusted, including applied voltage, bell rotating speed, paint flow rate, shaping air flow rate and bell-to-target distance. For each parameter, three typical values are selected as low, median and high. The total combination is 3^5=243. By using a D-optimal design of experiment (DOE) plan, only 26 tests are needed.

Analysis of Experimental Data

The experiments were conducted at the SAMES facilities. A PPH608 Accubell and PPH707 bells were installed on a robot and tested with waterborne white paint and solventborne white paint, respectively. The target is an aluminum foil 1m×1m in size and is grounded through a microampere meter. During the experiment, the foil is replaced with new one for every single test.

Preliminary tests:

The preliminary tests are used to see how the single factor such as the applied voltage, bell-to-target distance, bell rotating speed and shaping air flow rate will affect the current flow in the painting system. The results are shown in Figs. 2-4 below.

Fig. 2 shows that when the rotary bell is in standstill condition and voltage is applied, the total current begins to increase. Before corona discharge takes place at the bell tip, the total current shows the power consumption of the voltage source itself. When the applied voltage reaches 55kV, corona discharge takes place and both the target current and total current increase dramatically with the applied voltage. Since almost all the ions produced in the corona discharge reach the target, the difference between the total current and the target current is the current consumed by the voltage source.

When shaping air is applied, the target current increased compared with the condition without shaping air as shown in Fig. 3 since the shaping air helps the ions move faster to the target.

When the bell rotates, the target current also increased compared with the condition when the bell is in standstill as shown in Fig. 4. The reason is that the rotation of the bell accelerates the corona discharge process, i.e. let the negative ion move away from the bell tip more quickly. The effect of the bell speed is greater than that of the shaping air.

When both the shaping air is applied and the bell is rotating, the increase of target current is mainly due to the bell speed and the experimental results are not displayed.

Full tests:

The full tests will demonstrate electric currents under different paint types and flow rates, as well as other operating parameters. During a painting process, all paint droplets acquire different levels of charge. The target current relates directly to the charged droplets and ions deposited on the target. Through this set of full tests, not only the required data for computer modeling can be acquired, but also the correlations between these operating parameters can be better understood.

Comparison of the current- voltage characteristics with and without paint:

When paint is applied to the rotating bell along with shaping air and voltage, atomization and charging take place at the bell tip. The charging may include induction and/or corona charging, depending on the voltage applied. It is also affected by the bell rotating speed and paint flow rate, paint type and its physical properties, and the space charge formed by the charged paint droplets which is also affected by the shaping air flow rate and bell-to-target distance. So the physical process is much more complicated by the interaction of these parameters. Figs. 5 and 6 show the current-voltage characteristics for waterborne white paint and solventborne white paint under two different levels of paint flow rate, and they are compared with the data without paint.

When there is no paint, the current-voltage characteristics curve (also called I-V curve) is the typical curve for corona discharge which shows the corona onset voltage and a rapid increase of current with voltage. For a low level of paint flow rate (200ml/min.), both total current and target current increase linearly with voltage because of conduction charging (Fig. 5). As the voltage further increases, the currents increase more quickly, showing some degree of corona discharge taking place.

For a high level of paint flow rate (500ml/min.), both total current and target current increase linearly with voltage up to 80kV (Fig. 6) , corona charging is unlikely to happen. The results also showed that water borne paint produces much larger total current and target current than solventborne paint. So conduction charging is quite dependant on the paint conductivity (or resistivity). Waterborne paint may need to apply a lower voltage whereas solvent borne paint needs a higher voltage.

Target current vs. paint flow rate:

Paint flow rate is the most important operating parameter for painting as it is directly related to productivity. It needs to be adjusted with the bell speed in order to produce droplets of the proper size to ensure good surface quality and transfer efficiency.

The relationship between the target current and paint flow rate is affected by other operating parameters. The correlations are shown in Figs. 7-10 for waterborne paint. Solventborne has similar trends and thus will not be discussed thereafter.

Fig. 7 shows that at a given bell speed, when paint flow rate increases, more charged paint droplets arrived at the target surfaces and causes increase in target current. At the same time, higher (mass) flow rate causes decrease in charge-to-mass ratio and thus reduces the transfer efficiency. So at higher bell speed, it can achieve higher target current at the same fluid flow rate compared at lower bell speed. Either way, the influence on target current is not significant.

Fig. 8 shows that target current increases a little with paint flow rate for a wide range of voltage. This is a strong evidence that charge-to-mass ratio is not a constant. Higher paint flow rate is compensated with lower charge-to-mass ratio to maintain a near constant target current.

Fig. 9 shows that when shaping air flow rate is small, target current increases with paint flow rate because that the shaping air directs more paint droplets toward the target surface. When shaping air flow rate is large, the target current saturates and no longer increases with paint flow rate.

Fig. 10 shows that target current decreases with target distance as more paint droplets drift away and miss the target. At any given target distance, target current increases slightly with paint flow rate as larger paint droplets increase paint transfer efficiency.

In summary, target current increases a little with paint flow rate for a wide range of other parameters. By far, the voltage is the most dominant factor in affecting target current. As paint flow rate increases, the charge-to-mass ratio decreases.

Target current vs. bell speed:

The importance of selecting the right bell rotating speed is to ensure proper atomization of paint into droplets. When bell speed increases, finer and finer charged droplets can be produced. Also a wider spray pattern will be formed which may lead to lower transfer efficiency with more overspray. The correlations between target current and bell speed under other parameters are shown in Figs. 11-13.

The correlation of bell speed and paint flow rate has shown in Fig. 7 and mentioned above. Fig. 11 shows that when bell speed increases the target current changes little for a wide range of applied voltage. Voltage is a more dominant factor compared to bell speed.

Fig. 12 shows that when the shaping air flow rate is small, the target current increases with bell speed as smaller droplets can be carried more easily by the shaping air toward the target surface. When shaping air flow rate is large, the target current saturates, and little changes can be caused by changing bell speed. This is similar to that of paint flow rate.

Fig. 13 shows that when bell-to-target distance is small, the target current changes little with varying bell speed. When bell-to-target distance is large, the target current increases a little as higher charge-to-mass ratio at higher bell speed pulls more paint droplets toward the target surface.

In summary, target current has a small change with bell speed for a wide range of other parameters. This is similar to the effect of paint flow rate. Both are not dominant factors.

Target current vs. shaping air flow rate:

The function of the shaping air is to direct the paint droplets to the target. The shaping air needs to be adjusted so that it will not cause splashing of the droplets when they reach the target surface, or to overcome the Faraday cage effect by driving the droplets to the electrostatically shielded area. The correlations of shaping air flow rate and liquid flow rate and bell speed have shown in Fig. 9 and 12. The correlations among target current, shaping air flow rate and other parameters are shown in Figs. 14-15.

Fig. 14 shows that increasing shaping air flow rate increases target current. Same holds true for the applied voltage. This chart also shows that the influence of shaping air flow rate does not have as strong an influence on target current as the applied voltage.

Fig. 15 shows for a given bell-to-target distance, the target current increases a little with shaping air. Again, though, the influence of shaping air is not as strong as the target distance.

In summary, target current generally increases a little with shaping air flow rate under a wide range of conditions.

Target current vs. bell-to-target distance:

A proper bell-to-target distance should allow for good paint atomization and spray uniformity as well as proper droplet charging without causing breakdown between the bell and the target. The correlation between target current and bell-to-target distance and applied voltage is shown in Fig. 16. Other parameter correlations have already been shown in the previous sections.

Fig. 16 shows a rather linear relationship among target distance, applied voltage and target current. For any given applied voltage, target current decreases a little as bell-to-target distance increases. Target distance's influence on target current is not as strong as applied voltage.

In summary, target current generally decreases a little with bell-to-target distance for a wide range of other parameters.

Summary

Experiments were designed and carried out to measure the electric currents for the rotary bell atomizers under different operating parameters in order to provide the required information for computer simulation. The preliminary tests without paint showed that corona discharge initiates at 55kV for a bell-to-target distance of 10”. However, the voltage-current characteristics with paint show that induction charging dominates for both waterborne and solventborne paint. For the same voltage and other parameters, waterborne paint has much larger total current and target current than solvent borne paint. When paint flow rate increases, there is a small increase of the target current. The bell speed and shaping air flow rate have similar effects. When bell-to-target distance increases, there is a decrease of the target current. Applied voltage and type of paint have the greatest effects on target current which in term influences the droplet charge-to-mass ratio and transfer efficiency.

References

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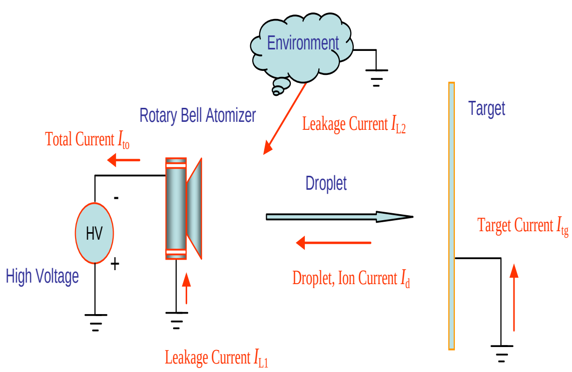

Figure 1. Electrostatic rotary bell painting system

Table 1. Example of a table appearing at the end of the paper.

Parameters	Still State	Rotating Bell	Shaping Air	Rotating bell + Shaping air
Bell-to-target distance	6”, 8”, 10”	10”	10”	10”
Applied voltage	Low, medium, high	Low, medium, high	Low, medium, high	Low, medium, high
Bell rotating speed	0	Low, medium, high	0	Low, medium, high
Shaping air flow rate	0	0	Low, medium, high	Low, medium, high

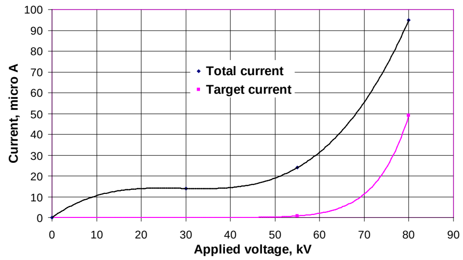

Figure 2. Total current and target current vs. applied voltage under standstill condition for 10" target distance

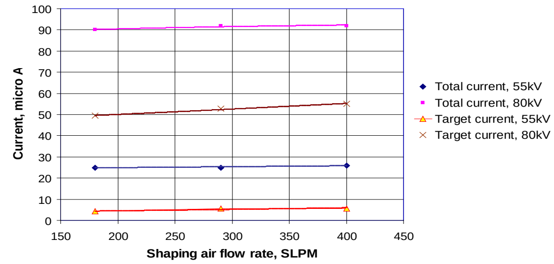

Figure 3. Total current and target current vs. shaping air flow rate for 10"target distance

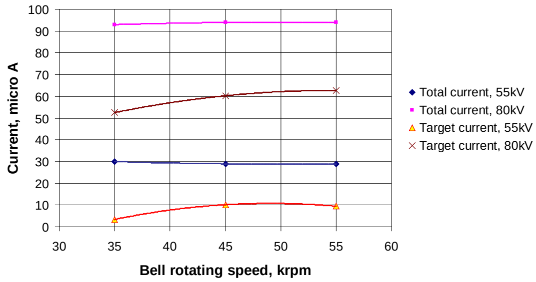

Figure 4. Total current and target current vs. bell rotating speed for a bell-to-target distance of 10"

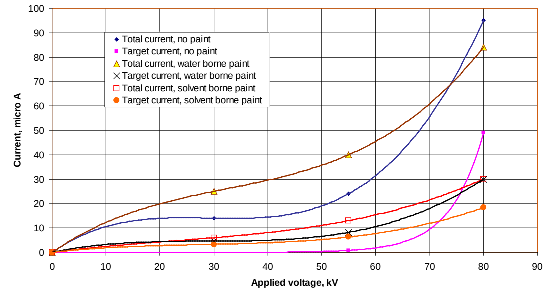

Figure 5. Current-voltage characteristics for waterborne and solventborne paint with liquid flow rate of 200ml/min., bell speed of 35krpm and shaping air flow rate of 180SLPM

Predicted Target

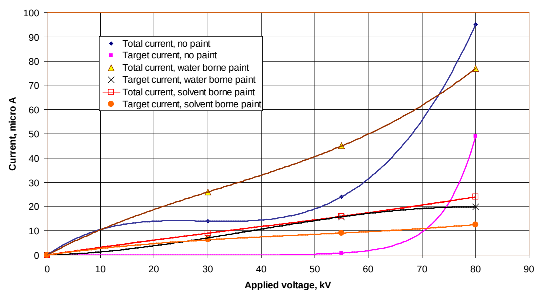

Figure 6. Current – voltage characteristics for waterborne and solventborne paint with liquid flow rate of 500ml/min., bell speed of 35krpm and shaping air flow rate of 180SLPM

Figure 7. Target current vs. bell speed and paint flow rate

Predicted Targe

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Figure 8. Target current vs. paint flow rate and applied voltage

Figure 9 Target current vs. paint flow rate and shaping air flow rate

Figure 10. Target current vs. paint flow rate and target distance

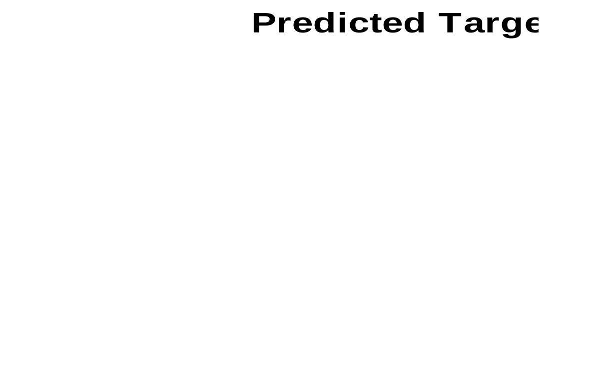

Figure 11. Target current vs. bell speed and applied voltage

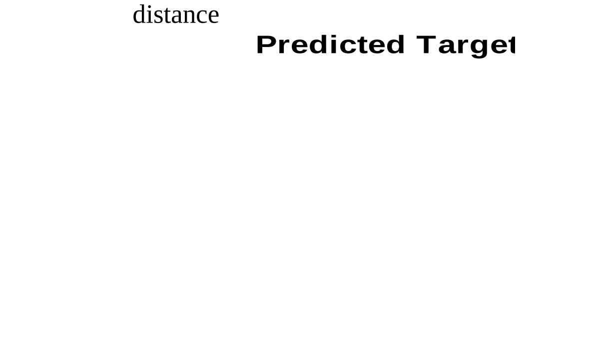

Figure 12. Target current vs. bell speed and shaping air flow rate

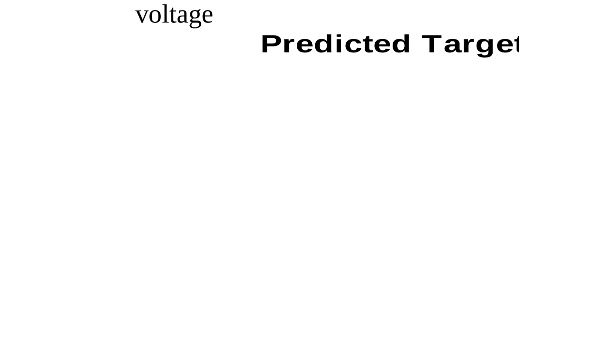

Figure 13. Target current vs. bell speed and target distance

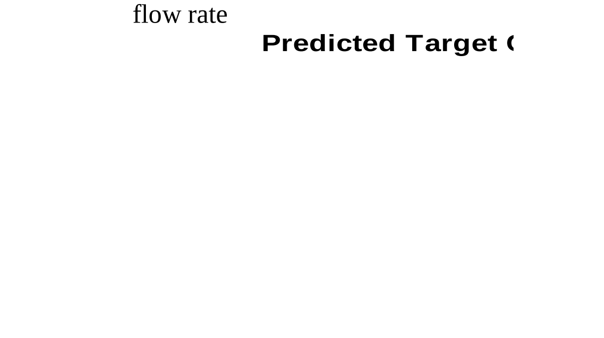

Figure 14. Total current vs. shaping air and applied voltage

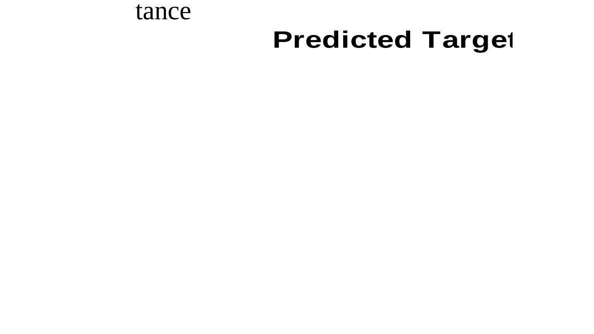

Figure 15. Target current vs. shaping air flow rate and target distance

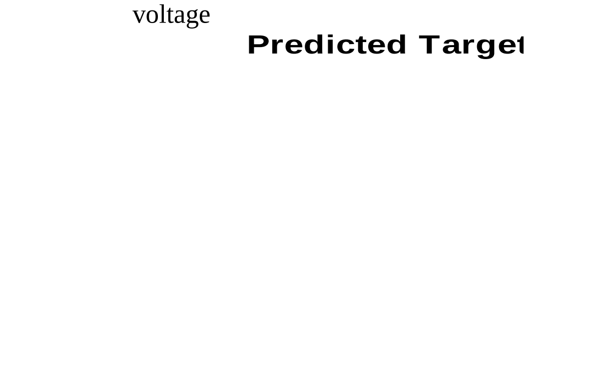

Figure 16. Target current vs. target distance and applied voltage