CONTROLLING POWDER DEPOSITION PROCESS USING FUZZY LOGIC SYSTEMS

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Abstract: This paper presents an application of Fuzzy Logic Systems (FLS) to control a powder deposition process, which is used for depositing coatings on the surface of products. Four input variables: work piece rotation speed, gun to work piece distance, powder volume pressure and gun current and one output variable, the first-pass transfer efficiency was chosen. Fuzzy rules have been introduced in this study. Results showed that FLS can be easily implemented in a company; and has the capability to increase first-pass transfer efficiency, minimize waste, reduce the time involved in selecting the best combination of application variables for coating jobs and improves savings.

Key words: Fuzzy Logic Systems; Powder Coating; Rule-Based Inference.

1. INTRODUCTION

Electrostatic powder coating process works on the principle that opposite charges attraction. The powder composed of resins and pigments is pneumatically fed from a reservoir through a spray gun where the powder gains low amperage, high voltage positive charge. Cleaned parts that are to be painted are electrically grounded so that the positively charged powder particles are strongly attracted to the parts' surface. The powder coated part is then pulled through an oven where the powder melts and fuses into a smooth coating. Powder coating can be done manually or through an automatic system.

This technology is used in many applications such as clear coating on brass fixtures and on aluminum cans (Gill, 1990). In powder coating

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processes, the most crucial questions are how to improve efficiency of powder coating and how to reduce overspray and maximize transfer efficiency while achieving high coating quality. Previous studies showed that parameters related to the powder coating process are adjusted manually and randomly according to the experiences of operators, and it is very difficult to establish a mathematical formula to model the coating process.

This paper presents the design and development of a Fuzzy Logic System (FLS), via a development tool: NEUframe (NEUframe User's Guide) for modelling and controlling the parameters of coating processes. The result obtained shows FLS is an excellent tool for modeling and controlling complex systems that are difficult to model using mathematical approach.

2. PROBLEM DESCRIPTION

The efficiency of a powder application process is indicated by two common terms: (1) System utilization efficiency (STE): ratio of powder applied to powder used (including reclaim) (2) First-pass transfer efficiency (FPTE): the ratio of powder applied to powder sprayed (without reclaim). We are focusing FPTE problem because is the main efficiency used to measure a powder coating system. FPTE describes the productivity of the powder application process.

$$\text{FPTE}(\%) = \frac{\text{amount of powder deposited on part}}{\text{amount of powder sprayed}} * 100$$

Optimizing powder deposited on the work piece is important in achieving higher FPTE, which result in reduced waste and increased savings.

3. FUZZY LOGIC SYSTEM

Fuzzy logic systems have been increasingly applied to wide range of engineering problems since introduced by Zadeh in 1965. Fuzzy Logic modeling is a heuristic method and is suited for systems which require the ability to handle uncertainties and /or approximate reasoning problems. FLS consists of three important procedures: (1) fuzzification; (2) fuzzy inference; and (3) Defuzzification. The system structure is shown in Figure 1. (Wang, 2005; Hopgood, 1998):

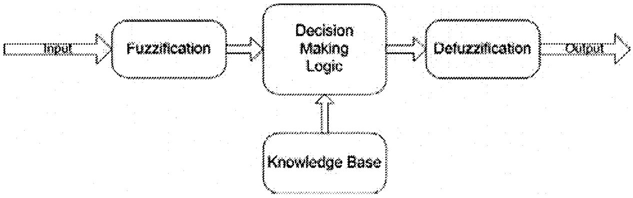

Figure 1. Structure of Fuzzy Logic Systems

4. MEMBERSHIP FUNCTIONS

There are many factors which can affect FPTE. For the problem under review, the four input variables that principally affect the FPTE were selected as inputs: (1) PVP: Powder Volume Pressure (psi); (2) WRS: Workpiece Rotation Speed (r/sec); (3) GPD: Gun to Part Distance (mm); (4) GC: Gun Current (μA). The output variable is PD: Powder Deposition on the work piece. FPTE is easily obtained by dividing Powder Deposition by the amount of powder sprayed. The input variables were divided into three linguistic values: low-, medium- and high-values. To get a more precise result, the output variable was divided into five linguistic values: too low, low, medium, high and too high. All inputs and output investigated in this model use triangular membership functions shown in Table 1.

Table 1. Fuzzy Values for all Variables

Variables	Linguistic Value	Fuzzy Value
PV	Low, Medium, High	(17, 17, 20), (17, 20, 23), (20, 23, 23)
WRS	Low, Medium, High	(1.5, 1.5, 2.25), (1.5, 2.25, 3), (2.25, 3, 3)
GPD	Low, Medium, High	(6, 6, 9), (6, 9, 12), (9, 12, 12)
GC	Low, Medium, High	(40, 40, 50), (40, 50, 60), (50, 60, 60)
PD	Too Low, Low, Medium, High, Too High	(0.82, 0.82, 0.84), (0.82, 0.84, 0.86), (0.84, 0.86, 0.88), (0.86, 0.88, 0.9), (0.88, 0.9, 0.9)

5. DATA ANALYSIS

The work pieces used for the study were 3-piece aerosol containers manufactured from large pre-decorated flat tinplate sheets. A black epoxy polyester gloss was chosen. This is able to produce 60-70 microns coating thickness (Conesa et al, 2004), and when cured gives a glossy surface finish. The 3-piece tinplate aerosol containers were powder coated in the pilot equipment, which utilizes corona charge. During the experiments, 30 cans were sent through the powder booth at various gun to product positions varying from 9 to 23 mm. In all, 135 cans were taken as samples for data analysis. The weights of powder deposited on cans were obtained by measuring the weight of the cans using a microbalance before and after coating. The variations of the four input variables to the output are shown in Figure 2.

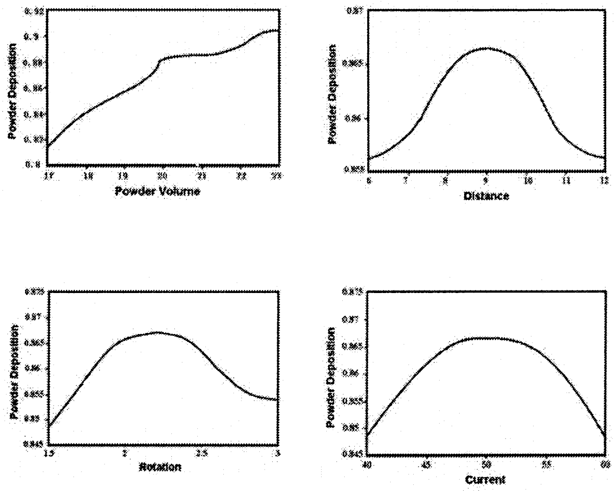

Figure 2. One-dimensional surface view of the four fuzzy input variables

6. DEVELOPING THE DATABASE

The rules for the fuzzy logic were obtained by extracting from the behavior of the process. This approach is preferable because it has the advantage of modeling the behavior of the fuzzy logic model to resemble data diagram of the process. The rule base was modified after a series of testing and simulation to improve the performance of the fuzzy logic system. As the four input variables have three states, there are a total of 3*3*3*3 = 81 rules in the rule base. An example of the rule used to manipulate variables is as follows:

IF Powder volume is High **AND** Work piece rotation speed is Medium **AND** Gun-to-part distance is Medium **AND** Gun current is Low **THEN** Powder deposition on the work piece is Low.

7. RESULTS AND DISCUSSION

To demonstrate the accuracy of this FLS, a sample experimental data input set was chosen and the fuzzy logic model run NEUframe (Figure. 3). The results from the model were then compared with the results obtained from the experiments, which has the same input variables. The outputs predicted by the model matched closely with the plots obtained from the data of experiments at same condition with an average accuracy of 98%. Consequently, the fuzzy logic model performed very well under the conditions investigated.

A three-dimensional surface view indicating the shape of the response variable, powder deposition, given two inputs, rotation speed and powder-volume pressure (psi) has been developed. An optimal powder deposition above 9.0 grams can be achieved if powder-volume pressure (psi) is set at 23 psi and workpiece rotation speed is at 2.25 turns while maintaining gun-to-part distance and gun current at the present levels. The fuzzy-logic based powder coating system thus has the capacity significantly to improve first-pass transfer efficiency by maximizing powder deposition.

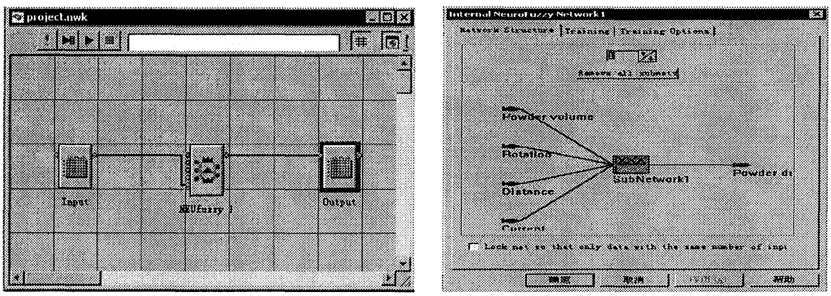

Figure 3. Running Windows of the Development Tool NEUframe

8. CONCLUSIONS

So far, a fuzzy logic model of powder coating system was presented. In powder coating operations, there is the regular need to determine the input variables settings that optimize powder deposition. While each input variable is important in optimizing powder deposition efficiency, it is important to understand how the combination of parameter settings affects coating jobs. A successful model can reduce energy consumption; reduce waste generated and consequently, waste disposal costs; reduce labour and maintenance costs; increase production rates and therefore, reduce reject rates; and increase first-pass transfer efficiency. Because the results derived from the model and results from experiments correlate well, it can be concluded that the model is efficient, and therefore can be used in practice

9. REFERENCES

1. Conesa, C., Saleh, K., Thomas, A., Guigon, A., and Guillot, N., (2004), *Characterization of Flow Properties of Powder coatings used in the Automotive Industry*, Hosokawa Powder Technology Foundation pp 22-106.
2. Gill D. E., (1990), *Powder coatings and their uses, Powder Coating Applications*, Dawson S. and Reddy V., eds., Society of Manufacturing Engineers, Dearborn, Michgam, pp. 52-53
3. Hopgood, A. A., Phillips, H. J., Picton, P. D., and Braithwaite, N. St. J., (1998), Fuzzy logic in a Blackboard System for Controlling Plasma Deposition Processes, *Applied Intelligence in Engineering*, Vol. 12, pp. 253-260.
4. NEUframe User's Guide, www.neusciences.com
5. Wang, K., (2005), *Applied Computational Intelligence to Intelligence Manufacturing Systems,* Advanced Knowledge International (ISBN 0-9751004-9-1).
6. Zadeh, L. A., (1965), Fuzzy Sets, *Information and Control*, Vol. 8, pp. 338-353.