

Optimization of Robotic Spray Painting process Parameters using Taguchi Method

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Abstract: Automated spray painting process is gaining interest in industry and research recently due to extensive application of spray painting in automobile industries. Automating spray painting process has advantages of improved quality, productivity, reduced labor, clean environment and particularly cost effectiveness. This study investigates the performance characteristics of an industrial robot Fanuc 250ib for an automated painting process using statistical tool Taguchi's Design of Experiment technique. The experiment is designed using Taguchi's L25 orthogonal array by considering three factors and five levels for each factor. The objective of this work is to explore the major control parameters and to optimize the same for the improved quality of the paint coating measured in terms of Dry Film thickness(DFT), which also results in reduced rejection. Further Analysis of Variance (ANOVA) is performed to know the influence of individual factors on DFT. It is observed that shaping air and paint flow are the most influencing parameters. Multiple regression model is formulated for estimating predicted values of DFT. Confirmation test is then conducted and comparison results show that error is within acceptable level.

Keywords: Robotic spray painting, Optimization, Taguchi Method, Orthogonal array.

1. Introduction

Spraying process is extensively used in painting applications of automobiles, home appliances etc. In this process liquid paint is atomized and deposited on the target surface. Spray coverage and coating layer thickness are the parameters governing quality of the process. Automating this spray painting process using Robots provides an opportunity for improved quality, productivity, reduced labor, clean environment and particularly cost effectiveness[1,2]. Robotic arms come in many different sizes with different control options. A typical software driven controller can manage color change, provide analog fluid and air control, part queuing, arm homing, conveyor synchronization, path and function editing and simple lead through, and Cartesian teaching methods. With a slim wrist design, the robotic arm can provide 360 degree of roll and 90 degree of pitch and yaw with flexible spatial coverage. Large, complex parts can be painted very effectively with exceptional precision using a robotic arm. A spray gun or bell mounted on a robotic arm provides the advantages of manual application and multi axial movements with much more accuracy and consistency[3,4]. As a result of rapid advancement in related research, much improvement achieved in robot spray painting resulting in better production stability, reduced paint



wastages and energy consumption [5,6]. Further research also identified other factors such as Paint flow rate, shaping air pressure, speed of gun travel, viscosity, surface preparation, paint composition and temperature etc. influencing paint quality in spray painting process [7-10]. Prombanpong et al [1] studied the influences of supplying air pressure, spray time and nozzle size of spray gun on the weight of material used per shot and the dry film thickness obtained. The authors considered material consumption and dry film thickness as the two main indicators for identifying the efficiency of spray coating process. They showed that using a proper spray condition, less material consumption could be obtained as per a given dry film thickness. R. Bhalamurugan et al [2] investigated the performance characteristics of an industrial robot for an automated painting process using Taguchi's L9 orthogonal array (OA). The objective of that experiment was to identify the control parameters for the improved quality of paint coating measured in terms of thickness variation, surface roughness and film adhesion. D.Bharathi et al [1, 2] illustrated the analysis of the various parameters in painting process by experimental design. They used Taguchi's L8 OA to minimize the excess consumption of paint in steel structures and to improve the paint coverage, coating thickness, to reduce the rework, touch-up painting process.

2. Experimental procedure

The experiments were carried out on automated robotic spray painting Fanuc 250ib with a specially designed end-effector with Titanium spray Bell. This is a six axis articulated industrial manipulator. Each axis is servo controlled with resolver or feedback. The payload capacity of the end wrist is 15kg and then reach is 2800mm. The robot is controlled through Fanuc 30ib controller. The experiments were conducted based on the ISO 9001 - ISO/TS 16949 Standards.

The robotic spray painting is affected by different parameters like paint flow, shaping air, turbine speed, high voltage and viscosity. In the present work the output quality of robotic spray painting is measured in terms of Dry film thickness(DFT). The DFT is measured in microns using Elcometer. The experiment was designed using Taguchi's Design of experiment technique. To arrive at the control parameters majorly affecting the process, brain storming session with the experienced workers on the shop floor was conducted. Later based on these data cause and effect diagram was drawn[12]. Then it was concluded that paint flow, shaping air and viscosity were the main parameters which were affecting the DFT. Paint flow and shaping air was measured by robot itself by using digital meter and viscosity was measured by Fordcup in seconds. Usually the levels for these parameters are selected, based on the previous experience or from hand book values[2]. The target process was observed continuously for a week, related values were noted down and based on discussion with the experienced workers involved in the process levels for all control parameters were finalized and given in Table 1.

Table 1. Design Factors

| SL.NO | Control factor | Units | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|-------|----------------|--------|---------|---------|---------|---------|---------|
| 1 | Paint flow | cc/min | 200 | 250 | 300 | 350 | 400 |
| 2 | Shaping air | bar | 2 | 4 | 6 | 8 | 10 |
| 3 | Viscosity | sec | 16 | 16.5 | 17 | 17.5 | 18 |

2.1 Design of experiments

For designing the experiments an appropriate OA needs to be selected, based on total number of degrees of freedom (DOF) [13]. Since the present study considers 3 factors with 5 levels, total number of DOF = (No of levels - 1) x No of Main factors = (5 - 1) x 3 = 12 neglecting the interaction the factors is. Therefore minimum number of experiments = Total number of DOF + 1. Therefore suitable OA is the one which has number of experiments equal to or greater than total number of DOF. Hence L25 OA was selected and physical layout of the experimentation is given in Table 2.

Table 2. Physical layout of experimental design

| Experiment No. | Paint flow(cc/min) | Shaping air(bar) | Viscosity(sec) |
|----------------|--------------------|------------------|----------------|
| 1 | 200 | 2 | 16.00 |
| 2 | 200 | 4 | 16.50 |
| 3 | 200 | 6 | 17.00 |
| 4 | 200 | 8 | 17.50 |
| 5 | 200 | 10 | 18.00 |
| 6 | 250 | 2 | 16.50 |
| 7 | 250 | 4 | 17.00 |
| 8 | 250 | 6 | 17.50 |
| 9 | 250 | 8 | 18.00 |
| 10 | 250 | 10 | 16.00 |
| 11 | 300 | 2 | 17.00 |
| 12 | 300 | 4 | 17.50 |
| 13 | 300 | 6 | 18.00 |
| 14 | 300 | 8 | 16.00 |
| 15 | 300 | 10 | 16.50 |
| 16 | 350 | 2 | 17.50 |
| 17 | 350 | 4 | 18.00 |
| 18 | 350 | 6 | 16.00 |
| 19 | 350 | 8 | 16.50 |
| 20 | 350 | 10 | 17.00 |
| 21 | 400 | 2 | 18.00 |
| 22 | 400 | 4 | 16.00 |
| 23 | 400 | 6 | 16.50 |
| 24 | 400 | 8 | 17.00 |
| 25 | 400 | 10 | 17.50 |

3. Experimental results and Discussion.

Experiments were conducted based on Taguchi's L25 OA and collected data was analyzed using statistical software tool Minitab 17.0. Table 3 shows the Signal to noise ratio (SNR) for DFT obtained in each experiment. Apparently values in experiment no. 1 result in optimal DFT.

Table 3. Experimental results with computed S/N ratio.

| Experiment No. | Paint flow(cc/min) | Shaping air(bar) | Viscosity(sec) | S/N Ratio |
|----------------|--------------------|------------------|----------------|-----------|
| 1 | 200 | 2 | 16.00 | 35.2686 |
| 2 | 200 | 4 | 16.50 | 34.9638 |
| 3 | 200 | 6 | 17.00 | 34.4855 |
| 4 | 200 | 8 | 17.50 | 33.9794 |
| 5 | 200 | 10 | 18.00 | 33.6248 |
| 6 | 250 | 2 | 16.50 | 34.8073 |
| 7 | 250 | 4 | 17.00 | 34.4855 |
| 8 | 250 | 6 | 17.50 | 34.1514 |
| 9 | 250 | 8 | 18.00 | 33.9794 |
| 10 | 250 | 10 | 16.00 | 33.6248 |
| 11 | 300 | 2 | 17.00 | 34.8073 |
| 12 | 300 | 4 | 17.50 | 34.4855 |
| 13 | 300 | 6 | 18.00 | 33.4420 |
| 14 | 300 | 8 | 16.00 | 32.8691 |
| 15 | 300 | 10 | 16.50 | 32.6694 |
| 16 | 350 | 2 | 17.50 | 34.1514 |
| 17 | 350 | 4 | 18.00 | 33.8039 |
| 18 | 350 | 6 | 16.00 | 33.4420 |
| 19 | 350 | 8 | 16.50 | 33.2552 |
| 20 | 350 | 10 | 17.00 | 33.0643 |
| 21 | 400 | 2 | 18.00 | 33.6248 |
| 22 | 400 | 4 | 16.00 | 33.9794 |
| 23 | 400 | 6 | 16.50 | 33.8039 |
| 24 | 400 | 8 | 17.00 | 33.0643 |
| 25 | 400 | 10 | 17.50 | 33.2552 |

Table 4 presents response table for SNR's. The rank values provide the level of influence of input factors on response variable. Thus Shaping air influences DFT to the maximum extent next comes the paint flow and viscosity has the least effect. Same is presented in percentage in the last column of ANOVA results shown in Table 5. P-value in the ANOVA table tells which factors are significant on DFT. Paint flow and shaping air are significant factors affecting DFT because their P-values are less than 0.05 and viscosity has no effect on DFT. R^2 value measures degree of fit. As R^2 value approaches unity, fitted model fits the actual data better. It also tells how much performance characteristics are affected by unaccountable factors[2]. 79.91% of variability in data can be explained by present R^2 value. Thus it confirms that present model presents fairly good explanation of relationship between input factors and the response variable.

Table 4. Response Table for Signal to Noise Ratios

| Level | Paint flow | Shaping air | Viscosity |
|-------|------------|-------------|-----------|
| 1 | 34.46 | 34.47 | 33.84 |
| 2 | 34.21 | 34.28 | 33.90 |
| 3 | 33.52 | 33.86 | 33.92 |
| 4 | 33.54 | 33.43 | 33.94 |
| 5 | 33.55 | 33.25 | 33.69 |
| Delta | 0.94 | 1.22 | 0.24 |
| Rank | 2 | 1 | 3 |

Table 5. Result of Analysis of variance(ANOVA) for response variable

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | %contribution |
|-------------|----|---------|---------|---------|---------|---------------|
| Paint flow | 1 | 106.580 | 106.580 | 36.78 | 0.000 | 30.78 |
| Shaping air | 1 | 176.720 | 176.720 | 60.98 | 0.000 | 51.05 |
| Viscosity | 1 | 2.000 | 2.000 | 0.69 | 0.415 | 0.57 |
| Error | 21 | 60.860 | 2.898 | | | |
| Total | 24 | 346.160 | | | | |

R-sq = 82.42% R-sq(adj) = 79.91%

Notes: DF, Degree of Freedom; Adj SS, Adjusted Sum of Squares; Adj MS, Adjusted Mean Squares;

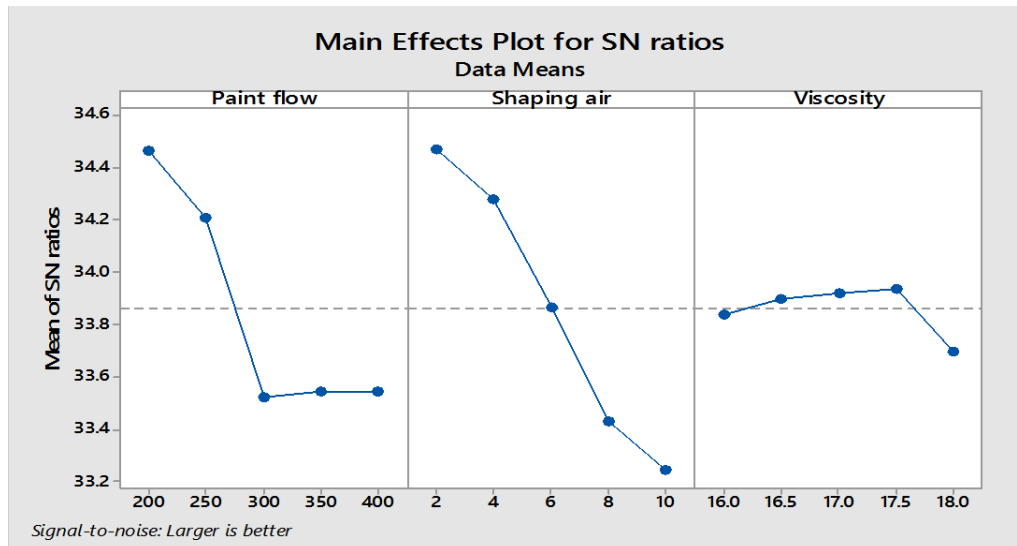


Fig 1. Main effect plot for S/N ratios

Fig 1 depicts main effect plot for S/N ratio. It shows that S/N ratio decreases with the increase in paint flow up to 3rd level. After that increase in paint flow has no effect on DFT. Shaping air has inverse relation with DFT. Up to 4th level viscosity has no much effect on DFT, after that it sharply reduces with the increase in DFT. Since it is desirable to have maximum S/N ratio, as per larger the better option, SN ratio graph depicts that maximum DFT is achieved at 200cc/min of paint flow, 2 bar of shaping air and 16 to 17.5secs of viscosity. Because viscosity slope changes are very less from 16 to 17.5.

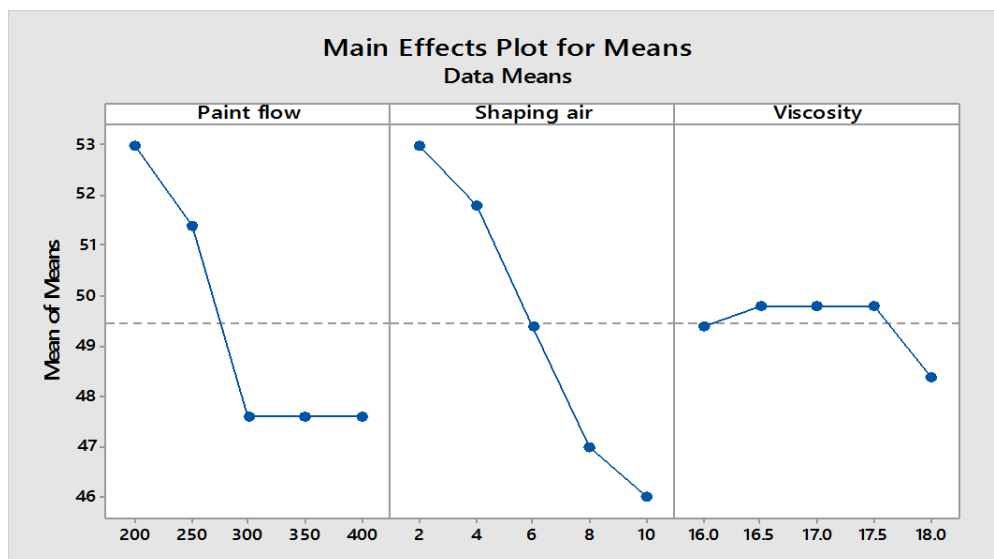


Fig 2. Main effect plot for Means

Fig 2 portrays principle impact plot for DFT. It demonstrates that control factors have similar influence on DFT as shown by S N ratio plot

4. Confirmation Test

Confirmation test was conducted to evaluate the design parameters influencing automated spray painting process. For this control parameters with the optimal levels of 200cc/min of paint flow, 2bar of shaping air and 17.5secs of viscosity were considered. The results of conducted experiments were compared with the predicted value obtained from statistical analysis. The comparison showed that confirmation test results were very close with the predicted values and the maximum error percentage was within 10%. Table 6 shows the confirmation test results.

Table 6. Confirmation test results

| Experiment no | Levels | | | Dry film Thickness | | Error % |
|---------------|------------|-------------|-----------|--------------------|-----------|---------|
| | Paint flow | shaping air | viscosity | Experiment result | Predicted | |
| 1 | 190 | 2 | 16 | 56 | 56.81 | 1.44 |
| 2 | 210 | 4 | 16.5 | 55 | 56.22 | 2.21 |
| 3 | 220 | 2 | 17 | 53 | 53.85 | 1.60 |
| 4 | 230 | 4 | 17.5 | 54 | 55.24 | 2.29 |
| 5 | 240 | 2 | 16 | 52 | 52.87 | 1.67 |

5. Conclusion

Robotic spray painting process of plastic component was successfully examined in this work using Taguchi's DOE. The objective was to maximize DFT. Three factors were considered namely; Paint flow, Shaping air and Viscosity. Out of these, most influencing factors, Paint flow and Shaping air were explored and optimized to achieve most favorable value of response variable, DFT using L25 OA.

Anova results showed that DFT was most influenced by shaping air with 51.05% and paint flow with 30.78% contribution respectively. Also viscosity was found to be non significant factor. Later confirmation test was conducted with the optimal values of designed parameters. When confirmation experimental results were compared with predicted model values the error percentage was falling within 10%.

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