Influence of the Normal Angle on the Thickness Uniformity for the Concave Combination with Two Flat Patches

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Abstract: Due to the influence of the normal angle on the thickness uniformity for the concave combination with two flat patches, considering the paint spread impact on the thickness uniformity, a new spray trajectory optimization scheme for the concave combination with two flat patches is developed. The paint thickness deviation from the required paint thickness is optimized by modifying the paint gun velocity and the distance between adjacent trajectories. The results of simulations have shown that trajectory planning algorithm is effective.

Introduction

In order to promote the paint thickness uniformity on a product, many scholars, at home and abroad, developed a lot of researches in the spray model modeling and automated trajectory planning method. At present, automated trajectory planning has been widely studied for the complex free surface. H. P. Chen [1, 2] et al developed a spray trajectory planning method based on vertical spray technology for the complex free surface. But they did not report how to deal with the thickness uniformity on the horn place of complex free surface. C. D. Conner et al. [3] developed an automatic trajectory planning method for simple automotive surfaces. But their method cannot suitable for paint gun trajectory optimization of large complex free surfaces. D. A. Zhao [4] et al developed a spray trajectory generation method for the free-form surface in basis of H. P. Chen’s studies. However, their studies ignored the paint spread that influences the thickness uniformity at the junction of two patches.

In order to the thickness uniformity for the concave combination with two flat patches after the complex free surface partitioned. In this paper, considering the paint spread impact on the thickness uniformity, a new spray trajectory optimization scheme for the concave combination with two flat patches is developed such that the influence of the normal angle on the thickness uniformity for the concave combination with two flat patches are obtained.

Complex Free Surface Partition

The complex free surface has some characteristics, such as complex connected region and large curvature of some points. In order to simplify the spray trajectory planning so that the spray trajectory planning feasible and effective, the complex free surface is usually divided into several patches [5]. Each patch can be seen as a flat, and it is simply connected. So the spray trajectory planning for complex free surface is transformed into the spray trajectory planning for the flat and its combination, where the trajectory optimization for flat combination is a difficulty.

Spray Trajectory Optimization for the Concave Combination between Two Flat Patches

The Paint Thickness at the Junction of Two Patches. Here the PA-PA case is used to planning spray trajectory between two flat patches, as shown in Figure.1. Consider the influence of paint diffusion from the neighboring patch on the paint thickness optimization, the distance between the intersection line and the boundary of paint diffusion can be expressed as:

$$X(h) = \frac{(R-h)\cos(q/2)}{\cos(q/2-a)} \quad , \qquad h \le R. \tag{1}$$

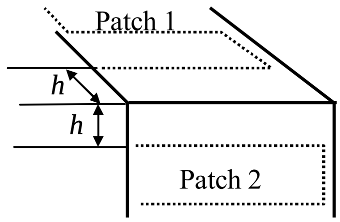

Figure.1 Trajectory planning between two patches in PA-PA case

Paint diffusion will affect the optimized thickness distribution on the neighboring patch each other. Assume the paint thickness is T_1(x) on the patch 1, according to the area magnification theorem of differential geometry [6] and the paint thickness growth principle, as shown in Figure 2, the paint thickness that diffuse on the patch 2 can be expressed as follows:

$$T_{1^*}(x) = T_1(x)\left(\frac{H}{H_s}\right)^2 \frac{\cos(a - q_S)}{\cos q_S} \tag{2}$$

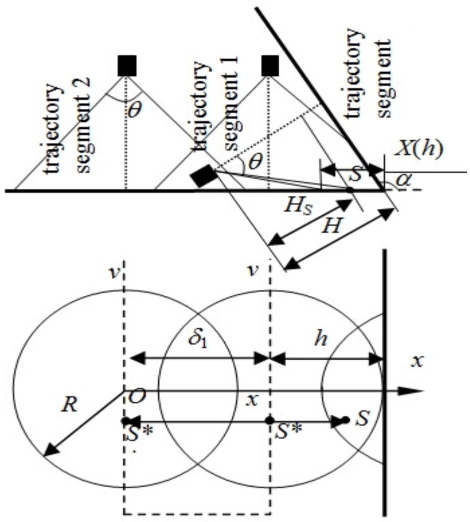

Figure.2 Paint thickness superposition at the intersection part

Where H is the vertical distance between the spray gun nozzle and the patch, namely the spray height; H_S is the distance of the any point S to the spray gun nozzle along the axes direction of spray gun within the fan angle; q_S is the angle between the line from the point S to the spray gun nozzle and the spray gun axis.

Assume the paint from the patch 2 diffuses within N+1 segments range of spray trajectory on the patch 1. So the value in the range of $X(h)$ is:

$$X(h) \in [0, \sum_{i=1}^{N} d_i + h] \tag{3}$$

Where d_i is the distance between the i segment and the i+1 segment.

By the superimposed rule of the paint thickness, as the $X(h)$ change, the paint thickness superposition model will change accordingly. And the corresponding variation nodes are:

$$\begin{aligned}&[X_1, X_2, \mathbf{L}, X_J]^{\mathrm{T}} \\ &= [d_1 + h - R, h + R, h + d_1, \mathbf{L}, \sum_{i=1}^{N} d_i + h - R, \sum_{i=1}^{N} d_i - d_N + h + R, \sum_{i=1}^{N} d_i + h]^{\mathrm{T}}\end{aligned} \quad , J=3N. \tag{4}$$

Optimization Model of Thickness Uniformity. Here for N = 1 as an example, so to optimize the paint thickness in the range [0, d_1+h]. The paint thickness distribution is symmetric with respect to the intersection line of two flat patches, as shown in figure 2. In order to obtain the best paint thickness uniformity at the intersection part, the optimization objective function that based on the minimum variance between the paint thickness of any point S and the ideal thickness is established. According to the document [5], the objective function can be represented as:

$$E(h,v_1,\mathbf{L},v_N,d_1,\mathbf{L},d_N)=\min\int_0^{\sum_{i=1}^{N}d_i+h}(T_S(x,h,v_1,\mathbf{L},v_N,d_1,\mathbf{L},d_N)-T_d)^2\,dx$$
$$\text{s.t}\begin{cases}R\le d_i\le 2R\\ X(h)\in[0,\sum_{i=1}^{N}d_i+h]\end{cases}\qquad(5)$$

Where x is the distance between the any point S and its subpoint on the trajectory segment 2; h is the distance between the trajectory segment 1 and the intersection line; T_d is the ideal paint thickness.

For the solution problem of objective function with constraint and multivariate, because $T_S(x,v_1,...,v_N, d_1,...,d_N)$ change with $X(h)$, $X(h)$ is the function of variable h. So combine with the pattern search method to analyze the relationship between the optimized $X(h)$ and the constraint condition, thus the optimized results are outputted. The specific steps are as follows:

Step.1: order initial values v_i=v_0, d_i=d_0, i=1, N=1, J=3N, constraint condition $X(h)\in[0, X_i]$.

Step.2: the pattern search method is used to solve the formula (5), then v_i, d_l and h are obtained, put the h into the formula (1), if $X(h)\in[0, X_i)$, output optimal values, otherwise next.

Step.3: order i=i+1, $X(h)\in[X_{i-1}, X_i]$, if i>J, next, otherwise the pattern search method is used to solve the formula (5), then [v_1 v_2 ...v_N], [d_1 d_2 ...d_N] and h are obtained, put the h into the formula (1), if $X(h)\in[X_{i-1}, X_i)$, output optimal values, otherwise turn step.3.

Step.4: order N=N+1, i=i-1, turn step.3.

Simulation

Assume T_d=50μm, the allowable thickness error $\triangle T_d$ is 10μm. The spray height H and the spray radius are 150 mm and 50 mm respectively, and θ=36.9º. The paint deposition rate [13] is obtained by fitting to the experimental data on the flat (unit: $\mu m.s^{-1}$): $f(r)=0.1(R^2-r^2)$. The optimized spacing distance d_0 and the spray velocity v_0 are 60.8mm and 323.2mm. s^{-1} separately.

Assume the normal angle a changes within 0º-120º. According to the formula (1), when a>108.5º, the vertical spray technology cannot make paint to cover at the junction of two patches, but the dip spray technology can be used to processing. For the angle range within 0º-100º, the vertical spray technology is used to optimize spray trajectory at the junction of two patches. Optimized spray trajectory parameters under the different angle a can be obtained, as shown in table 1:

Tab.1 Optimized parameters for concave combination in the vertical spray technology

a(º)	h(mm)	v_1($mm.s^{-1}$)	d_1(mm)	v_2($mm.s^{-1}$)	d_2(mm)
10	30.8	320.9	60.9	-	-
20	30.7	320.8	60.9	-	-
30	30.4	321.6	60.8	-	-
40	29.8	323.3	60.7	-	-
50	28.8	326.1	60.5	-	-
60	28.7	332.5	60.1	-	-
70	28.4	336.3	59.9	-	-
80	12.9	402.3	69.4	-	-
90	19.6	340.5	69.5	335.0	60.0
100	32.7	275.6	68.4	322.2	61.4

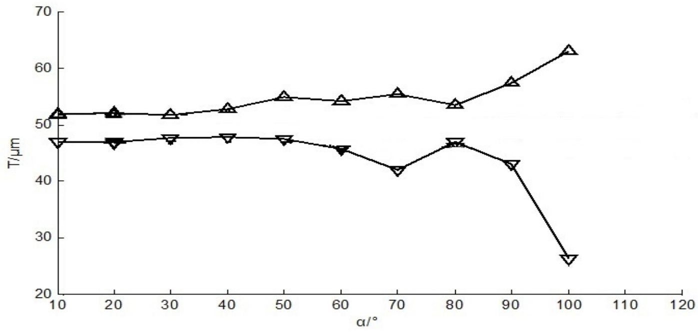

Figure.3 Influence of the normal angle on the minimum/maximum thickness for the concave combination

In the table 1, "-" is the default value. These expresses the spray velocity and the spacing distance are 323.2 mm. s^{-1} and 60.8mm separately. According to the optimized spray trajectory parameters, then the paint thickness extremum at the intersection part can be obtained, as shown in the solid lines of the figure 4. If the dip spray technology is used, the paint thickness extremum are represented as the dotted lines of the figure 4. By comparison, the dip spray process can get better thickness uniformity than the vertical spray technology.

Conclusions

Simulation results showed that trajectory planning algorithm is effective. the influence laws of normal angle on paint thickness uniformity can used to select reasonable spray technology for a complex free surface with multiple patches. Therefore, this method can used to improve the efficiency of spray trajectory for off-line trajectory generation system.

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