Modeling of polishing process for electric stainless-steel kettle

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Abstract: The market of stainless electric steel kettles is growing significantly, but the main mechanism for polishing kettles via traditional handwork operations limits the growth of electric kettle manufacturing. Based on the successful multi-tool automatic polishing system for electric stainless steel kettles, regression analysis and orthogonal tests were employed to construct a polishing process model, with a purpose to improve the automatic polishing technology for electric stainless steel kettles. The model reveals the relationship between the surface roughness and processing parameters including grinding depth, abrasive tangent speed, workpiece rotating speed and axial feeding speed. Simulation and experimental results are in agreement, which shows that this modeling method is feasible in practice, and it can also be used as a guidance for planning automatic polishing process of electric stainless-steel kettles.

Keywords: polishing process; regression analysis; orthogonal test; simulation

1 Introduction

With the improvement of people’s living standards, fashionable and convenient electric stainless steel kettles are becoming popular family appliances, and will contribute immense market value to the service provider. Polishing is the last working procedure in stainless steel electric kettle’s manufacture, it can not only reduce the surface roughness but prettify exterior quality of the workpiece. The material NTKD-11 stainless steel is frequently used to manufacture kettles, which has the characteristics of low rigidity, high toughness, less thermal conductivity and thin wall, so it’s hard to be polished by an automatic polishing machine. Besides, research on automatic polishing technology for electric stainless steel kettles is scarce, and the existing equipment still cannot meet the polishing requirements. As a result, most of the domestic enterprises still polish the kettle by handwork, which is associated with a lot of disadvantages, such as unstable quality, low efficiency, etc. In addition, much dust and noise given off during polishing process are harmful to workers’ health. Therefore, research on automatic polishing technology for stainless steel kettle becomes particularly important.

The efficiency of automatic polishing depends on two factors: one is the design of automatic polishing equipment; and the other is the planning of the automatic polishing process. Based on a successfully developed automatic polishing machine for stainless steel kettles, in this work we proposed novel models for the polishing process using regression analysis and orthogonal test which avail the selection of required parameters and interpretation of the relationships between processing parameters and polishing quality. Experimental results agreed well with...
the simulation data, which verifies the validity of the proposed process modeling.

2 Automatic polishing system

A typical automatic polishing system for stainless steel kettles consists of a computer, a controller and a multi-tool polishing machine. First, the system collects information about the polishing path with a teaching method, and generates a cutter location data (CL data) table. Next, according to the CL data table, the computer sends instructions to the controller via RS232 serial ports to control the multi-station and multi-tool equipment for polishing. The multi-station and multi-tool equipment is shown as Fig. 1. Specifically, there are 4 axles in this machine, the motion of one abrasive tool which is equipped on the top of the machine can make the other three abrasive tools simultaneously move along the radial. The work table is on the bottom of the machine. Three work pieces are distributed symmetrically on the work table, the mechanism propels the three work pieces to work up and down, swinging and rotating simultaneously. This machine uses the technology of multi-axis linkage so as to polish three work pieces at the same time. The efficiency is much higher than that of manual polishing.

3 Polishing process modeling

Polishing is a complex process, and the factors that influence the polishing quality are numerous and intricate. As for an automatic polishing system for stainless steel kettles, the influencing factors mainly include abrasive tangent speed $V_t$, work piece rotating speed $n_w$, work piece axial feeding speed $V_f$ and grinding depth $a_p$. The polishing quality is usually measured by the surface roughness $R_a$, the relation between the roughness and influencing factors can be described by the following equation:

$$R_a = k a_p V_t^{\beta_1} n_w^{\beta_2} V_f^{\beta_3}$$

(1)

where $k, \beta_1, \beta_2, \beta_3$ and $\beta_4$ are the model parameters to be estimated from experimental data.

Eq. (1) is a nonlinear function. Taking logarithm on its both sides leads to a linear function as follows.

$$\log R_a = \log k + \beta_1 \log a_p + \beta_2 \log V_t + \beta_3 \log n_w + \beta_4 \log V_f.$$  

(2)

Set $y = \log R_a$, $b_0 = \log k$, $b_1 = \beta_1$, $b_2 = \beta_2$, $b_3 = \beta_3$, $b_4 = \beta_4$, $b_5 = \beta_1$, $x_1 = \log a_p$, $x_2 = \log V_t$, $x_3 = \log n_w$, and $x_4 = \log V_f$. Considering the experimental error, the linear regression equation of Eq. (1) is refined as

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + e,$$

(3)

where $b_0, b_1, b_2, b_3$ and $b_4$ are undetermined regression coefficients respectively; $e$ is the experimental error.

To explore the effects of processing parameters with a smallest number of experiments, the method of orthogonal test was used in this work. The surface roughness $R_a$ was used as the test metric, $a_p, V_t, n_w$ and $V_f$ were the test factors, and each was tested on three levels as listed in Table 1. The orthogonal array $L_9(3^4)$ was used in this experiment. The sponge wheel swathed by green non-woven fabrics abrasive belt was made as the buff wheel, and a SJM100 stainless steel kettle with NTKD-11 material was tested by multi-tool automatic polishing machine. The experimental results are shown in Table 2.

<table>
<thead>
<tr>
<th>Level</th>
<th>$a_p$/mm</th>
<th>$V_t$/(m s$^{-1}$)</th>
<th>$n_w$/(r min$^{-1}$)</th>
<th>$V_f$/(m min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.003</td>
<td>14.7</td>
<td>20</td>
<td>0.150</td>
</tr>
<tr>
<td>2</td>
<td>0.006</td>
<td>22.0</td>
<td>30</td>
<td>0.187</td>
</tr>
<tr>
<td>3</td>
<td>0.008</td>
<td>26.4</td>
<td>35</td>
<td>0.250</td>
</tr>
</tbody>
</table>

Notes: $a_p$ is the grinding depth; $V_t$ is the abrasive tangent speed; $n_w$ is the work piece rotating speed; and $V_f$ is the work piece axial feeding speed.
Table 2  Orthogonal test results of surface roughness $R_a$ with test factors grinding depth $a_p$, abrasive tangent speed $V_t$, work piece rotating speed $n_w$ and the work piece axial feeding speed $V_f$ at 3 different levels

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Level of test factor</th>
<th>$R_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 1 1 1</td>
<td>0.083</td>
</tr>
<tr>
<td>2</td>
<td>1 2 2 2</td>
<td>0.080</td>
</tr>
<tr>
<td>3</td>
<td>1 3 3 3</td>
<td>0.082</td>
</tr>
<tr>
<td>4</td>
<td>2 1 2 3</td>
<td>0.085</td>
</tr>
<tr>
<td>5</td>
<td>2 2 3 1</td>
<td>0.076</td>
</tr>
<tr>
<td>6</td>
<td>2 3 1 2</td>
<td>0.079</td>
</tr>
<tr>
<td>7</td>
<td>3 1 3 2</td>
<td>0.084</td>
</tr>
<tr>
<td>8</td>
<td>3 2 1 3</td>
<td>0.081</td>
</tr>
<tr>
<td>9</td>
<td>3 3 2 1</td>
<td>0.078</td>
</tr>
</tbody>
</table>

The results of regression coefficients of Eq. (3) were obtained as follows: $b_0=-0.915 21$, $b_1=0.012 84$, $b_2=-0.101 06$, $b_3=0.007 09$, and $b_4=0.088 877$.

Eq. (3) can be rewritten as

$$ y = -0.915 21 + 0.012 84 x_1 - 0.101 06 x_2 + 0.007 09 x_3 + 0.088 877 x_4 . $$  

Consequently the empirical formula of roughness $R_a$ is

$$ R_a = 0.12 a_p^{0.012 84} V_t^{0.007 09} n_w^{0.007 09} V_f^{0.101 06} . $$  

4 Simulation and experiment

The orthogonal test indicates that the best polishing quality was achieved with $a_p=0.006$ mm, $V_t=22$ m s$^{-1}$, $n_w=35$ r min$^{-1}$, and $V_f=0.15$ m min$^{-1}$. The single factor experiment was performed to verify the feasibility of this model and simulation was conducted following Eq. (6) to compare with the experimental results. The experiment equipment and work pieces are the same as those in the aforementioned orthogonal test.

As we can see from Fig. 2, with the growth of the grinding depth, the surface roughness increases only a little; whereas in Fig. 3, the surface roughness decreases with the increment of the abrasive tangent speed, approximately in direct proportion. Fig. 4 shows that the influence of work piece rotating speed is not obvious, given that the lower the work piece rotating speed the less the surface roughness. Fig. 5 shows that the surface roughness increases along with the increase of axial feeding speed.
The axial feeding speed and abrasive tangent speed have an important influence on the surface roughness, whereas the grinding depth and work piece rotating speed only slightly affect the surface roughness. The experimental results agree well with the simulation, which verifies that the proposed model is feasible and correct.

5 Conclusions

A model is established for polishing process of stainless steel kettles by using regression analysis. The regression coefficient is attained through the orthogonal tests, and the empirical equation of stainless steel kettle surface roughness with abrasive belt polishing obtained. The experiment results show that the surface roughness is related to the grinding depth, workpiece rotating speed, axial feeding speed and the abrasive tangent speed. The axial feeding speed and abrasive tangent speed influence the surface roughness remarkably, while the grinding depth and workpiece rotating speed only slightly affect the roughness. The coincidence between simulation and experiment indicates that the polishing process modeling with regression analysis is feasible and correct, and it also provides guidance for running the automatic polishing process of stainless steel kettles and similar machining processes.

References


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