Investigation of Effective Parameters on the Traverse of Root of the Gas Turbine Blade by Design of Experiments

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Abstract: - Creep feed grinding is widely used in manufacturing superalloy materials. The main objectives of this research deal with the influences of major process parameters and their interactions of creep feed grinding process such as wheel speed, workpiece speed, grinding depth and dresser speed on the traverse of gas turbine blade by design of experiments using design of experiments (DOE). Experimental results are analyzed by analysis of variance (ANOVA) and empirical model of traverse is developed. It is found that increasing the wheel speed, workpiece speed and width of cut and decreasing the dresser speed causes suitable dimensional changes for the traverse of root with good tolerance.

Key-Words: - Creep feed grinding, Traverse, Analysis of variance, Regression, Interactive effect.

1 Introduction

Grinding has traditionally been associated with small rates of material removal and fine finishing operations. Using an approach known as creep-feed grinding (Fig. 1), a large-scale metal removal similar to milling can be achieved. Using this approach, higher material removal rates can be performed by selection of higher depth of cut and lower workpiece speed. The correct selection of the cutting conditions and the wheel specifications can provide a greater material removal rate and a finer surface quality. One of the most important applications of creep-feed grinding is the production of the aerospace parts used in jet engines such as turbine vanes, and blades where parts should have high strength to the fatigue loads and creep strains. These parts are made from nickel-based super-alloys such as Inconel, Udiment, Rene, Waspaloy, and Hastelloy. They provide higher strength to weight ratio, and maintain high resistance to corrosion, mechanical thermal fatigue, and mechanical and thermal shocks [1].

A. Vafaeesefat modeled and predicted the grinding forces of the creep feed grinding of superalloy materials using the neural network. This model was then used to select the working conditions (such as depth of cut, the wheel speed and workpiece speeds) to prevent the surface burning and to maximize the material removal rate. The results showed that the combined neural network and an optimization system are capable of generating optimal process parameters [1]. S.-B. Wange et al. [2] provided a thermal model that focused on the heat transfer to the fluid, workpiece and grain for creep feed grinding. In their model, the conduction effect in the moving direction of the workpiece was considered which was found to be very significant especially for creep feed grinding. Moreover, the thermal partition ratios to the workpiece, fluid and grain were well defined and discussed. The results revealed that the cooling effect of the fluid is more crucial especially at larger grinding depth. Hann [3], Malkin and Anderson [4], Malkin [5], Rowe and Morgan [6] derived thermal partition and workpiece temperature in dry grinding that failed to take into account the cooling effect of the fluid. Lavine et al. [7] presented a conical grain model, with grain slope set to one. Lavine and Jen [8] derived a separate thermal model among the fluid, wheel and workpiece to predict the occurrence of boiling. S.-B. Wange et al. [9] depicted that the grinding energy when the fluid begins to cause boiling is defined as the critical grinding energy for the workpiece burning. The results showed that the workpiece burning can be predicted or evaluated so as to avoid the working conditions of burning occurrence. Shafto et al. [10] proposed that workpiece burning could be explained by the phenomenon of fluid film boiling. Ohishi and Furukawa [11] derived the relationship between the grinding heat flux and grinding zone temperature at burning using the fraction of the grinding energy entering into the workpiece at 10%. S.-B. Wange et al. [12] modeled the grinding force of the creep feed grinding by using the improved back propagation neural (BPN) network in view of the avoidance of the workpiece burning. The results showed that the grinding energy can be accurately predicted by the application of the grinding force model and that a larger size of wheel is available to have a better working efficiency. Traverse is one of
the important geometrical dimensions in root of gas turbine blade that has high effect in correct assembly of blade on disk of turbine. If this important dimension isn't controlled correctly and be higher than from its tolerance (within 0.062), the blade can't assembly on the disk of turbine. Fig. 2 shows the gas turbine blade. Also Fig.3 illustrates the traverse that is one of the important geometrical dimensions in root of gas turbine blade. In this research, the influences of major process parameters and their interactions of creep feed grinding process such as wheel speed, workpiece speed, grinding depth and dresser speed on the traverse of gas turbine blade by design of experiments using design of experiments (DOE). It is desirable to know the effects of the major parameters and interactive influences among the process parameters on traverse and relationship between traverse and process parameters to obtain the best conditions of parameters for optimum production. For modeling and determining the influences of main parameters and interaction effects among parameters of the process on traverse, design of experiments method (DOE) has been employed. The DOE is a statistical method which is used to find the significance of interactive effects among variables and relations among process parameters using variance analysis. Finally, using this model and suitable traverse, input parameters has been achieved for optimum production.

2 Description of Material

We have chosen Inconel 738 LC supper alloy as experimental sample. This supper-alloy provide higher strength to weight ratio, and maintain high resistance to corrosion, mechanical thermal fatigue, and mechanical and thermal shocks. The chemical composition of this supper-alloy is presented in Table 1.

Table 1: The chemical compositions of Inconel 738 LC supper-alloy

<table>
<thead>
<tr>
<th>Element</th>
<th>Min</th>
<th>Max</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.09</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>15.7</td>
<td>16.3</td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>3.2</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>3.2</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>(Al+Ti)</td>
<td>6.5</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.007</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>Zr</td>
<td>0.03</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>1.5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td></td>
<td>Bal.</td>
</tr>
</tbody>
</table>
3 Experimental Modeling

3.1 The output parameters
Output parameter, traverse measured in terms of mm with inside micrometer 0-25, 0.01 mm precision.

3.2 The input parameters
Input parameters were selected from the various parameters of creep feed grinding process such as the properties of the work piece material, tools, dresser rotational speed, rigidity of machine tools and type of coolant. The selected parameters are:
- The wheel speed.
- The workpiece speed.
- The grinding depth.
- The dresser speed.

3.3 The experiment conditions
Grinding wheel type was Strato/Tyrolit (F13A70FF1) and coolant type was Cutzol zt 130 (oil Canada).

3.4 The experimental design
It is difficult and expensive to perform all experiments. The DOE method can be employed as an efficient technique to accomplish the suitable and necessary experiments with high accuracy. To investigate main and multiple interactions between parameters [13], in this study, a fractional-factorial design was employed with two levels for each parameter (+,-), quadrant fraction with resolution (IV).

Since we have several steps of grinding to accomplish the grinding of root, steps of grinding are divided to three sections (P1, P2, and P3) and in each section, we use constant grinding depth. Table 2 shows the input parameters of the process. The procedure includes 16 experiments. Since the considered levels for each of the input parameters are two levels, the number of experiments is conducted to determine whether three levels is necessary for each parameter or not which is called the center points. If these points were recognized as the effective points by the analysis of variance, then the experiments should be performed in three levels. Table 3 indicates the center points.

This subject has to attend that we use absolute value of difference between the measured dimensions and nominal dimension of traverse in statistical analysis. Therefore using design of experiments and ANOVA analysis, according to the input parameters, this absolute value is minimized.

4 Analysis of the experimental results
The analysis of variance (ANOVA) is a statistical method to investigate the importance and effect of the parameters. After statistical calculations and implementation of the F-test on the experimental data by ANOVA, probability values of each parameter are extracted from the table of variance analysis. The risk level as considered as 0.05 for the ANOVA.

Once the experimental results are obtained, the coefficients and analysis of variance (ANOVA) are then calculated with MINI TAB software to determine the significance of the parameters, and the P-Values is used to determine which parameter is most significant. The F-ratio test is conducted to check the adequacy for the proposed model.
Through experiments, traverse dimensions are collected and then fed into a DOE/STAT program to construct statistical regression equations for achieving the initializing of input parameters for optimum production.

After the initial variance analysis and elimination of the unimportant parameters (with low effect coefficient) and use of projection (due to lack of repeat), and with regards to the calculated values of F and P for each one of the effective parameters which is extracted from the table of variance analysis, it can be concluded that the center points have no effect (P=0.599). Therefore the two levels design is appropriate and we do not need to consider the effective parameters in 3 or more levels.

The risk level of less than 0.1 for parameters in Table 4 shows that the related parameter is significant. The R squared and the adjusted R squared is shown in bottom of the Table 4. Also, the lack of fitness is insignificant which shows the adequacy of the developed model. Fig. 4 indicates the residuals analysis graph of the regression model. As it observed, the residuals have a normal distribution.

Fig. 4: Residuals analysis graph of the regression model

**Table 4:** The variance analysis (ANOVA) for the wall thickness changes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>DOF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effects</td>
<td>6</td>
<td>0.0012</td>
<td>0.0016</td>
<td>2.90</td>
<td>0.205</td>
</tr>
<tr>
<td>2-Way Interactions</td>
<td>4</td>
<td>0.0016</td>
<td>0.0019</td>
<td>5.64</td>
<td>0.093</td>
</tr>
<tr>
<td>3-Way Interactions</td>
<td>2</td>
<td>0.0018</td>
<td>0.0001</td>
<td>12.52</td>
<td></td>
</tr>
<tr>
<td>Residual Error</td>
<td>3</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-Sq = 95.59  R-Sq(adj) = 77.95

Fig. 5 shows the graphs of each input parameter effect on the traverse dimension. Also, Fig. 6 indicates interactions effects of the parameters on the traverse dimension.

Fig. 5: The graphs of mean parameter effect on the traverse dimension

Fig. 6: The graphs of the parametric interactions effect on the traverse dimension

Fig. 6 shows that for the traverse dimension there are significant interactive influences among grinding depth (first section) and workpiece speed,
grinding depth (first section) and workpiece speed. According to the graphs of mean parameter effect and the graphs of the parametric interactions effect, higher wheel speed, dresser speed, grinding depth (first section) and lower grinding depth (second and third section) and slower workpiece speed, lead to smaller absolute value of traverse dimension. Finally, the hierarchical model was developed for traverse dimension by multiple linear regression technique. The insignificant terms were removed from the model and the final models were developed with significant terms which were determined by ANOVA equation (1) for traverse dimension.

\[
T = -0.650 + 0.931 (P1) + 1.270 (P2) + 0.237 (P3) + 0.003 (f) + 0.095 (E) + 0.008 (V) - 0.015 (P1 x f) + 0.01 (P1 x P2 x f) + 0.008 (P1 x P2 x V) - 0.004 (P1 x f)
\]

5 Discussion

Fig. 7 summarize the workpiece speed on the traverse dimension at grinding depth (second section). The result show that increase of workpiece speed combined with the increase of grinding depth (second section), produces small absolute value of traverse dimension.

6 Conclusion

In the present study, the creep feed grinding process has been optimized by selection of significant input parameters including the wheel speed, dresser speed, grinding depth and slower workpiece speed. Finally, by means of ANOVA, the main effects of the input parameters and their interactions on the traverse dimension were determined. Based on the statistical analysis of the experimental data the following conclusions can be obtained.

1- With regards to the variance analysis and the effect of interactions between the input parameters, it can be concluded that increasing the wheel speed, workpiece speed and width of cut and decreasing the dresser speed causes suitable dimensional changes for the traverse of root with good tolerance.

2- In the creep feed grinding process center points have insignificant effects on the traverse dimension. It means that process can be modeled with two levels for each input parameters.

3- Finally, with regards to the large number of effective parameters in the creep feed grinding process, consideration of the creep feed grinding process through the design of experiments is shown to be the efficient method for achieving the acceptable results.

References:


approach to control of thermal damage in grinding. 

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