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On-machine Measurement Method of Machining Error Based on Mold Surface Feature Sampling

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ABSTRACT. *Based on the on-machine measurements feature sampling results, put forward a new way to get free-form surface processing errors, and the method of evaluation surface profile error, this method based on the feature sampling to get coordinate data, a few measuring points on the processing surface, Use the least square method to optimize the distance between the reconstructed surface and the original theoretical surface; To obtain the free-form surface machining error, and model surface profile error of experimental process to analyze. The experimental results show that, Surface reconstruction process surfaces method based on feature sampling can machine, effective obtain the free-form surface machining errors.*

KEY WORDS: *Feature sampling; On-machine measurement; NURBS surface; Machining error*

1. Introduction

With the booming manufacturing industry, the application of parts with free-form surfaces is becoming more and more widespread，at the same time, the requirements for its accuracy are increasing. In this regard, most domestic and foreign scholars have conducted in-depth research and discussion on how to improve and measure the processing errors of free-form surfaces. It is different from the processing error of a relatively simple part. the detection error range of the processing error range of parts with complex curved shapes is relatively large，so it becomes very difficult to evaluate it. However, the general method for obtaining high-precision free-form surface machining errors is often cumbersome and costly. For the finished free-form surface parts, move to a coordinate measuring machine to measure discrete points on the surface. The obtained data points are interpolated or other fitting methods to obtain a theoretical surface, and then the two surfaces are compared to obtain the distribution of processing errors.

The above several measurement methods have certain shortcomings. among them, if the measurement is performed on three coordinates, it is necessary to put the

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processed parts back on the measuring machine for measurement. In the process, a secondary clamping error will occur. If the size of the part is particularly large, a lot of manpower and material resources are wasted. The on-machine measurement step is to measure the part directly on the machine after the part is processed. This method avoids the secondary armor error mentioned above. At present, a large number of application researches have been carried out in related fields at home and abroad. He Xueming et al. [1] proposed an adaptive contact measurement method to measure unknown surfaces, so that the measurement points are distributed according to the curvature change of free surfaces, Bezier's algorithm is used to estimate the normal vector of the measured points. Experimental results show that this method has strong application value. Zhang Hongjin [2] studied the control method and control theory with 3D digital contact measurement method, carried out optimization and analysis simulation, and proposed a data extraction method, The application of in-machine measurement is realized. Shi Enxiu [3] and others proposed an in-situ measurement method in order to solve the difficulties of large and medium-sized workpieces in mechanical manufacturing due to their large size, easy deformation, and inconvenience of disassembly and assembly, and they were successfully applied to large curved forming machines. Wang Zhiyong [4] and others studied the application of in-machine measurement method on NC gear grinding machine, and studied the on-machine measurement method of large gear error, based on the relationship between the gear coordinate system and the CNC machine tool coordinate system. Established the coordinate conversion method and the measurement method and measurement process of tooth profile error. Foreign scholars Choi [5] analyzed the error caused by the operation of the machine tool during the production and processing of CNC machine tools and compensated. Some foreign companies, such as Hexagon and Renishaw in London, have developed and applied a variety of on-board measurement methods, including various high-precision and advanced heads, radios Both the receiving and triggering sides can measure the accuracy of the free-form surface very well, and it is also of great significance to processing and manufacturing.

According to the characteristics of the curvature of complex surfaces, the distribution of sampling points is arranged using the center of gravity theory of objects, and the processing surface is reconstructed based on the NURBS control point method. Using this method, a small amount of sampling data on free surfaces can be obtained. At the same time, these sampling points are used to reconstruct, effectively fit the processed surface, compare with the theoretical surface, use the least square method to calculate the distance between the surfaces, and finally evaluate the error.

2. Basic measurement principle and mold surface sampling method

According to the principle of center of gravity of objects, using the weighted average method, first select an object with mass and divide it into multiple small volumes ΔV_i, and treat each one as an entity, which is affected by gravity, Let the gravity of a small block be p_i, then the action point is set to $M_i(x_i, y_i, z_i)$, and the

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coordinate of the center of gravity of the received gravity is set to $C(x_c, y_c, z_c)$. According to the principle of combined moment, the formula of the center of gravity of the mass is:

$$\begin{cases} x_c = \sum_{i=1}^{n} x_i p_i / \sum_{i=1}^{n} p_i \\ y_c = \sum_{i=1}^{n} y_i p_i / \sum_{i=1}^{n} p_i \\ z_c = \sum_{i=1}^{n} z_i p_i / \sum_{i=1}^{n} p_i \end{cases} \quad (1)$$

From formula (1), we can see that each small cell that is divided is affected by the cell volume and the cell distance, and their weighted average is the center of gravity of the object. This method is used to establish a sampling model that conforms to the surface shape features. Let freeform surface:

$$P(u,v) = (x(u,v), y(u,v), z(u,v))$$

Where u and v are parameters of the surface.

Let the formula of the sampling surface be $P(u,v)$, and there are many discrete sampling points distributed on it, the total number is set to M, and the set of sampling points in the sampling range on the surface is:

$$D = \{1, 2, \cdots, M\}$$

The collection of sampling points is:

$$W = \{w_i, i \in D\}$$

Among multiple sampling points, if the neighborhood sampling set at the first sampling point is set to, then all neighborhood sampling sets are:

$$N = \{N_i, i \in D\}$$

In the formula $i \notin N_i$, if $i \in N_j$, then $j \in N_j$. N_i is on the sampling grid,Four fields or eight fields are defined, This is a set of non-uniform neighborhood forms, as shown in Figure 1. The sampling point data set is a four-neighborhood set of the i-th point. According to the description of the sampling point set above, the main problem we need to solve now is to adopt a certain optimization method to obtain the best method with the minimum number of sampling point sets Represents the shape characteristics of a free-form surface, and defines the sampling points on the surface according to the degree of curvature of the surface.

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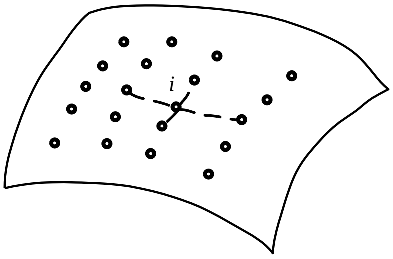

Figure. 1 Collection of sampling point neighborhoods

On the sampling area of the free-form surface under study, the location of the initial set of sampling points w_i must meet the following nonlinear equations:

$$\begin{cases} u_i = \dfrac{\sum_{j \in N_i} r\left(w_j\right) u_j}{\sum_{j \in N_i} r\left(w_j\right)} \\ v_i = \dfrac{\sum_{j \in N_i} r\left(w_j\right) v_j}{\sum_{j \in N_i} r\left(w_j\right)} \end{cases} \tag{2}$$

The above formula can be rewritten as:

Where $r(w)$ is a non-linear shape function used to reflect the degree of curvature change of the characteristic surface, that is, the degree of curvature of the surface. If the value of the shape function in the area where the surface is located is large, it indicates that the area has a high degree of curvature, otherwise The same is true. The solution is to meet the shape feature information of complex curved surfaces based on the above-mentioned balance system, and establish a mathematical model based on the curvature change of the curved surface to derive.

The formula for the surface curvature shape function is as follows:

$$r(\mathrm{w}) = r(u,v) = q + \frac{k(u,v) - \min k(u,v)}{\max k(u,v) - \min k(\mathrm{u},\mathrm{v})}$$

Where, q —Control element of the surface grid spacing, which ranges from 0 to 1;

$k(u,v)$ —Curvature of the surface;；

$\max k(u,v)$ —Maximum curvature of the surface;

$\min k(u,v)$ —Minimum curvature of the surface;。

For more complicated surfaces, the curvature of the surface has a great influence

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on the density of the entire surface. The control factor q directly controls the grid spacing of the control surface. Intuitively, you can see that the surface shape The area should be arranged with a larger number of sampling points, and vice versa. Therefore, the layout of the sampling points should be consistent with the curvature change of the surface. There should be a balance limit in the area. It should not be too small, otherwise it will affect the sampling efficiency, and vice versa, the number of sampling points must be appropriate, and it cannot affect the subsequent surface reconstruction.

Let the parametric expression of the parabola be:

$$\begin{cases} x = 4v^2 + 55v - 60 \\ y = 10u^2 - 68u \\ z = 6u^2v^2 + 12u^2v + 4u^2 - 35uv^2 + 24uv \\ -10u - v^2/2 + 5v + 10 \end{cases} \tag{3}$$

Where u and v respectively represent the parameters of the surface.

The three-dimensional model of the paraboloid is shown in Fig. 2.

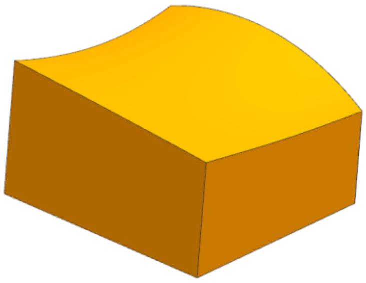

Figure. 2 Parabolic model

After selecting the sampling model, the second step is to select the sampling points for iterative calculation. The discrete point grid model is taken as the sampling point. The discrete initial network model is shown in Figure 3 (a). The control factor q = 0.2 is selected and the convergence After the criterion is iterated 180 times, the sampling grid obtained is shown in Figure 3 (b).

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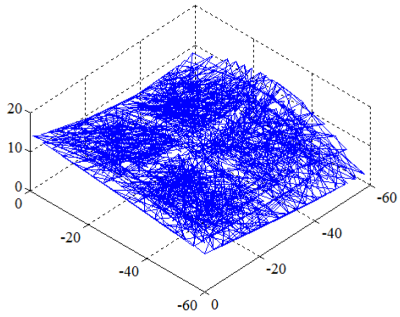
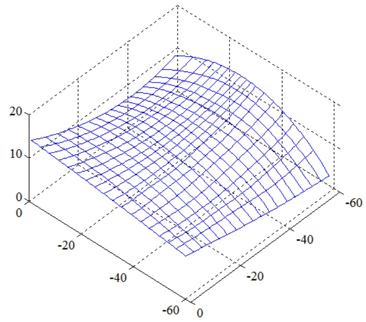


(a) Discrete grid



(b) Mesh after 180 iterations

Figure. 3 Sampling grid generation

3. Mold surface reconstruction method

After the generation of the sampling grid is calculated by the above sampling algorithm, the next step is to arrange the measurement points according to the grid distribution model, as shown in Figure 4. Through the sampling point arrangement, we can see that there are more sampling points in the place where the curvature of the surface changes a lot, which basically matches the curvature change of the surface model ,This calculation arranges 18×18 sampling point model, It is used to carry out on-machine measurement experimental research. After the experiment, the basic NURBS surface control point method is used to reconstruct the obtained sampling point data.

The specific method is as follows: by calculating the distance s between the actual sampling point p obtained after machining and the corresponding sampling point p on the theoretical model, and determining the value of the distance between the two surfaces according to the calculation result, If s = 0, no adjustment is required, and vice versa.

The reconstruction method is based on the NURBS surface control point reconstruction method. In order to verify the feasibility and superiority of this method, a NURBS surface reconstruction method without adding surface control points is selected for comparison experiments. The results are shown in Figure 5 (a).

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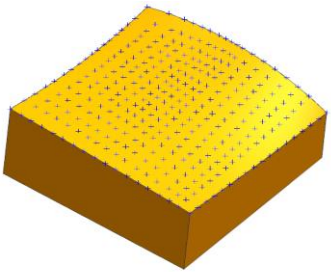
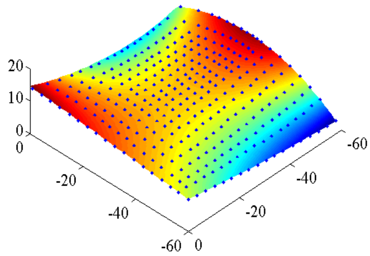
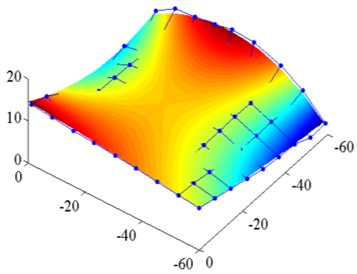


Figure. 4 Distribution of parabolic sampling points

Using the feature sampling method proposed in this paper, based on the theoretical design of the surface, the calculated sampling points are arranged on the actual processed surface, and the actual data points are input into the model through the experimental method of mechanical measurement As shown in Figure 5 (b), through simulation calculations, the corresponding control points are continuously adjusted, and the processing surface is reconstructed. Compared with other methods,The control point-based reconstruction method can improve the accuracy to 10% or more than the surface approximation reconstruction method.



(a) Parabolic sampling point reconstruction model



(b) NURBS surface control point reconstruction model

Figure. 5 Reconstruction of parabolic model based on NURBS control point method

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4. Experimental verification

In order to verify the correctness of the method in this paper, an experimental verification method is adopted. In this paper, VDL-1000E vertical machining center, OP550 infrared communication probe, BT40 tool holder and WIN7 computer equipped with on-board measurement software system are used for system construction and experiment. The specific method is as follows:

First, import the theoretical 3D model of the original workpiece into the 3D design software UG, set the corresponding process parameters and generate the NC sampling code, and enter the program into the VDL-1000E NC vertical machining center control module to NC the parabolic model. machining.

Import the 3D model of paraboloid into the measurement software and plan the sampling points, and finally generate the sampling program. Enter the program into the machine tool. In this experiment, the machine tool uses a contact-type measuring head as the switch sensor. The experiment is shown in Figure 6. After the measurement is completed, we return the data stored in the machine tool to the software through the communication device and perform the side measurement. Head error compensation and error evaluation, and finally generate on-board measurement report.

Figure. 6 Parabolic model workpiece and experimental process

5. Mold surface machining error and evaluation

After reconstructing the processed surface based on the NURBS surface control point method, the surface contour error calculation of the surface is performed next, and the minimum distance from the discrete point on the actual surface after processing to the theoretical surface is calculated. First, a plurality of points are scattered on the reconstructed surface and a normal vector of each point is calculated as shown in FIG. 8. Calculate the normal distance from any point on the reconstructed surface to the theoretical surface. Here we choose the simpler least square method for optimization calculation. The distance distribution range between

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the two surfaces is shown in Figure 7. The distance between the two surfaces is calculated by the method of least squares, with a minimum distance of 0.0174mm and a maximum distance of 0.0321mm. The calculation result of the maximum distance is taken as the minimum distance between the two surfaces to contain the area. The error value of the surface contour is 0.0642mm

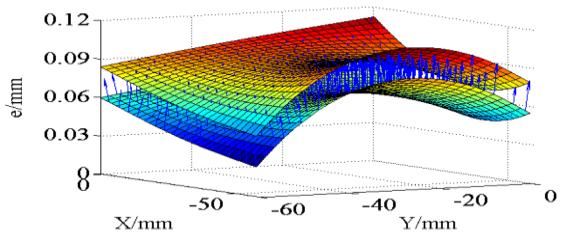
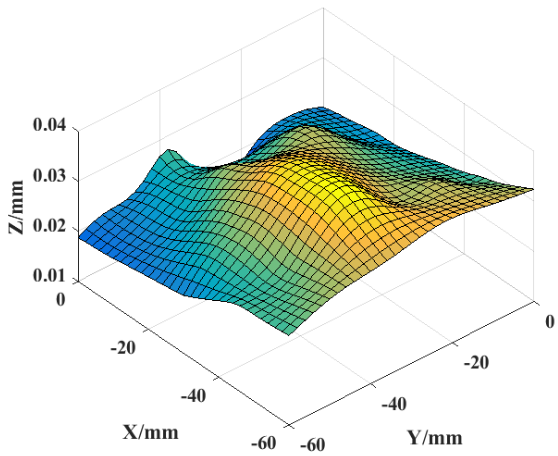


Figure. 7 Normal distance between the discrete points on the parabolic surface after reconstruction and the original design parabolic model

Based on the above calculation results, and in order to verify the superiority of the method in this paper, we use the equal chord height method for comparative experiments. We use the extracted 324 data points to reconstruct the processing surface and analyze the processing errors, as shown in Figure 8 (a) It is shown as the error distribution diagram obtained by the method of constant chord height, and the error distribution diagram obtained by the method proposed in this paper is shown in Figure 8 (b).



(a) Normal errors obtained by the equal-sinusoidal sampling method

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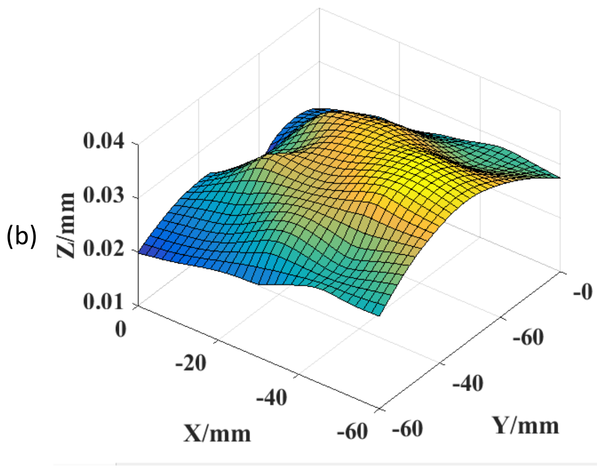

(b) The normal error obtained by the feature sampling method

Figure. 8 Normal error of machined surface

It can be seen that the error distribution obtained by the two methods is approximately the same in space, but the results obtained by the method in this paper have better spatial continuity, so the method applied in this paper has a good application effect.

6. Conclusion

This paper proposes an on-machine measurement method based on surface feature sampling and NURBS surface control point method to reconstruct the processed surface. This method first obtains a small number of adopted points based on the principle of the center of gravity of the object, and then reconstructs the processed surface based on the NURBS surface control point method, and uses the least squares optimization method to obtain the maximum distance from the small distance between the two surfaces to obtain Machining errors of free-form surfaces and performing error evaluation. Sampling points are denser in areas where the curvature of the surface changes greatly, and sampling points are relatively sparse in areas where the curvature of the surface is relatively smooth. Finally, experimental methods were used to verify the reconstruction of control points based on NURBS surfaces The method has a good application effect, is superior to the equal chord height method, and can also guarantee higher accuracy.

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