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Research on precision turning technology for microwave cavity modulation structure

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Abstract
Terahertz microwave devices have been widely applied in the field of communication engineering, detection and medical treatment, to further match the increasingly higher requirements of power, efficiency and frequency band, the machining accuracy of microwave devices need to be improved correspondingly. The processing technic of existing microwave devices cannot exactly match the accuracy requirement, especially for the slow wave structure which is the core components of microwave devices, therefore high-precision machining technology should be proposed. It is difficult to achieve high-accuracy machining for the sine modulation structure inside a cavity which has high depth-to-width ratio, with respect to the issue of low-accuracy machining, in this paper the precision SPDT (single point diamond turning) technology was employed to meet the high-accuracy requirements for the microwave cavity modulation structure. The method of equal-chord length in the linear interpolation model was adopted to optimize the way of generating discrete points, which can greatly improve machining efficiency. In addition, the spline interpolation mode was discussed and the cubic uniform B-spline interpolation arithmetic for trajectory planning was employed to further improve the contour approximation accuracy, at the same time the influence of tool-setting was took into consideration. Finally, a series of cutting experiments of microwave cavity modulation structure were carried out in a home-made ultra-precision diamond turning machine and the Taylor Hobson Talysurf PGI 1240 was used for accuracy measurement of machined workpiece. The experiment result demonstrated that the spline interpolation is a better way for sine structure and the cutting parameters play an important role in the machining accuracy.

Keywords: THz microwave device, sine wave structure, precision turning, trajectory planning

1. Introduction

The band of Terahertz is located in the middle transition zone of the infrared and millimeter wave, as a result, it has the features of both two bands, e.g., the characteristics of large bandwidth, narrow beam and the robustness for the outside environment. These characteristics make the THZ to be an ideal technique applied in the field of communication, biological imaging, radar and astrophysics[1-3]. Meanwhile, more and more attention has been focused on the research of Terahertz technology[4-6].

Unfortunately, the processing technic of existing microwave devices cannot exactly match the accuracy requirement, especially for the slow wave structure which is the core components of microwave devices, therefore high-precision machining technology should be proposed. It is difficult to achieve high-accuracy machining for the sine modulation structure inside a cavity which has high depth-to-width ratio, with respect to the issue of low-accuracy machining, in this paper the precision SPDT (single point diamond turning) technology was employed to meet the high-accuracy requirements for the microwave cavity modulation structure.

The rest of this paper is organised as follows. The linear and spline interpolation methods were discussed in Section 2. The influence of the tool-setting accuracy was taken into consideration in Section 3. The experiment result for microwave cavity modulation structure was discussed in Section 4. The conclusions for this paper were drawn in Section 5.

2. The interpolation method

Tool path planning is an important part of the ultra-precision turning processing and has a significant effect on machining quality, the commonly used linear method to generate tool path points are equal-step length, equal-chord length and equal-chord height. The equal-step length method is used to disperse the data by a constant step length between two adjacent data points along a certain direction, the equal-chord length method achieves the discrete data of profile curve based on the criterion that any chord length is equal in the process, the equal-chord height method is based on the criterion of the maximum chord height which is distance from a point on the profile curve to the straight line consist of two adjacent discrete data points. The B-spline interpolation method has been recently employed in sine structure as its superiority in complex surface, the comparison of the interpolation accuracy of the equal-chord height methods and cubic B-spline interpolation was shown in Fig 1, it is obvious that the cubic B-spline is more accurate and little affected by profile curve, it holds the capacity to reduce the error by an order of magnitude. The cubic uniform B-spline interpolation arithmetic for trajectory planning was employed to further improve the contour approximation accuracy in this paper.

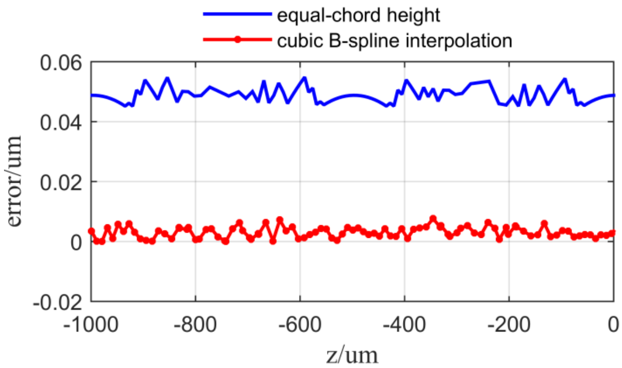

Figure 1. The interpolation accuracy for the equal-chord height and cubic B-spline methods.

3. Effect of tool

Diamond tool is an important component of the ultra precision turning, the accuracy of tool setting, tool radius compensation and tool parameters play a significant role in machining accuracy. The tool parameters used in this paper are shown in Fig 2(a), nose radius *R* is 80nm, tool angle *α* is 45°, relief angle *β* is 15° and rake angle is 0°. The tool-setting error will directly affect the size precision and the shape precision of workpiece, the schematic diagram of tool-setting error is shown in Fig 2(b), tool-setting error can be calculated by equation (1), and the effect of tool-setting error on machining accuracy is calculated and depicted in Fig 2(c).

$$\Delta\varepsilon = 2\times(R_2 - OB) = 2\times(R_1 + a_p - \sqrt{(R_1 + a_p)_2^2 - e^2}) \qquad (1)$$

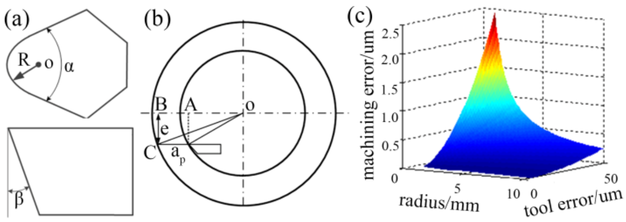

Figure 2. The effect of tool (a) tool parameters, (b) the schematic diagram of tool-setting error and (c) machining accuracy.

4. Experiment result

A series of cutting experiments of microwave cavity modulation structure were carried out in an ultra-precision diamond turning machine, form accuracy refers to the deviation between the actual machined surface and the theory surface, in general, two-dimensional form accuracy can be used to represent form accuracy. Usually, evaluation of machining quality can be calculated by eauqtion (2).

$$\begin{cases} PV = \max(x_i - y_i) - \min(x_i - y_i) \\ RMS = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(x_i - y_i)^2} \end{cases} \qquad (i = 1,2,3\cdots,m) \qquad (2)$$

Where, x_i is the coordinates in vertical direction for the theoretical curve, y_i the coordinates in vertical direction for the machined curve and *m* the amount of measurement points. *PV* value indicates the fluctuation of form error while *RMS* indicates the overall distribution of form error.

A microwave cavity sine structure with the period 1mm and amplitude 0.4mm, as shown in Fig 3(a), is machined in an ultra-precision diamond turning machine and measured by Taylor Hobson Talysurf PGI 1240, the measurement data is processed by MatLab software, the form error and roughness are shown in Figs 3(b) and (c), respectively. It is observed that the form error is 5µm and roughness is 80nm in length range of 6mm, and both of them are periodic.

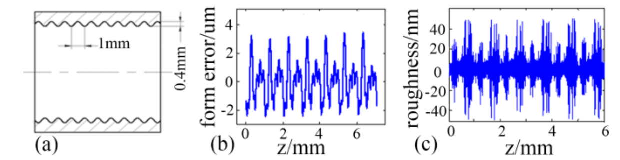

Figure 3. The measurement result (a) the schematic of sine structure, (b) form error and (c) roughness.

To investigate the influence of cutting parameters and depth-to-width ratio in sine structure on machining accuracy, a series of cutting experiments were carried out, and the result is showns in Fig 4. The result of varying spindle speed with 4µm cutting depth is shown in Fig 4(a), the influence of spindle speed on form error is relatively modest while it is significant on roughness. The result of varying cutting depth at 2400rpm is shown in Fig 4(b), the influence of cutting depth on form error is obvious. The result of varying depth-to-width ratio is shown in Fig 4(c), the influence of depth-to-width on both form error and roughness is synchronous, smaller depth-to-width ratio leads to a smaller value for both form error and roughness.

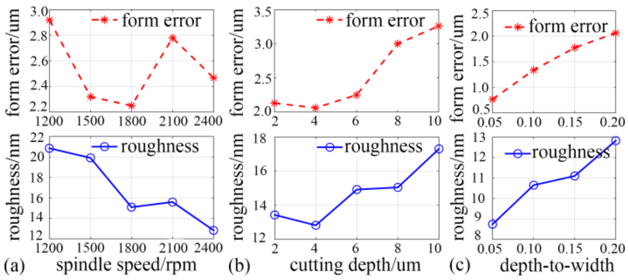

Figure 4. The influence on machining accuracy (a) spindle speed, (b) cutting depth and (c) depth-to-width ratio.

5. Conclusion

The methods of equal-step length, equal-chord length and equal-chord height were discussed, the cubic uniform B-spline interpolation was adopted to improve and optimize tool path planning. The influence of tool-setting compensation was introduced, a series of cutting experiments were carried out. The experiment result illustrates that the influence of cutting depth on form error is obvious and the influence of depth-to-width ratio on both form error and roughness is synchronous, smaller depth-to-width ratio leads to a smaller value for both form error and roughness. The future work will be focused on tool parameters and error compensation, these two factors vastly affect the machining accuracy which is the most important criterion for Terahertz microwave devices.

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