Tool Wear Characteristics and their Effects on Freeform Surface Quality in Ultra-precision Raster Milling

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Abstract:

Ultra-precision freeform surfaces are a kind of non-rotational symmetric surfaces with sub-micrometric form accuracy and nanometric surface finish. They are increasingly used in precise optical systems to realize some special functions due to their superior optical properties. However, it is quite difficult to fabricate high precision freeform surfaces due to their complex geometry and the existence of affecting factors in the freeform machining process like spindle vibration, tool wear, slide error etc. Up to date, the manufacturing method employed into freeform surface includes slow slide servo, fast tool servo, ultra-precision grinding/polishing and ultra-precision raster milling (UPRM). UPRM is an essential method to fabricate freeform surface since it is more suitable to fabricate optical components with complex surface structure. In UPRM, the diamond tool is installed on the spindle and rotates with spindle at a high rotation speed while the workpiece is fixed on a rotatable table. In every rotary cutting, a tiny crater is generated on the workpiece surface, while the freeform surface will be formed by one and another craters.

In the freeform surface machining process, the occurrence of tool wear certainly affects the freeform surface both in form accuracy and surface roughness. Although it is evident that tool wear affects freeform surface quality, little research has been conducted on tool wear in ultra-precision raster milling (UPRM). This study therefore explored tool wear characteristics in UPRM and their effect on freeform surface quality by conducting a series of experiments using a Precitech five-axis ultra-precision machine and a brass workpiece. In order to explore the tool wear characteristics and their effects on the freeform surface accuracy and surface finish, a long lasting cutting will be conducted on four workpieces with the same freeform topography. Preliminary results reveal that tool wear characteristics in UPRM of freeform surface includes cutting edge fractures, workpiece material welding on the rake face, wear plane formation, and the formation of sub-wear-plane. The effects of tool wear characteristics on the freeform surface are explored, it is found that cutting edge fractures formed ridges on the freeform surface, affecting the optical function and surface finish of freeform surface. Material welding on the rake face of diamond tools increased the thrust force and led to the formation of burns on the freeform surface. The formation of wear plane and sub-wear plane enlarged the tool nose radius and shifted the centre location of tool nose arc, which can seriously affect the form accuracy of the machined freeform surface.

This research presented is meaningful since it provides valuable information for tool wear monitoring and freeform surface finish improvement in UPRM.