Tool Orientation Control for 5-axis CNC Machining

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Abstract

We consider a 5-axis CNC machine whose tool axis maintains a fixed angle with respect to the surface normal as the machine tool cuts a given path on a smooth surface. The tool axis $\mathbf{a}(\xi)$ lies on a cone of constant angle ψ about the surface normal $\mathbf{n}(\xi)$ at each point of the path, but its azimuthal position on this cone remains indeterminate. Geometrically speaking, given a curve $\mathbf{n}(\xi)$ on the unit sphere, we have to choose $\mathbf{a}(\xi)$ among such curves on the sphere that satisfy $\mathbf{a}(\xi) \cdot \mathbf{n}(\xi) = \cos\psi$. We discuss several schemes to resolve the indeterminacy by focusing on the minimization of the residual motion of tool axis. The first method is to force the tangential component of $\mathbf{a}(\xi)$ to the surface to be parallel along the path, in other words requiring the component to be rotation-minimizing with respect to $\mathbf{n}(\xi)$. The second method is to find $\mathbf{a}(\xi)$ on the unit sphere with minimal length under the aforementioned constraint, which is formulated in terms of variational calculus. Finally we introduce a tractrix-like curve on the sphere that orient itself in such a way that locally minimizes its length. Although this curve does not achieve globally minimal length, its simple derivation and length-minimizing property can be more appealing in practice.

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