Mechanical Engineering Master's Defense

An Investigation of Kinematic Redundancy for Reduced Error in Micromilling

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abstract

Small metallic parts of size less than 1mm, with features measured in tens of microns, with tolerances as small as 0.1 micron are in demand for the research in many fields such as electronics, optics, and biomedical engineering. Because of various drawbacks with non-mechanical micromanufacturing processes, micromilling has shown itself to be an attractive alternative manufacturing method. Micromilling is a microscale manufacturing process that can be used to produce a wide range of small parts, including those that have complex 3-dimensional contours. Although the micromilling process is superficially similar to conventional-scale milling, the physical processes of micromilling are unique due to the scale effects. These scale effects occur due to unequal scaling of the parameters from the macroscale to the microscale milling. One key example of scale effects in micromilling process is a geometrical source of error known as chord error. The chord error limits the feedrate to a reduced value to produce the features within machining tolerances. In this research, it is hypothesized that the increase of chord error in micromilling can be alleviated by intelligent modification of the kinematic arrangement of the micromilling machine. Currently, all 3-axis micromilling machines are constructed with a Cartesian kinematic arrangement with three perpendicular linear axes. In this research, the cylindrical kinematic arrangement is introduced, and an analytical expression for the chord error for this arrangement is derived. The numerical simulations are performed to evaluate the chord errors for the cylindrical kinematic arrangement. It is found that cylindrical kinematic arrangement gives reduced chord error for some of the curves. Then, the kinematic redundancy is introduced to design a novel kinematic arrangement. Several desired toolpaths have been numerically simulated to evaluate the chord error for kinematically redundant arrangement. It is concluded that this kinematically redundant arrangement gives up to 5 times reduced error for all the desired toolpaths considered, and allows significant gains in allowable feedrates.

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