Optimization of Ball-End Mill Geometry for High Speed Machining

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Abstract: In this paper, optimal geometries of ball-end mills are developed according to cutting force models. Cutting coefficients for the prediction of the cutting forces are acquired by two-dimensional orthogonal cutting experiments of SKD11. Through the geometric and cutting force model, geometric optimal solutions of ball-end mill that can minimize the stress of the tip at the cutting edge and the total cutting force in the tool, are searched by the genetic algorithm. A stress analysis at cutting edge is the basis of designing cutting edge geometry and the results play an important role over the tool life and the cutting forces of ball-end milling. After optimizing ball-end mill geometries, the cutting forces are compared with a conventional un-optimized ball-end mill.

Keywords: High Speed Machining, Ball-End Mill, Optimization, Genetic Algorithm, Helix Angle, Rake Angle, Relief Angle, Cutting Forces

1. Introduction
The high speed machining (HSM) is one of the most effective ways to improve the machining accuracy and productivity of fabricating dies and moulds. Previous cutting methods are based on deep cutting and low speed feeding condition. The HSM, however, is based on shallow cutting and high speed feeding conditions. This reduces the burden on the cutting edge of the tool, which prolongs the tool life and realizes the high quality surface finishes. The essential conditions for realizing the HSM are the use of high speed spindle, a cutting tool for high cutting speed and dynamically well balanced tool attachment system. Cutting tools for the HSM require high rigidity during high speed rotating, good dynamical balance and good wear characteristics.

As a tool for the HSM of sculptured surfaces of difficult-to-cut workpiece, the ball-end mill is extensively used. There have been significant researches reported in modeling mechanics of helical flat-end milling, but little work has been done on the mechanics of ball-end milling. Since the geometries of ball-end mill are so complicated, many researchers have studied geometries and cutting mechanics. The geometric parameters of ball-end mill, i.e., relief angle, helix angle, rake angle and cutting speeds vary along helical flutes. Also, for the different geometric parameters, the cutting coefficients, i.e., shear, friction angle, etc., vary along helical flutes. Because cutting forces during ball-end milling influence the deflection of tool and surface finishes of products, its prediction is important. Over different geometries and material of ball-end mill, the cutting forces show different values. Consequently, the machinistic model requires large amount of cutting tests and acute mathematical models, and can be applicable to just a particular workpiece material-cutter only. If the cutting force can be predicted accurately and reduced by the optimized ball-end mill, the productivity of fabricating dies and moulds will be increased.

In this paper, the geometries of ball-end mill are represented mathematically and simulated. The cutting force coefficients are acquired by two-dimensional orthogonal turning experiments with SKD11 that is the material for the pipe form and heat-treated to HRC40. Then the results are used for the prediction of cutting forces of ball-end mill. Through the geometric and the cutting force models, geometric optimal parameters of ball-end mill that can minimize the stress of cutting edge and the total cutting force in the tool, are searched by the genetic algorithm. A stress analysis of the tool tip at the cutting edge is the basis of designing cutting edge geometry and the results affect tool wear and cutting forces of ball-end milling. After optimizing ball-end mill geometries, the cutting forces compared with a conventional un-optimized ball-end mill.

2. Orthogonal cutting force coefficients
In this section, in order to predict cutting forces of ball-end milling, the cutting force coefficients are acquired by two-dimensional orthogonal turning