Rapid Calibration of Cutting Force Control System Using Motor Currents in End Milling Processes

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Abstract: In this paper, an easy and rapid calibration method for a cutting force estimator with motor currents is proposed for end milling machines. The rapid calibration method consists of following three steps: selection of standard cutting conditions for the end-mill and the workpiece, calibration of drive systems, and calibration of cutting force coefficients. The proposed method makes cutting force estimator calibrated easily and rapidly without additional cutting force measurement system, so that it is possible to raise practicality of the cutting force control system.

Keywords: Cutting force coefficients, Cutting force estimator, End milling process, Motor current, Rapid calibration, Standard cutting condition

1. Introduction

In modern manufacturing processes, there is an ever-increasing demand for higher productivity by reducing machining time with the increase of cutting force and material removal rate.[1] However, the excessive increase of cutting force results tool breakage, poor machined quality, and bad effects on the machine tool. One of the most straightforward methods of improving productivity and quality in machining processes is real-time estimation and control of cutting forces.[2] If we develop a cutting force estimator through the measurement of motor currents in end milling processes, we should calibrate the motor currents according to cutting force values as quickly as possible. In this case, the easy and rapid calibration method is required for initial set up of the cutting force estimator on the milling machine.

In this study, an easy and rapid calibration method of a cutting force estimator with motor currents is proposed for end milling machines. The rapid calibration method consists of following three steps: (1) selection of standard cutting conditions for the end-mill and the workpiece, (2) calibration of drive systems, and (3) calibration of cutting force coefficients. In the first step, general end-mill and workpiece are selected standards for measuring cutting forces without an expensive dynamometer. And construct database of cutting forces as motor currents according to the standard cutting conditions. The calibration of drive systems means identification of relationships between motor currents and cutting forces without dynamometers through the measured currents and already known cutting forces obtained from standard cutting conditions. From this result, system parameters of the drive systems, and relationships between currents and cutting forces can be calibrated. The last step is to identify cutting coefficients for an end-mill and a workpiece. Through experiments with the standard cutting conditions for a new end-mill and a workpiece, the cutting coefficients can be identified with estimated cutting forces from the calibrated cutting force estimation system. The calibrated cutting coefficients become important parameters of an analytical model that estimate axial and radial depth of cuts and various cutting forces using estimated feed cutting force and cutting torque obtained from motor currents.

For various end-mills and workpieces, the validity of the developed rapid calibration method is verified on a horizontal machining center through experiments of the cutting force control.

2. Cutting Force

2.1 Force Modeling of End Milling

Cutting forces are described as functions of cutting pressures acting on the instantaneous chip load area [3-6] as shown in Fig. 1,

\[ dF_x, dF_y, dF_z = K_x, dF_z h(\phi), \]

where \( dF_x = [\frac{dL}{d\phi} \tan(\beta)] dp \) is thickness of the axial element of the cutting edge, \( h(\phi) = t, \sin(\phi) \) is instantaneous chip thickness, \( t \) is feed per tooth. The cutting pressure \( K_x \) can be expressed as a function of the average chip thickness. In the peripheral down-milling process instantaneous forces in the X and Y directions along the chip load of a single flute are given by