Mathematical Model of a 
CNC Rotary Table Driven by a Worm Gear

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ABSTRACT

This paper proposes a mathematical model of a CNC rotary table driven by a worm gear. The CNC rotary tables are generally utilized as rotary axes of 5-axis machining centres. In this study, a mathematical model which can simulate dynamic behaviours of rotary table is proposed. The model consists of inertia of motor, spur and worm gears, and table. Axial displacement of the worm is also considered into the model. Various motions are measured and simulated to confirm effectiveness of the model. As the results show, the proposed model can simulate step response, rotational fluctuations, and influence of unbalanced mass.

Keywords: 5-Axis Machining Center, Backlash, Mathematical Model, Rotary Table, Simulation, Worm Gear

INTRODUCTION

In the present day, because of the complexity of the products, the 5-axis CNC (Computerized Numerical Control) machines are becoming popular on the shop floors. Most of these machines consist of three linear and two rotary axes (Bohez, 2002; Lin & Shen, 2003). The rotary axes reduce expensive reconfiguration just by reorienting the tool and/or workpiece outside the cut. These rotary movements saves setup time by letting the spindle reach opposing faces of the part in a standard milling cutter, held at an angle, and machine an angled surface that would otherwise require a custom tool.

The rotary axis can be a rotary table which supports the work or a rotary head which supports the tool. Therefore, to build most of the 5-axis machines, as well as to convert the conventional 3-axis machines to 4 or 5-axis machines, the rotary table becomes an important and necessary part. Further, the accuracy of these machines determines the dimensional accuracy and surface finish of the parts produced by the machine. Therefore, in order to keep the accuracy level of the machine high, the motion performances of the rotary tables also have to be at a high degree.

International Organization for Standard (ISO) 230-7 (2006) defines static positional and rotational errors allowed in the rotary axes. They are called location errors in the standard. Mayer et al. (1999) applied a telescoping magnetic ball bar to calibrate the errors, and Tsutsumi and
Saito (2003, 2004) proposed identification and compensation method for geometric errors of rotary axes in 5-axis machining centers. The method can identify the geometric errors, such as location and angular deviations of rotary axes rotational center using a ball-bar system. The method also can be applied to other types of machine tools (Dassanayake et al., 2006, 2011). Bringmann and Knapp (2006) also proposed a calibration method for geometrical errors of rotary axes using R-test (Weikert, 2004). R-test is also applied to produce error maps of the rotary axes (Ibaraki et al., 2011).

On the other hand, it had already been investigated that the dynamic behaviour of controlled axes is also an important factor to achieve higher performance in such machines (Tsutsumi et al., 2007; Sato & Tsutsumi, 2011). From this point of view, various research studies on the modelling and analysis for feed drive systems of linear axes were conducted (Ebrahimi & Whalley, 2000; Erkorkmaz & Altintas, 2001; Sato & Tsutsumi, 2005; Sato, 2011). On the rotary axes, however, the dynamic behaviours of the driving mechanism have not sufficiently investigated. Although, Zirn (2008) described modelling methods for machine manipulators including rotary axes, and Dassanayake et al. (2008, 2009) investigated the motion characteristics of the rotary axes.

In this study, a mathematical model of a rotary table driven by a worm gear is proposed. Worm gear is one of the main mechanisms adopted for the rotary axes of 5-axis machine tools, because of its irreversibility and costs. Parameter identification method and effectiveness of the proposed model will be shown by comparing the measured and simulated results of various motions. Influence of unbalanced mass is also discussed in causes where the mechanism is utilized for the tilting axis.

**EXPERIMENTAL SET-UP**

Figure 1 describes the experimental set-up used in this study. The system consists of a rotary table, a servo amplifier, and a personal computer with a DSP board. The rotary table is powered by an AC servo motor, spur gears, and a worm gear. Figure 2 illustrates the driving mechanism of the rotary table. Reduction ratios of the spur gears and the worm gear are 4/5 and 1/72, respectively. Consequently, the total reduction ratio becomes 1/90.

A rotary encoder which has a resolution of 0.0001 deg is attached to the rotary table to measure the rotational angle of the table. Rotational angle of the motor can also be detected by a rotary encoder equipped on the motor, with...