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MOTION ERROR AND ACCURACY EVALUATION METHOD FOR VERTICAL CNC MILLING MACHINE

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MOTION ERROR AND ACCURACY EVALUATION METHOD FOR CNC VERTICAL MILLING MACHINE

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A report submitted in fulfillment of the requirements for the degree of Master of Manufacturing Engineering (Manufacturing System Engineering)

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2014

DECLARATION

I declare that this report entitle “Motion Error And Accuracy Evaluation Method For Vertical CNC Milling Machine” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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Date : 18.03.2014

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Manufacturing System Engineering).

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ABSTRACT

This report represents a method that uses the double ball bar to inspect motion errors of the rotary axes of three axis CNC milling machine tools. This method uses a particular circular test path that only causes the two rotary axes to move simultaneously and keeps the other linear axes stationary. Therefore, only motion errors of the two rotary axes will be measured during the double ball bar test. Minimum circular radius that can be inspecting with standard double ball bar circular interpolation test kit is 150mm. Therefore, machine with less than 150mm circular radius need to use measuring magnification in order to enable the circular interpolation test by double ball bar method. The characteristic of measuring magnification for machine with circular radius less than 150mm is proposed. The theoretical trace pattern of error origins which is squareness error is established. Consequently, the error origins in the rotary block can be diagnosed by examining whether similar patterns appear in the motion error trace. Testing procedure performed by means of detecting the motion errors characteristic. Then based from this trace pattern, the current state of the machines can be known and this information is beneficial for the user to take necessary actions.

ABSTRAK

Kajian ini mengetengahkan satu kaedah yang menggunakan bar bebola berganda untuk memeriksa ralat pergerakan bagi gandar perkakasan mesin CNC. Kaedah ini menggunakan laluan ujian membulat yang khusus yang mana hanya membenarkan dua gandar memusat bergerak serentak manakala gandar yang ketiga adalah dalam keadaan pegun. Akibatnya, hanya ralat pergerakan bagi kedua dua gandar tersebut yang diambil kira untuk perhitungan oleh bar bebola berganda. Bar bebola berganda yang piawai hanya boleh memeriksa jejari bulatan yang berukuran 150mm. Oleh itu, mesin yang mempunyai jejari bulatan yang kurang daripada 150mm perlu menggunakan kaedah pembesaran pengiraan bagi membolehkan pemeriksaan menggunakan bar bebola berganda. Kajian ini mencadangkan ciri-ciri pembesaran pengiraan bagi mesin yang mempunyai jejari bulatan yang kurang daripada 150mm. Teori kesan corak bagi asal usul ralat iaitu ralat persegi akan diwujudkan. Akibatnya, asal usul ralat di dalam blok pusingan boleh diagnosis dan dikaji samaada ciri-ciri yang sama hadir di dalam kesan corak bagi ralat. Kaedah ujikaji dilakukan untuk mengesan ciri ralat pergerakan. Berdasarkan keputusan yang telah direkodkan, keadaan semasa mesin tersebut boleh diketahui dan maklumat ini sangat penting dan berguna untuk tindakan pencegahan pada masa hadapan.

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C	-	Error vector
x,y,z	-	Direction of linear motion error
a,b,c	-	Rotation around X,Y,Z axis
X,Y,Z	-	Direction of nominal axis' movement

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the CNC machine tool is the most preferred manufacturing equipment for production. It has been widely used for various purposes such as for flexible automation, machining accuracy improvement, reduce lead time, and aggressively reduce the production cost. Therefore, the ability of CNC machine tools should be improved in order to meet the various needs. The most desirable improvement is the ability to achieve high efficiency and high precision machining.

There are many factors that determine the machining accuracy and efficiency of CNC machine tools (for roughing, it is mainly determined by the limit of the chip removal rate with regard to chatter vibration). Primary factor that influences machining accuracy is the motion accuracy of the machine tool. When there is a motion error in a machine tool, it will be transferred to the machined profile and thus increases the profile error of the machined surface. Therefore, knowing the motion accuracy is indispensable for high precision machining. If the dimensional error and the profile error of the elements of a machine tool are large, the motion accuracy will be bad. It is also influenced by the assembly and the adjustment of the control system.

There are different types of motion errors existing in CNC milling machines. As the increasing number of CNC machines in manufacturing field, there is a need to ensure the machines are in good running condition. Machine tools such as CNC vertical milling machines are required to achieve certain machining accuracy. Therefore periodic and preventive maintenance of the machine is crucial.

The predictive maintenance has grown to become popular in maintenance activities. This is due to the current CNC machines have become more complicated, integrated and expensive. The costs of parts or components are expensive and uneconomic to use regular preventive maintenance system. The predictive maintenance has been reputed as the most suitable types of maintenance activities.

Motion error characteristic is one of predictive maintenance techniques in CNC machines. The purpose of this research is to find out any abnormalities to machine performance. This machine performance will convert to high quality product. These motion errors of CNC are analysed by using Double Ball Bar (DBB) Circular Interpolation Test Kit. This equipment is designed to analyse the machine performance by measuring the accuracy of its movements.

This device has two identical size balls at the end of the bar was mounted on spindle and onto a special holder which is mounted on the working table. The machine is made to move in a circular motion, clockwise and anti-clockwise in desire planes such as XY, YZ or ZX. Any deviation from the standard data will represent the imperfection of machine condition especially mechanical components such as slide bearing, spindle bearing or servo motor responses.

Methods for performance evaluation of computer numerically controlled machining centers (ASME, 2005) will be used in the analysis. Motion error analysis is actually the analysis of contouring performance of the machine. This involved machine servo motor performance, feedback performance, mechanical structure and servo control system.

Motion error characteristics activities should be performed at early stage of machine life. When the machine is new, the motion error analysis should be recorded as the reference for future analysis. Machine performance will be deteriorated, as time passing by therefore it's a crucial to compare the reference data which has been taken at early stage with the existing machine condition. Any deviation from the data shows the machine performance. The research is focused on the on circular type of motion errors.

Data from this analysis is essential for maintenance engineer to predict a failure and make necessary actions to resolve the issue. There several methods for measuring circular motion accuracy which are double ball bar method, master ring and a displacement type probe method besides direct cutting test. Double ball bar is selected for this research, because of its simplicity and yet capable of giving high accurate result. The equipment also suitable for predictive maintenance usage to record and diagnose machine condition. The double ball equipment used as the measurement tool is from Heidenhain Double Ball Bar Circular Interpolation Test Kit (DBB 110). This equipment also is equipped with Heidenhain ACCOM Evaluation Software to ease data retrieving and diagnosis guides.

1.2 Statement of Research Problem

This research is concentrated on measuring machine motion accuracy by using the double ball bar device on the vertical CNC milling machines. Standard double ball bar circular interpolation test kit came with 150 mm, 200 mm, 250 mm and 300 mm extension bar sets. These restriction cause a smaller machine with axis stroke, R less than 150mm are unable to be measured by double ball bar method. This research will propose the motion error characteristics for CNC milling machine that have axis stroke, R less than 150mm.

Accuracy measurement for CNC machines by double ball bar method are highly dependent on number of machine axis stroke that involve. Performing accuracy measurement which covers multiple machine axis strokes will require multiple set of circular interpolation test. Circular interpolation test such as master ring method, displacement type probe and the direct cutting test are expensive, troublesome and time consuming. Furthermore, there are problem concerning the measuring accuracy of the measuring equipment. Even if the measurement is accurate, there is no method to analyse which part of the machine tool lowers the accuracy and thus the error origins cannot be diagnosed.

1.3 Research Objectives

The primary factor that influences machining accuracy is the motion accuracy of the machine tool. When there is a motion error in a machine tool, it will be transferred to the machined profile and thus increases the profile error of the machined surface. Therefore, knowing the motion accuracy is indispensable for high precision machining. The main objectives of this research are:

i. To measure the motion accuracy and to diagnose error origins of CNC vertical milling machine.

ii. To establish error characteristics for CNC vertical milling machine that have axis stroke, R less than 150mm.

iii. To perform accuracy measurement which covers multiple machine axis strokes.

1.4 Scopes of The Project

The scopes of work define the specific field of the research and ensure that the entire content of this research is confined within the scope. Heidenhein double ball bar circular interpolation test kit and Heidenhain ACCOM Evaluation Software package were used as the tools for this analysis. Thermal deformation is neglectable and the error is caused only by feed motion. The elements of the machine are considered as rigid bodies where each vector will remain the same even if angular error exist. Use of R=150mm as the standard value for measuring radius and the four other standard values which are 140mm, 130mm, 120mm and 110mm are obtain by using magnification of measurement. The circular interpolation motion (G03) is used to rotate the spindle in clockwise (CW) and counter clockwise (CCW) direction in the XY plane with feed rate of 500, 800, 1100 1400 and 1700 mm/minute. This research is based on ASME B.5.54-2005 standard which is developed by American Society of Mechanical Engineers (ASME, 2005).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains the accuracy tests definition, definition of motion error, circular interpolation test, previous research on motion errors analysis, equipment for measuring motion accuracy errors, and double ball bar procedure. This literature is useful as background to introduce CNC vertical milling machine motion error analysis by double ball bar (DBB) method.

2.2 Accuracy Tests Definition

The primary factor that influences machining accuracy is the motion accuracy of the machine tool. When there is a motion error in a machine tool, it will be transferred to the work part machined profile and thus increases the profile error of the machined surface. Therefore, knowing the motion accuracy is indispensable for high precision machining. If the dimensional error and the profile error of the elements of a machine tool are large, the motion accuracy will be bad. It is also influenced by the assembly and the adjustment of the control system.

For machine tools which have a circular interpolation function, such as the CNC vertical milling machine, the following tests are used for motion accuracy inspection:

i. Test of dimension and profile accuracy by linear cutting

ii. Test of positioning accuracy by boring and

iii. Test of profile accuracy by cutting the circumference of a disk using an end mill cutter

These tests are made after the assembly and the adjustment of the machine tool, therefore there is an advantage of knowing how precise machining can be and what the influences of tool, work piece and fixtures are. However after machining, it is necessary to measure the accuracy of the work piece by a three coordinate measuring machine, a roundness measuring machine, or a surface roughness measuring machine. This is troublesome and time consuming. Furthermore, there are problems concerning the measuring accuracy of the measuring equipment. Even if the measurement is accurate, there is no method to analyse which part of the machine tool lowers the accuracy, and thus the error origins cannot be diagnosed.

For these reasons, Double Ball Bar (DBB) is an excellence device to resolve several issues of fast measuring accuracy and able to perform diagnosis. For the telescoping bar type DBB, the bar which connects the two balls has an elastic mechanism or a sliding mechanism that enables the telescopic movement to be read out. It can be used to measure the motion error of a three coordinate measuring machine, a milling machine, a machining centre, a boring machine, a planer type milling machine, a jig boring machine, a jig grinding machine, an industrial robot, or any other machines that are driven by CNC and have circular interpolation motion. In the measurement with the telescoping DBB, any point on the surface of the balls of the DBB can be used as the measuring point. Practically, the motion of one axis is fixed and has a circular interpolation motion on the other two axes. The measuring equipment records the points on a circular curve, enlarges the extension or compaction of the bar and then shows them in polar coordinates (it is called the motion error trace).

Then the trace is analysed and the volumetric accuracy is evaluated. In addition, since most of the CNC machine tools do not have a circular interpolation motion by a three axis continuous path control, the circular interpolation motion only can be used on a two axis continuous path control for measurement.

There is a measuring method which is similar to the DBB method. It was conducted by Knapp and Matthias (1983) using a master ring and a displacement detecting type probe and was developed in the same period as the DBB method. It is similar to the DBB method theoretically but is different in the apparatus. The probe is a contacting type, therefore it is not as good as the DBB method for high speed and high precision measurement, but it is suitable tor measurement on a small machine.

Kakino et al. (1993) have developed a method to diagnose the main error origins in machine tools by motion error traces. To do this, they first defined the error vector caused by each origin and then derived its trace pattern. The error origins can be located by observing whether these patterns appear in the motion error trace. To apply this method, some experience and some knowledge about the mechanical structure and the servo control systems are required. But normally, simple machine tool manufacturers who were introduced to the DBB method could master it within a short period of time and make full use of it. At present, there are three uses for the DBB method:

i. To discover the weak points in the mechanical structure of prototype machines and to eliminate them during the developing stage of CNC machine tools.

ii. To make the last adjustment and accuracy inspection when CNC machine tools are delivered or received.

iii. To make accuracy inspections during regular inspection of CNC machine tools.

2.3 Definition of Motion Error

In their book on Accuracy Inspection of NC Machine Tools by Double Ball Bar Method, Kakino et al. (1993) had explained the definition of motion error. This type of error is also known as error vector. The specified position of a point in three dimensional orthogonal coordinates is labelled as (X, Y, Z), and the actual position is (X', Y', Z'), then the error vector of the specified position is defined as

$$C = (C_x, C_y, C_z) \tag{3.1}$$

Where,

$C_x = X' - X$

$C_y = Y' - Y$

$C_z = Z' - Z$

The vector that shows the linear motion errors of each axis movement is defined as

$$\overrightarrow{E_j} = (e_{xj}, e_{yj}, e_{zj}) \qquad j = X, Y, Z$$

And the vector that shows the angular motion errors of each axis movement is expressed as

$$\overrightarrow{R_j} = (a_j, b_j, c_j) \qquad j = X, Y, Z$$

Where,

x,y,z : direction of linear motion error

a,b,c : rotation around X,Y,Z axis

X,Y,Z : direction of nominal axis' movement

Let a point on a workpiece clamped on the table be P_w (X_w, Y_w, Z_w) and the spindle nose be P_s (X_s, Y_s, Z_s). With reference to a coordinate system whose origin is P_w and whose axes are parallel to the nominal axes movements, the relative coordinate of the spindle nose is expressed as (X, Y, Z). Let the machine datum be O, the centre points on the sliders of the X, Y and Z axes, at which each slider contacts its guide way or ball screw, be A, B, and C, and the position of A, B, and C when P_w agrees with P_s will be A_o, B_o, and C_o respectively.

$$\overrightarrow{P_w P_s} = \overrightarrow{OP_s} - \overrightarrow{OP_w}$$

$$= (X_s - X_w, Y_s - Y_s - Y_w, Z_s - Z_w)$$

$$= (X, Y, Z) \tag{3.2}$$

Furthermore, when the machine elements and the guide mechanism are considered, $\overrightarrow{OP_s}$, $\overrightarrow{OP_w}$ can be expressed as follows.

$$\overrightarrow{OP_s} = \overrightarrow{CP_o} + \overrightarrow{C_o C} + \overrightarrow{CP_s} \tag{3.3}$$

$$\overrightarrow{OP_w} = \overrightarrow{OB_o} + \overrightarrow{B_o B} - \overrightarrow{BA_o} + \overrightarrow{A_o A} + \overrightarrow{AP_w} \tag{3.4}$$

Where,

= (X, 0, 0)

= (0, Y, 0)

= (0, 0, Z)

Figure 2.1 : Typical CNC Vertical Milling Machine

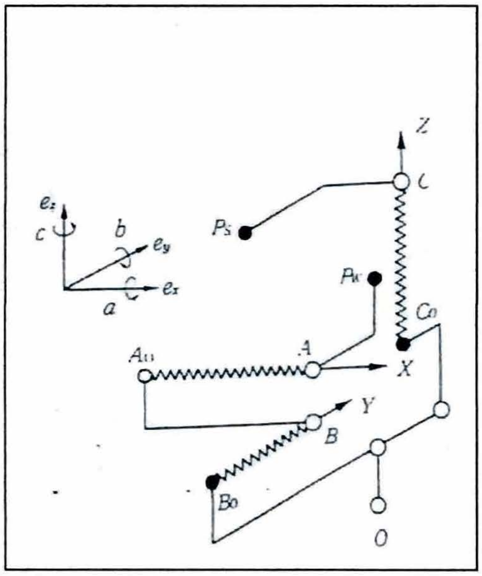

Figure 2.2 : Structure of The Vertical Type Machining Centre

2.4 Circular Interpolation Test

There are three methods that can be used for the circular interpolation test which are:

i. The Double Ball Bar (DBB) method

ii. The method using a master ring and a displacement type probe

iii. The direct cutting test

As shown in Figure 2.3, the detecting part of the DBB device has two steel balls that are supported by three point contact magnetic sockets which are clamped to the spindle nose and on the table, respectively. These balls are connected by a telescoping bar whose telescopic movement can be detected, the centre of the ball clamped on the table socket. P_w. is used as the centre of rotation and the centre of the ball on the spindle socket. P_s performs a circular interpolation motion at a radius, R and the telescopic movement of the bar is expressed in polar coordinates.

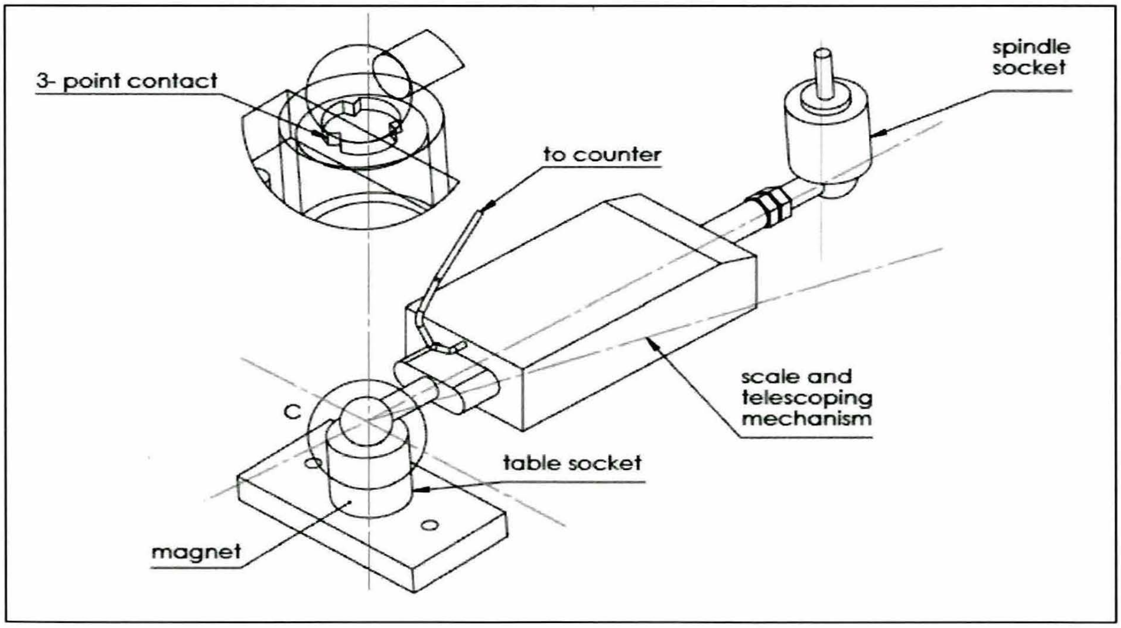

Figure 2.3 : DBB Device