CHARACTERISTICS OF MOTION ERRORS OF 3 –AXIS CNC VERTICAL MILLING MACHINES

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ABSTRACT

This project presents a systematic approach to understand the different types of motion errors exist in Computer Numerical Controlled (CNC) machines. This research focused on five units of identical CNC milling machines, that is, the same brand, model and years of operation. 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 meant to produce precise workparts, therefore is important to maintain their accuracy. Periodic and preventive maintenance of the machine is crucial, whereby motion error inspection is one of predictive maintenance activities in ensuring CNC machines are in good working condition. The purpose of this project is to find out any abnormalities to the machine performance. The motion errors of CNC machines were analysed by using Double Ball Bar (DBB) measuring device. This equipment is designed to analyse the machine performance by measuring the accuracy of its movements. This device having 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 three planes, XY, YZ and 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. Based on the study, DBB equipment has successfully captured the motion errors of five units of 3-axis CNC vertical milling machines. Diagnosis has been done and several error origins have been presented in this study. By knowing the most significant error origin, the corrective countermeasures can be carried out.

ABSTRAK

Kajian ini di lakukan untuk memahami kewujudan pelbagai jenis ralat gerakan dalam pemesinan CNC pengisar. Kajian ini akan tertumpu kepada mesin CNC pengisar yang sama jenis, pembuat dan jangka hayat.Peningkatan pengunaan mesin CNC di dalam bidang pembuatan, telah wujud kepentingan untuk memastikan mesin yang diguna sentiasa dalam keadaan yang baik. Pemesinan mesin seperti CNC pengisar amat mementingkan untuk mencapai ketepatan yang tertentu.Oleh sebab itu, penyelengaraan ramalan adalah penting untuk memastikan mesin sentiasa berada dalam keadaan memuaskan.Pemeriksaan ralat gerakan untuk mesin CNC pengisar adalah selari dengan kehendak penyelenggaraan ramalan. Tujuan aktiviti tersebut adalah untuk mendapat sebarang bentuk kecacatan pada prestasi mesin.Ralat pergerakan akan diukur dengan mengunakan alat pengukur yang di kenali sebagai “double ball bar”. Kegunaan peralatan tersebut adalah untuk mengukur ketepatan mesin dalam pergerakan. Peralatan ini akan di pasang pada “spindle” dan pada permukaan mesin dengan mengunakan peralatan yang khusus.Sebarang bentuk penyimpangan pada data pada peralatan tersebut, menunjukkan ketidak sempurnaan komponen mesin terutama bahagian mekanikal seperti galas pada “spindle, galas pada “working table”, motor servo dan banyak lagi.Berdasarkan kajian yang di buat, peralatan tersebut telah berjaya merakam beberapa ralat gerakan pada 5 mesin yang di kaji.Diagnostik pada ralat tersebut telah dikaji dan punca ralat tersebut telah di bentangkan dalam kajian ini. Punca ralat tersebut adalah amat berguna kepada pemilik mesin untuk membuat tindakan susulan.

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ABBREVIATIONS

ABBREVIATIONS	DESCRIPTION
NC	Numerical Control
CNC	Computer Numerical Control
DBB	Double ball bar
ASME	American Society of Mechanical Engineers
ANSI	American Standard Institute
DC	Direct Current
LVDT	Linear variable differential transformer
JIS	Japanese Institute Standard
MZCRW	Minimum Zone Centre Radial Width
PCRW	Polar center radius centre
CW	Clockwise direction
CW	Counter Clockwise direction
PID	Proportional Integral Devices

LIST OF SYMBOLS

X,Y,Z	= Direction of nominal axis
Cx	= Error vector in X-axis
Cy	= Error vector in Y-axis
Cz	= Error vector in Z-axis
x,y,z	= Direction of linear motion
a,b,c	= Rotation around X,Y,Z
Pw	= Workpiece clampn on table
Ps	= On spindle base
Ay,by,cy	= Angular motion
exX	= Positioning error of X-Axis feed
eyX	= Straightness in Y axis
ezX	= Straightness in Z-axis
Xs, Ys	= Centre offset
Rs	= Centre offset
μm	= Mirometer
ω	= Angular velocity

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CHAPTER 1

INTRODUCTION

1.0 Introduction

This project presents a systematic approach to understand the different types of motion errors existed in CNC machines. This research was focused on five identical units of CNC machines with same brand, model and years of operation. As the increasing number of CNC machines in manufacturing field, there is a need to ensure the machines are at good running condition. Machine tool such as CNC vertical milling machines is important to achieve certain machine accuracy. Therefore periodic and preventive maintenance of the machine is crucial.

Now days, 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 characteristics are one of predictive maintenance 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). This equipment is designed to analyse the machine performance by measuring the accuracy of its movements.

This device having 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 three planes, XY, YZ and 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.

The ANSI/ASME B.5.54-1991 standard method of performance evaluation of computer numerically controlled machining centres was need 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.

The data obtained from the measurement was analysed based on previous recorded data from manufacture. This data is actually based on historical records made by actual machine performance. This type of maintenance 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 is suitable also 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 110. This equipment also is equipped with software to ease data retrieving and diagnosis guides.

Maintenance is one crucial aspect in manufacturing engineering. It started with Industrial evolution, where parts or components are massively produced. Machine is designed to produce all of the required components in massive volume. Even though that, long hours operation requires the machine to be maintained to avoid unnecessary breakdown. At early stage, they still can afford to have a machine breakdown since the machine is manually operated and the machine is simple thus easy to repair. At this stage, they practice breakdown maintenance, which seems suits to their requirement of operation.

In new modern manufacturing industry, machine has become more efficient, complicated and fully automated. This type of new generation machines only required fewer man powers to operate because of automation functions. Thus this new feature, able to increase the volume of production but it requires new maintenance principles. This new machine cannot afford to breakdown, since the investment cost of the machine is high. Each downtime is a lost for the investor. From economic point of view, in order to produce part at effective cost is by producing at high volume. Machine components become expensive which requires new type of maintenance to cater this problem.

There several new maintenance principles which are preventive maintenance, condition based maintenance and predictive maintenance. Preventive maintenance is an activity performs based on periodic basis. For example replacement of bearing in DC motor is scheduled 5 years once. This means every 5 years the bearing must be replaced even though the condition still good. This type of maintenance is suitable for low cost mechanical and several electrical components. For high expensive components and electronic components condition based maintenance is more suitable. Condition based maintenance is based on scheduled inspection of desired parts. Parts are only replaced if it is damaged. This will reduce the maintenance cost, but this type of maintenance requires regular checking and checking equipment which are quite expensive. This type of maintenance also always combined with predictive maintenance which helps in performing maintenance at effective method. Compare to preventive maintenance, condition based and predictive maintenance is the best maintenance program for ensuring and preserving machine performance.

Motion errors analysis is one of condition and predictive maintenance for CNC machine application. Double ball bar is a device to measure the volumetric errors which consists of two high precision ball and magnetic sockets. The system can measure the distance between two points of the balls with high accuracy.

Figure 1.0 : Double ball bar device

5 identical Vertical CNC machines with 5 years of operation were used for this research. From this analysis, it is hoped to discover a few errors, Thereby will able to help reducing maintenance cost without jeopardize machine performance.

Figure 1.1 : Vertical CNC milling machine

1.2 Background and rationale

1.2.1 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. 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.The main objective of this project is to analyze the conditions of 3 axis CNC vertical milling machines by using the double ball bar equipment after 5 years of operations. Testing procedure performed by means of detecting the motion errors characteristic. The data recorded and characterized according to the suggested data trace pattern by manufacturer. 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.

1.2.2 Scopes of the project

The scopes of work define the specific field of the research and ensure that the entire content of this thesis is confined within the scope. It begun with the literature review on double ball bar. The next step is to determine which machine has the same type, model, manufacturer and years of operation. Five machines were chosen for this analysis with the same type, model and manufacturer. Heidentein Double ball bar and software package were used as the tools for this analysis. For each testing, 3 different types of motion and speed were used for this analysis. These are based on standard

posted by ANSI /ASME B.5.54.1991. The scope of work can be described in terms of flowchart as per the following Figure 1.2

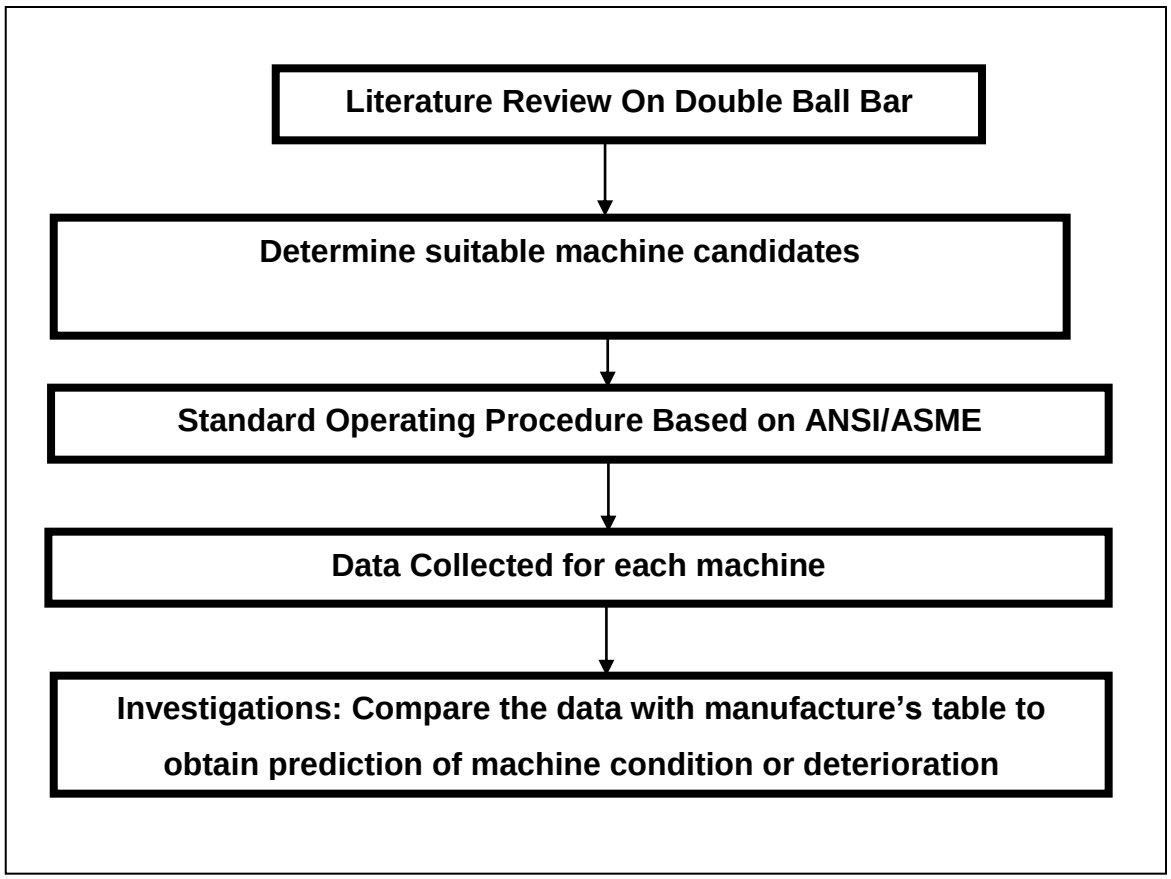

Figure 1.2: Flow chart represents the scope of work

1.3 Research problems and hypotheses

1.3.1 Statement of research problem

The measurement of motion errors are carried out to check whether the CNC machine are within the required performance, in terms of producing product within the expected tolerances. Measuring motion errors is part of the condition based maintenance for CNC machines. The exercise should also be performed at early age of the machine to use as benchmarks reference. This is crucial for the maintenance engineer to predict any possible breakdown. Performing ordinary preventive maintenance on CNC machine is too costly and ineffective; therefore condition based maintenance is the best way to maintenance the machine. This research is concentrated on measuring machine motion accuracy by using the double ball bar device on to machines which have been operation for 5 years. The machines selected are identical in terms of model, brand and years of operation. The user currently did not know what the machine accuracy condition as no precise test cut was performed. Performing test cut is an expensive and tedious method and also time consuming. Another alternative method is proposed by using double ball bar equipment, which able to produce accurate, reliable and high repeatability results.

1.3.2 Research questions.

Based on condition based maintenance data, several analysis and diagnosis can be made for future prediction of maintenance activities. This will prevent the machine to breakdown and to reduce the maintenance cost. This research concentrated on motion errors analysis onto machine with 5 years of operation. Different types of machine motion characteristics in terms of accuracy after 5 years of operations. If there are errors

found during the research, the errors will be characterized and narrowed down to the root cause of the errors.

1.3.3 Research hypotheses

To diagnose the motion error origin of a CNC machine tool from the motion error traces obtained by DBB measurements. However, there are several error origins that produce the same trace pattern. The mechanical structure and the control system of machine tools should be taken into consideration when specifying the error origin. Generally, if the error traces changes for different measuring positions, then we can conclude that an angular motion error exists. However, usually, both angular motion error and parallel motion error exist simultaneously.

The CNC machine is an electromechanical installation which encompasses a wide range of technologies, including mechanical machine components, hydraulics, pneumatics, electro technology, and electronic. As a result, the repair of CNC machines demand a high standard of knowledge and experience on the part of maintenance technicians. Training programs for CNC maintenance technicians often go into too much detail. The explanation of this principle serves only to satisfy the technical curiosity of trainees, but does not train the student to maintain the machine. Caution should be exercised with respect to randomly exchanging “plug-in” modules; this can be a costly practice. Components may be damaged during the exchange process, an inventory of parts will grow containing damage components, and more damage may be done to the machine. The systematic approach of error location is much better. In this context, CNC machines can be divided into three main groups:

Group 1 : Machine tool - axis and spindle drives, machine components, hydraulics, and pneumatics.

Group 2 : Measuring systems and control loops including transfer systems.

Group 3 : Electronic control - technology for digital and data processing, logic links, inputs and outputs units.

Through intensive cross-linking of these three groups – through control loops, measuring circuits, feedback circuits, and interlocks, for example –an error can become visible in one part of the system which is not directly linked to the defective part. This necessitates a complete understanding of the total system before a satisfactory error search can be performed.

Mechanical parts are usually one of the major causes of machine breakdown. This is because mechanical parts, involves with wear due to contact with other components. Mechanical parts also subjected to a lot of stresses which give the higher tendency to fail.