A Study of Pre-travel Variation of Coordinate Measuring Machine with Different Stylus Configurations

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Process) (Hons.)

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Saya **AHMED SAEED ALI SAEEDAN**

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) (Hons.). The member of the supervisory is as follow:

………………………………

P.M. Dr. Mohd Rizal bin Salleh

ABSTRACT

Coordinate measuring machine (CMM) is one of the sophisticated, most powerful and versatile metrological instruments. CMM measurements are not accurate as they are always subjected to errors due to various causes. Nevertheless, quantifying an error and later uncertainty puts doubts on the validity of the measurement result. Such a probe system is much responsible for the CMM measurement accuracy and the most important parameter characterizing probe inaccuracy is the pre-travel variation. This project studied the influence of using different stylus configurations toward the pre-travel variations and later identify the source of errors and the factors affecting the uncertainty of the measurement. Three factors were evaluated (stylus length, tip diameter of the stylus, and the approach distance) and a full factorial design was adopted for the experimental design followed by an ANOVA analysis to identify the significance of the factors toward the pre-travel variation and the uncertainty of the measurements. The experimental results showed significant effect of the three factors on both the pre-travel variation and the uncertainty of the measurement and there was an interaction between the stylus length and the tip diameter. It was also found that the stylus length has much influence on the results than the tip diameter and the approach distance was the least factor affected the measurements. Moreover, it was found that the increment of stylus length lead to a significant variations of pre-travel and uncertainties while the increment of the tip diameter at the smallest length of the stylus reduced the error propagation. Also, it was found that the smallest approach distance produced relatively higher pre-travel variation and uncertainties.

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LIST OF ABBREVIATIONS

ANOVA	–	Analysis of Variance
CMM	-	Coordinate Measuring Machine
CMS	–	Coordinate Measuring System
CNC	–	Computer Numerical Control
DOE	-	Design of Experiment
GUM	-	Guide to the expression of Uncertainty Measurement
ISO	-	International Organization for Standardization
PTV	–	Pre-travel Variation
RSS	-	Root Sum of the Square
TP	-	Touch Probe
UTeM	-	Universiti Teknikal Malaysia Melaka
VIM	-	International Vocabulary of basic and general terms in Metrology

CHAPTER 1
INTRODUCTION

This chapter presents a general overview of coordinate measuring machines (CMMs), states the problem of the project, and identifies the objectives as well as the scope of the project. Generally, this project is carried out to study, evaluate and analyze the probing system of CMM which is highly contributes to the uncertainty of CMM measurement and reduce its accuracy.

1.1 Overview / Background

In relation to the continuous advances in science and technology, measurements role has increased over the years in fields like manufacturing, information systems, electronics, nuclear, space, etc. According to International Vocabulary of Basic and General Terms of Metrology (VIM), it defines measurement as a process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity (VIM, 2012).

Measurements have become a tool of science. Metrology, however, is the science of measurement. It comprises all theoretical and practical aspects of measurement, such as units of measurement and their standards, measuring instruments and their field of application.

The list of metrology instruments and their capabilities have grown through the years. Coordinate measuring machines (CMMs) are one of the sophisticated, most powerful and versatile instruments CMM is an advanced quality control system. It used for many purposes to make inspection meet modern production requirements. Its primary function is to measure the actual shape of a workpiece, and compare it against the desired shape and evaluate the metrological information such as size, form, location, and orientation.

CMM is traced back to the year 1959 where it first appeared commercially at the International Machine Tool exhibition in Paris, exhibited by the British company Ferranti. The key element of the development of the CMM was the availability of an accurate, long-range, electronically compatible digital measuring system (Hocken & Pereira, 2012).

CMM is used in assembly and manufacturing processes to test a part or assembly against the design intent. It precisely records the X, Y, and Z coordinates of the target. Then, it generates points and analyses them, through algorithms, for the construction of features. These points are collected by using a probe that is positioned manually by an operator or automatically via computer control. The part for measurement is placed on the table of the CMM and aligned along the coordinate axis of the machine. The coordinate system of the part is created by the software and transferred to the coordinate system of the machine.

The economic success of most manufacturing industries is critically dependent on how well its products are made, a requirement in which measurement plays a key role. Coordinate Measuring Machine (CMM) is one of the most adequate measuring machines to meet the requirement. Due to high sensitivity and speed, CMMs have to be in a controlled environment to yield accurate results. Even with the advent of the CMM digital equipment readout and software packages to compensate errors and improve measurements, these measurements are not accurate because they are always subject to errors that are caused by either humans or materials. Quantifying an error to later quantify an uncertainty proves that the validity of the measurement result is doubted.

1.2 Problem Statement

There are many factors affect the uncertainty of CMM measurement. These effects that interact might be due operator when selecting a different probe or stylus. Other issues that can highly reduce the accuracy measurement of CMM are those errors related to temperature variations, vibrations, and even dirt. Different errors related to CMMs performance could be geometric errors due to the limited accuracy of the individual machine components such as guideways and measuring systems, errors related to the final stiffness of the moving parts, and thermal errors related to heat and cooling source in the environment, like lighting, air conditioning, ventilation, humidity, people around the machine and heat generated by the machine itself.

Quantifying uncertainty of CMM measurements is a very complex object, however minimizing an error factor will contribute to the accuracy improvement of CMM measurements (Ali, 2010). Such a probe system of CMM is much responsible for the coordinate measurement accuracy. It includes stylus and stylus tip which have its own dynamic characteristics during the measuring process. The probe stylus tip is a key element of coordinate measurements; it contributes to the overall performance of the CMM.

The most important parameter characterizing probe inaccuracy is the pre-travel variation which can be determined using a master sphere of known radius (Woźniak & Dobosz, 2005). Desai and Bidanda (2006) mentioned that the type of probe used for measurement is an important factor that influences the accuracy of CMM; such a touch-trigger probe, it has several factors related to its motion (e.g. approach speed, and probe acceleration) and configuration (e.g. probe stylus length) which influence its performance. Therefore, this study was carried out to compare the influence of using different stylus configurations toward the pre-travel variations and later identify the source of errors and the factors affecting the uncertainty of the measurement in order to minimize errors and increase the overall performance and measurement accuracy of the CMM.

1.3 Objectives

The objectives of this project are:

i. To identify the probing factors affecting the uncertainty of measurement.
ii. To compare the pre-travel variation of touch-trigger probe using different range of stylus configuration and extensions.

1.4 Scope

The accuracy of CMM measurement can be affected by various errors sources. In order to improve and obtain more accurate results, the source of errors should be eliminated or controlled. However, this study is focused on the performance and the evaluation of uncertainties of touch-trigger probe utilizing different stylus configurations and extensions which is highly related to reduce the accuracy of CMM measurements. The scope of this project will ensure that the project is conducted within its intended objectives and it should be eventually achieved. The scopes of this project are listed in the following points:

i. Literature study on the related theories and most updated researches will be reviewed.
ii. The parameters to be used which are highly related to reduce the CMM accuracy are probe stylus length, different tip diameter and probe approach distance.
iii. The measurements will be done using a master sphere of a known radius.
iv. All results will be compared, and errors, uncertainties and pre-travel variation of the result will be evaluated as well.

1.5 Project Organization

This project is divided into two phases. The first phase comprises of three chapters. The first chapter contains a general overview of coordinate measuring machines (CMMs), states the problem of the project, and identifies the objectives as well as the scope of the project. In the second chapter, a literature review will be provided to investigate, analyze and compare the various and most updated research on the area related to the project. While the third chapter provides a methodology to accomplish the project, where it explains and illustrates the direction and the flowchart(s) of the project. The second phase will then start after all studies being carried out which includes chapter 4 and chapter 5. The results and discussion will be provided in chapter 4, while the last chapter will enclose the project with conclusions and suggestions. The Gantt charts of phase one and phase two are provided in appendix A.

CHAPTER 2

LITERATURE REVIEW

Many researches were conducted on evaluating the performance of CMM in general. Some of such researches are on probing system where as others were on identifying the dynamic errors of CMMs and other likely studies. The main purpose of this chapter is to investigate, analyze and compare the various and most updated research on the area of CMM probing systems. This chapter basically presents the literature reviews on the areas of the research. A brief review about the types of CMM will be presented. A classification of probing system and its types will also be reviewed as well as the mechanism and the performance of touch trigger probe. In addition, a brief overview about uncertainties and errors in CMM measurements and their sources will be covered. Finally, the most factors influence the accuracy of CMM probing system will be discussed.

2.1 Types and Constructions of CMM

The general basic components of any CMM consists of three linear axes(x , y, and z) mechanical frame, a probing system, a control unit, and a computer system which are integrated to enable readout and analyze the distances of the part being measured (Hocken & Pereira, 2012). The mechanical frame provides a guide way that enable precise movement along a straight line. Each of these guide ways (x, y, z) has a carrier that moves along by which it enables the second carrier to move along a straight line based on the first guide way. Each of three linear axes is fitted with a precision scale that records the position of the carrier measured from a reference point. The probe system is fitted to the carrier on the third axis, and the object is being measured by the probe touches. Subsequently, the measurement system records the position of all three axes (Ratnam, 2009).

There are several physical configurations of CMMs. Each of these configurations plays an important role in its performance aspects such as accuracy, flexibility, cycle time, and life time cost. Although there are many commonly used configurations of CMMs but they can be grouped into five basic types as follows:

1. Cantilever type,
2. Bridge type,
3. Horizontal arm type,
4. Column type and
5. Gantry type.

This study will be carried out on a moving bridge CMM since it is the most widely used type. Figure 2.1 illustrates the components of bridge type CMM.

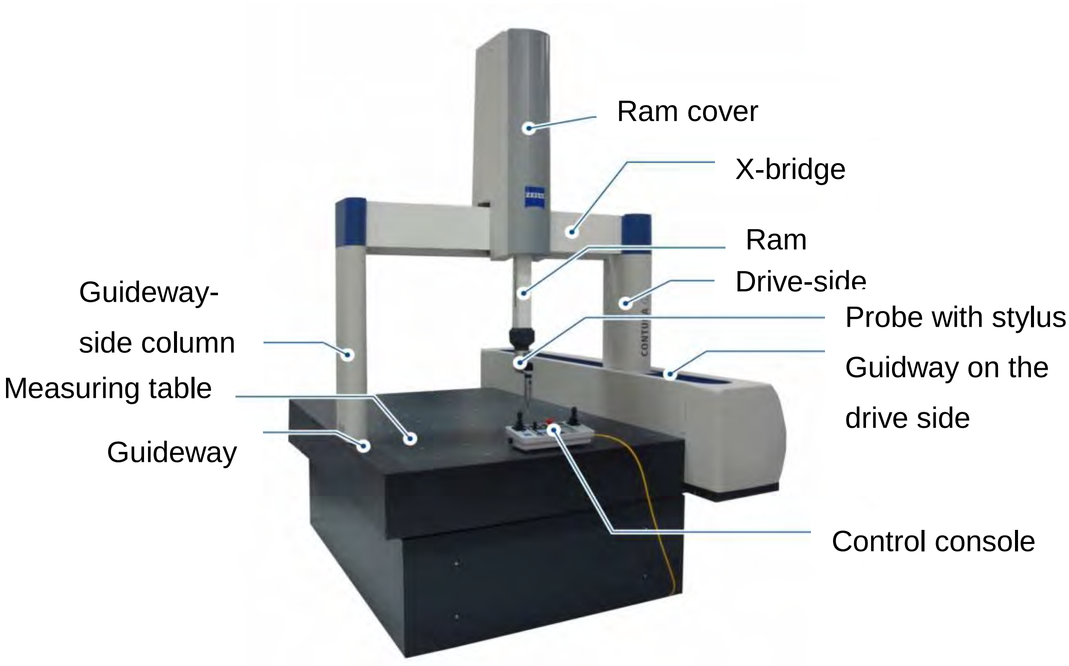

Figure 2.1 Bridge Type CMM CONTURA G2

2.2 Probing System

The probe is one of the most important elements of coordinate measuring machine (CMM), it integrates the entire measuring system and forms a link between the machine and the work to be measured and it is responsible for the overall accuracy of a measurement (Weckenmann et al. 2004). It is the sensing element that makes contact and causes readings to be taken.

2.2.1 Classifications and Categories of Probing System

There are a verity of probes exist, these can be categorized into two different types of probe: contact (tactile) and non-contact probes which are practically used in modern CMMs (Hocken & Pereira, 2012). The type of probe to be utilized however is an important aspect to take into account when the precision of a particular CMM is going to be evaluated (Puertas et al., 2013).

Ali (2010) noted in his research that contact probes can also be classified into two specific families of manual hard probes and touch-trigger probes. However, Woźniak and Dobosz (2003) stated that contacting probes are categorized into tough trigger and measuring systems. Figure 2.2 calcifies the huge variety of probing systems to distinct application-oriented aspects, and Figure 2.3 classifies the probing systems according to principle of operation.

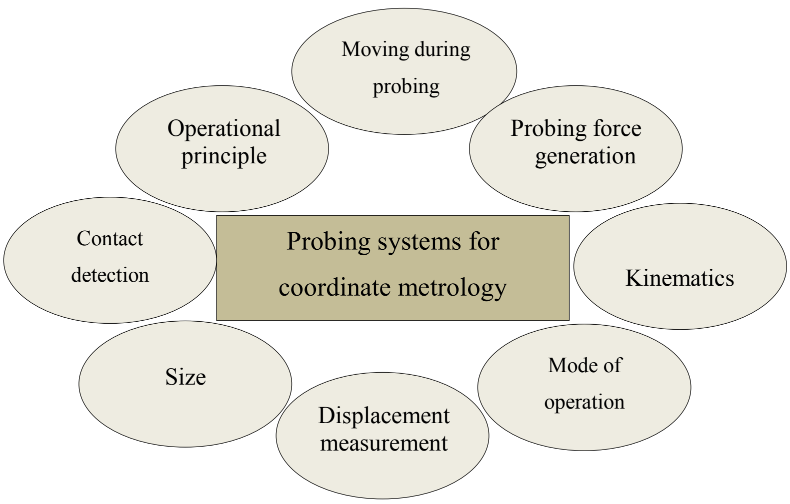

Figure 2.2 Classification criteria for probing systems (Hocken & Pereira, 2012).

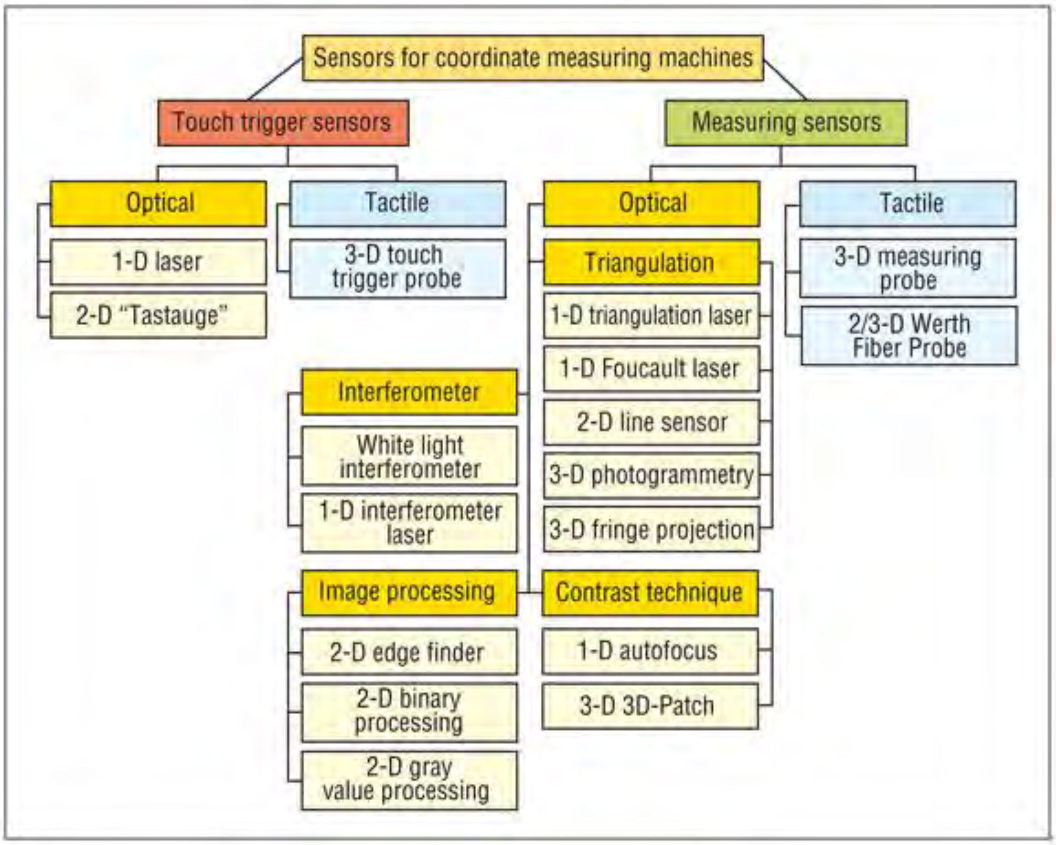

Figure 2.3 Sensors for coordinate measuring machines classified by principle of operation (Christoph & Neumann, 2007)

The literature of Weckenmann et al. (2004) has explained all of the above mentioned types of contact probes. In the same literature the authors also stated that the contact probes have at least the following components (Figure 2.4) to fulfil their task as the linkage between CMM and part to be measured:

i. A probing element to establish an interaction with the workpiece surface.
ii. A transmitting device to transfer information about the interaction from the touching element to the sensor (e.g. stylus shaft)
iii. A force generating and controlling element to produce a defined probing force (e.g. spring).
iv. A sensor to sense the interaction of the touching element with the workpiece (e.g. electric switch, force sensor).

v. An output (interface to the CMM) transmitting the information for triggering a length measuring device (e.g. scale) or for further processing (e.g. correction of bending, taking into account qualified tip ball radius, evaluation in instrument's software).

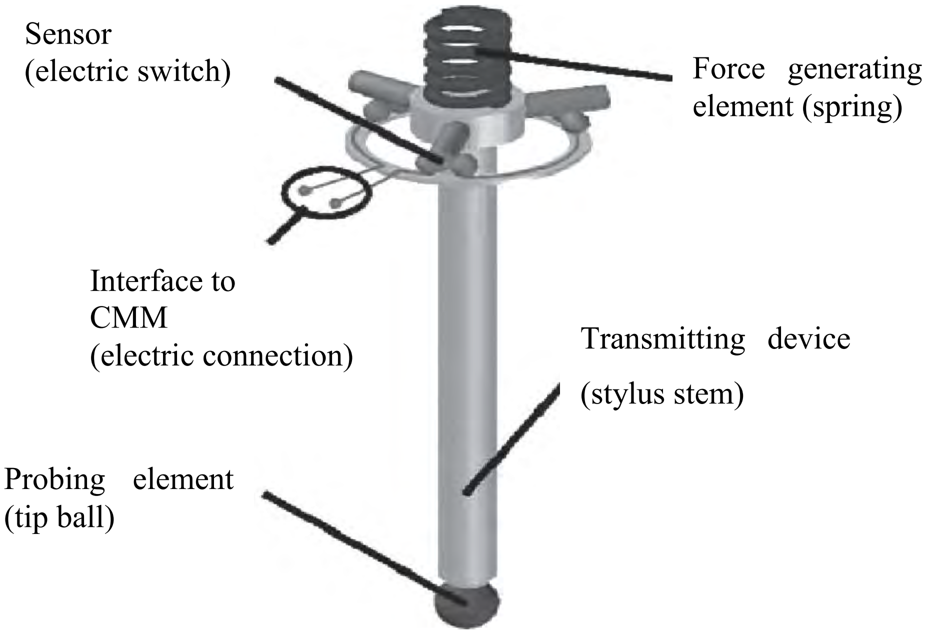

Figure 2.4 Basic tactile probing system in kinematic resistive design (Hocken & Pereira, 2012)

The hard probes are used with manual CMMs for low and medium accuracy requirements, because their repeatability quality depends upon their operator touch. Recently the touch-trigger is the common used probe in CMM, it gives a higher quality of measured data compared to the hard probe type by eliminating the influence of operator touch, as it can be fitted on direct computer numerical control (CNC-CMMs) and manual CMMs system.

Many studies were conducted to describe the optical and large range probing and measurement systems (Estler et al., 2002; Schwenke et al., 2002), others were to evaluate and improve the optical probing measuring accuracy of CMM (Chao et al., 2011; Carmignato & Savio, 2011). Because of the huge variety of implementations, and the general nature of the task of probing systems, this study will focus on the touch-trigger probes.