Ain Shams University

**Ain Shams University**

**Faculty of Engineering**

**Design & Production Engineering Department**

# Performance Evaluation of CNC Machine Tools

By

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Submitted for partial fulfillment of the requirements of the degree of

Doctor of Philosophy

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# STATEMENT

This Thesis is submitted in Partial fulfillment for the degree of Doctor of Philosophy in Mechanical Engineering.

The work included in this Thesis was carried out by the Author in the Design & Production Engineering Department, Faculty of Engineering, Ain Shams University.

No part of this Thesis has been submitted for a degree or a qualification at any other University or Institution.

Eng. Omar Monir Mohamed Farid Koura

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# ABSTRACT

Accuracy could be defined as the degree of agreement or conformance of a finished part with the required dimensional and geometrical accuracy. Error, on the other hand, can be understood as any deviation in the position of the cutting edge from the theoretically required value to produce a workpiece of the specified tolerance. The extent of error in a machine gives a measure of its accuracy; that is the maximum translation error between any two points in the work volume of the machine.

Over the years, machine tool evolution has allowed faster equipment, using new configurations, to manufacture parts that were almost impossible to machine in the past. Workpieces with contours composed of several straight lines or curved surfaces are applied widely in various types of CNC machinery components, as well as in cutting and stamping tools, gages, templates, etc. The finishing quality of these composite or non-regular contour surfaces has always been accepted as obtained directly from the CNC machines. Thus, the dimensional and geometrical accuracy of the component are mainly function of machine geometrical accuracy, thermal distortion in both components to be machined and in the structure of the machine itself and errors developed due to cutting forces. The first cause is usually considered to be the main factors due to the stiffness and rigidity by which CNC machines are produced nowadays. But still the geometrical accuracies of the machine are measured as separate parameters.

ASME and ISO standards defined the Geometrical errors in what is known as 3-axes Machining centers. Although the manufacturers of the CNC machines try to control each error individually between certain limits depending upon the aimed accuracy of the machine, but still the cumulative error of the machine or the volumetric error is not known. However, further nine sources of errors force themselves to look to be more effective. Those errors are related more to the dynamic operation of the machine. Three are the kinematic (linkage) errors of

the drives and moving parts, three result from the heat generated due to environment, cutting motions and drives, thus causing distortion to the part to be machines and to the structure of the machine. The last three are due to the cutting forces which, again, cause deflection of parts.

For this reason, the aim of the present work is to determine the overall volumetric error which gives real indication of the expected accuracy of the part to be produced. At the same time, this volumetric error can be used for error compensation.

The thesis consists of six chapters, four appendices and both Arabic and English summaries.

In this work linear regression, non-linear regression and Artificial Neural Network technique (which can be defined as a data processing system consisting of large number of simple, highly interconnected processing elements in an architecture inspired by the structure of the cerebral cortex of the brain) are used to present different models combining all 33 errors to get an output representing the volumetric error. In the case of ANN model, the thesis contains its formulation and the trials that were followed till the proper number of hidden layers was determined. The model was, then, trained by some data and finally verified by other set of data. The three models were compared and the ANN model proved to present good results for the volumetric errors.

**Summary of Ph.D. Thesis**
**"Performance evaluation of CNC machine tools"**
**By**
**Omar Monir Mohamed Farid Koura**

Over the years, machine tool evolution has allowed faster equipment, using new configurations, to manufacture parts that were almost impossible to machine in the past. Workpieces with contours composed of several straight lines or curved surfaces are applied widely in various types of CNC machinery components, as well as in cutting and stamping tools, gages, templates, etc. The finishing quality of these composite or non-regular contour surfaces has always been accepted as obtained directly from the CNC machines. Thus the dimensional and geometrical accuracy of the component are mainly function of machine geometrical accuracy, thermal distortion in both components to be machined and in the structure of the machine itself and errors developed due to cutting forces.

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For this reason the aim of the present work is to determine the overall volumetric error which gives real indication of the expected accuracy of the part

to be produced. At the same time this volumetric error can be used for error compensation.

The thesis consists of six chapters, four appendices and both Arabic and English summaries. The content of each is:-

Chapter one contains a general introduction summarizing the errors involved with the CNC machining operation.

Chapter two contains the literature review summarizing part of the researches which has been published and has relations with the errors in machining on CNC machine tools. The problem was identified and the aim of the present work was fixed.

Chapter three contains analysis of the theoretical methods; namely the multiple linear regression, the non-linear regression and the artificial neural network technique.

Chapter four contains the application of the multiple linear regression and the non-linear regression on the errors in CNC machine tools.

Chapter five contains the application of the artificial neural network to solve the problem. The chapter, also, contains its formulation and the trials that were followed till the proper number of hidden layers was determined. The model was, then, trained by the data and finally verified. The three models were compared and the ANN model proved to present good results for the volumetric errors.

Chapter six contains the conclusion of the work.

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# CHAPTER ONE

# INTRODUCTION

In the past, when higher dimensional accuracy or better surface quality is needed for a manufactured part, extra finishing operations were carried out on other type of finishing machines such as grinding machines. Dimensional and geometrical accuracy of the component are mainly function of machine geometrical accuracy, thermal distortion in both components to be machined and in the structure of the machine itself and errors developed due to cutting forces. But, as CNC machine tools came to existence by the end of 1950s and as their technology has grown very fast to be improved to the extent that work pieces with contours composed of several straight lines or curved surfaces are now being manufactured with highly reasonable dimensional tolerances and surface quality. The finishing quality of these composite or non-regular contour surfaces has always been accepted as obtained directly from the CNC machines. Thus, the dimensional and geometrical accuracy of the component are mainly function of machine geometrical accuracy, thermal distortion in both components to be machined and in the structure of the machine itself and errors developed due to cutting forces. The first cause is usually considered to be the main factor due to the stiffness and rigidity by which CNC machines are produced nowadays. But still the geometrical accuracies of the machine are measured as separate parameters. Such facts were achieved due to maintaining in those machines tight clearances in their slide ways, almost backlash elimination in the ball screws and spindle bearings together with rigidity and stiffness in the machine construction.

Added to the great improvement in the mechanical side of the machine parts, came the tremendous improvement in the control systems, interpolation techniques, servo drives and computer utilization in a broad range of applications. All that resulted, with advanced cutting tool