EXPERIMENTAL ANALYSIS OF MACHINING PERFORMANCE BASED ON SELECTED CUTTING PARAMETERS FOR SMART CNC TURNING ENVIRONMENT

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To my beloved family, Father, Hj. Mohamad Bin Lebai Ibrahim, Mother, Hjh. Kuntom Binti Abdul, Wıfe, Noor Shaliza Binti Zainal Abidin, my Sons and Daughter, Muhammad Amirul Farish, Nur Aliya Nabila, Muhammad Amirul Hakimi, Brothers and Sisters. Thank for all your support .

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ABSTRACT

The purpose of this study is to analyze turning performance of Aluminium Alloy 6061 based on selected cutting conditions such as cutting speed, feed rate and depth of cut, in terms of acceptable range of surface roughness, with the integration of STEP-NC as a data structure. STEP-NC, an acronym for Standard for the Exchange of Product Model Data for Numerical Control is developed by the ISO committee with the intention of replacing the outdated G-codes used for machine execution. G-codes only contain point to point instructions directing the machine to move and machine the parts with lack of intelligence. Important machining parameters such as tolerance information, feature information and cutting tools information are missing and cannot be utilized at CNC level. In addition, it commonly embedded with specific extension of different vendors' added code depending on its controller making it lacks of interoperability. STEP-NC on the other hand provides comprehensive data structure and may provide information such as material properties, value of surface roughness, part feature and workingstep for the process. In this study, dry cutting operations of a 100mm Aluminum Alloy 6061 bar were turned into a 50mm length and 24mm final diameter based on the combinations of various cutting parameters set using Design of Experiments (DOE) method. The experimental results were statistically analyzed to study the influence of cutting parameters on surface roughness. Based on this, to suit the smart CNC turning environment, regression model were developed and were used in Graphic User Interface (GUI) algorithm in STEP-NC for the surface roughness value output. The outcome of this study shows that feed rate, cutting speed and depth of cut have significance effects on the surface roughness and the best surface roughness condition is achieved at a low feed rate 0.07 mm/rev, high cutting speed 280 m/min and depth of cut 0.1 mm. The results also show that the feed rate has big effect on surface roughness followed by cutting speed and depth of cut.

ABSTRAK

Tujuan kertas penyelidikan ini adalah untuk mencari prestasi pemesinan untuk kekasaran permukaan Aluminium Alloy 6061 berdasarkan memotong syarat (kelajuan pemotongan, kadar suapan dan kedalaman pemotongan,) dengan integrasi STEP-NC. STEP-NC menyediakan struktur data yang komprehensif dan berupaya memberikan maklumat seperti sifat bahan, nilai kekasaran permukaan, ciri bahagian dan langkahkerja untuk proses pemesinan yang dibuat. Dalam kajian ini, operasi pemotongan kering (tanpa menggunakan cecair memotong) bar 100mm Aluminium Alloy 6061 telah dilarik sepanjang 50mm panjang dan 24mm diameter akhir berdasarkan kombinasi pelbagai parameter pemotongan yang telah ditetapkan menggunakan kaedah Rekabentuk Eksperimen (DOE). Mengkaji hubungan yang wujud di antara panjang, pada diameter tertentu, dan kekasaran permukaan stok bar dalam operasi perubahan yang tidak disokong dalam usaha untuk mengurangkan sisa persediaan dalam mengubah operasi. Konsep Rekabentuk Eksperimen (DOE) telah digunakan untuk uji kaji perlu. Keputusan eksperimen telah dianalisis secara statistik untuk mengkaji pengaruh parameter proses kepada kekasaran permukaan. Model regresi telah dibangunkan dan digunakan di dalam algorithma Antara Muka Pengguna Grafik (GUI) dalam STEP-NC bagi mendapatkan nilai output kekasaran permukaan. Analisis varians mendedahkan dalam kajian ini adalah bahawa kadar suapan, kelajuan pemotongan dan kedalaman pemotongan mempunyai kesan penting kepada kekasaran permukaan dan keadaan kekasaran permukaan yang terbaik dicapai pada kadar suapan yang rendah 0.07 mm / rev pemotongan tinggi kelajuan 280 m / min dan kedalaman potong 0.1 mm. Keputusan juga menunjukkan bahawa kadar suapan mempunyai kesan yang besar kepada kekasaran permukaan diikuti dengan kederasan pemotongan dan kedalaman pemotongan.

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i	Material Safety Data Sheet	MSDS
ii	Computer Numerical Control	CNC
iii	Revolution Per Minute	RPM
iv	Analysis of Variance	ANOVA
v	Machine Condition Monitoring	MCM
vi	Surface Roughness	Ra
vii	Standard for the Exchange of Product Model Data	STEP-NC
viii	International Standard Organization	ISO
viiii	Design of Experiment	DOE

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical toolpath by moving more or less linearly while the workpiece rotates. The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear. Turning is also one of the most important processes in manufacturing to make various products and parts where the material removal process is made according to the desired design and shape. It may also produce accurate and precise results compared with other processes.

The modern technologies of turning are directed toward development of optimization tables that list specific feed rates, spindle speeds, and depths of cut for different materials. These tables then will be the standard used in industry as a source of reference, when making various turning operations from one job to another where the machining parameters of each may be quite different. The time, material, and tooling costs associated with the experimental steps needed to be properly planned according to the appropriate machining parameters to eliminate high setup costs as well as to sustain the product quality.

In the process of machining, surface roughness (*Ra*) is very important indicator to ensure good quality products. Surface roughness is a result very critical in the sense that in some industries such as medical implant, surface roughness can result in injury to the user if the *Ra* value exceeds a certain limit. To ensure that *Ra* is within range, various factors need to be considered such as machining parameters, workpiece shape and material, cutting tools properties and also cutting phenomena such as vibrations, cutting force and chip formation. The cause and effect diagram shown in Figure 1.1 highlights these factors that need to be considered in order for manufacturers to maximize their production.

To suit the smart CNC turning environment, one way to mathematically represent the relationship of the abovementioned parameters is by using Design of Experiment (DOE) techniques. DOE is used to generate models, including regression in order to get a model that generates an accurate prediction of surface quality which were used in STEP-NC and gives a robust mathematical representation of the related parameters. Such models will then leads to optimization and efficient machining process.

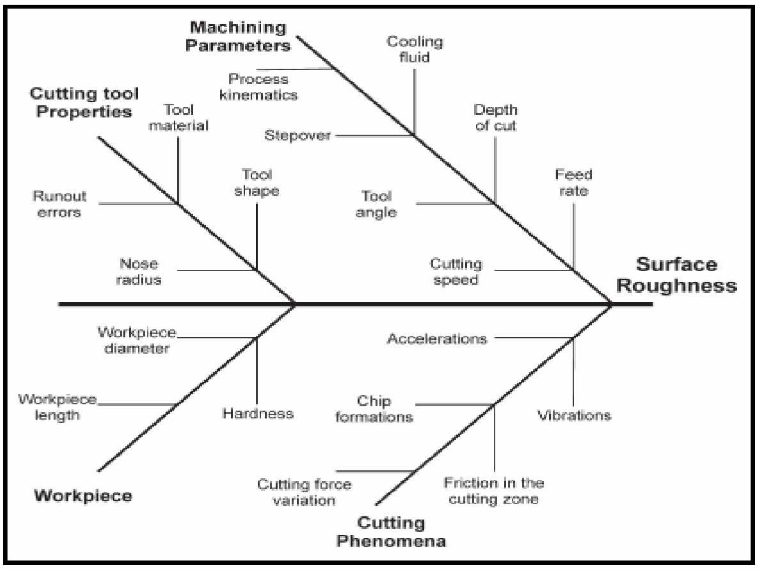

Figure 1.1 : Fishbone diagram with factors that influence on surface roughness [1]

Aluminum Alloy 6061 is used as a main material because of its good mechanical properties. It also exhibits good weld ability [2]. It is one of the most common alloys of aluminum for general purpose use. Originally called "Alloy 61S," it was developed in 1935. This material commonly used for wide purposed such as construction of aircraft structures, yacht construction, including small utility boats, automotive parts such as wheel spacers and for the manufacture of aluminum cans for the packaging of foodstuffs and beverages. It is known as a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements as shown in Figure 1.2.

Component	Amount (wt.%)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4 – 0.8
Iron	Max. 0.7
Copper	0.15-0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04-0.35
Others	0.05

Figure 1.2 : Typical composition of Aluminum Alloy 6061 [2]

1.2 Statement of the Problem

The quality of machined components is evaluated by how closely they adhere to set product specifications of length, width, diameter, surface finish, and reflective properties. For machining, surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controlled and some cannot. Controllable process parameters include feed rate, cutting speed, tool geometry, and tool setup. Other factors, such as tool, workpiece and machine vibration, tool wear and degradation and workpiece and tool material variability cannot be controlled as easily. There are usually based on experience and trial and error to obtain suitable cutting data for each cutting operation involved in machining a product. Therefore, such traditional machining practices will results to high setup time with less efficiency

In traditional machining, lack of information available that can be obtained during machining where during machining process, machine tools are executed based on simple point to point geometry data by means of NC codes known as ISO 6983 (G-code). It contains low level information and has been used for more than 60 years. It consists of geometric coordinate information in (point to point form) directing the machine to move and machine the parts. This code lacks of other important machining parameters such as tolerance information, feature information and cutting tools information. In addition, it commonly embedded with specific extension of different- vendors added code depending on its controller. Realizing these drawbacks, ISO committees have been working to improve this existing standard. The outcome of this international effort leads to the development of a new standard called Standard for the Exchange of Product Model Data for Numerical Control (STEP-NC) or also known as ISO 14649 was published.

With the introduction of STEP-NC, high level data information such as material properties, parts tolerances, part features and surface roughness value to be incorporated during machine execution. STEP- NC may recognize part feature, surface roughness, dimension of the stock part and material properties at CNC level and therefore enables further optimization and analysis to be conducted. It enables bi-directional data flow making it an intelligent machining platform. It may also provide interoperability as it eliminated the vendor specific extensions. Figure 1.3 illustrates the difference between the traditional machining practice and STEP-NC interface. This will leads to a smart CNC turning environment.

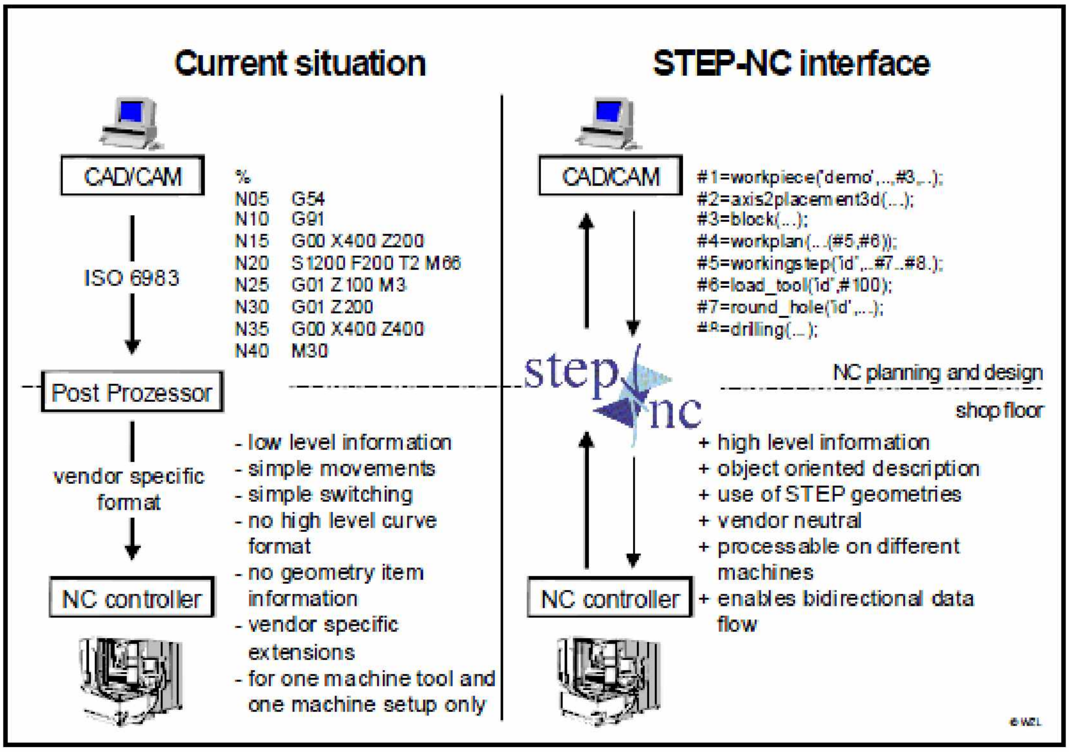

Figure 1.3: Difference between the current machining situation and the use of the STEP-NC [4]

Since then, a lot of effort and studies has been performed to enhance the capability of this new standard. For example, an enabled machine condition monitoring system for adaptive execution of a STEP-NC based optimization controller has been realized and developed for feed-rate optimization [3]. Therefore, in supporting such effort, this study intends to portray how the comprehensive data provided by STEP-NC can be utilized at CNC level. For example, in traditional machining, in monitoring the machining parameters with respect to the desired surface roughness values, machined parts were first measured to obtain the *Ra* values using a surface roughness instrument. Following that, a series of analysis should be performed in order to obtain the right parameters for the right surface roughness. These procedures are very time consuming, reduce the machining efficiency and high in cost. With the use of STEP-NC, the values of *Ra* after machining can be monitored and embedded with a developed algorithm.

1.3 Research importance and impact

The importance of this research is to bring awareness of an advanced machining environment especially towards local manufacturing industry in Malaysia. STEP-NC is the first NC program that contains details about the steps to complete machining and easily understood by the user. It contains a description of tools, machining strategy and machining processes that are not available in ISO 6983 before. So, any loss of information to abstract movements and switching information, as in the case of conventional programming interfaces, is avoided [4]. As STEP-NC can bring ease and agile data transfer, it is an opportunity to develop a system that may replace the old system thus it makes variety in manufacturing industry.

Other significant impact of this research is to promote the advantages of STEP-NC. This will open an opportunity to hold cooperation between researcher in universities, manufacturing industries, users, software developers and CNC vendors. Consequently, this research brings understanding to ISO 14649 fundamental and concept behind it, as the standard is the brain to the key in developing software to generate STEP-NC code. ISO 14649 part program is generated by clicking the generate code button. The program is based on workpiece and machining working steps in a physical file text. This file text can be saved to a selected directory folder and can be edited by the user based on manufacturing features, strategies and tools. When the user has finalized the part program, it can be sent to the machine controller that tallows bidirectional data flow. Apart from that, the study aims to promote the understanding of ISO 14649 fundamentals and concepts, as the standard that can store various machining data in executing CNC machines via STEP-NC codes and instructions.

In the future, STEP-NC promise great profits to current manufacturing environment where it does not have to depend on CNC machine functions that need post-processors. The vision is to have a STEP-NC Controller that is open, intelligent and interoperable (Xu et al., 2006). In this way, G & M code is not necessarily needed to be generated continuously to suit various kind of CNC controller functions. Data transfer can also be done at anytime and anywhere. With STEP-NC, the process cycle of machining operation can be reduced. Correction of machining data can be done directly at shop floor stage where the STEP-NC controller is success to develop. Hereafter, data can be shared all over the world in a more effective way. STEP-NC controller not only can machine part due to the machine movement but it will provide comprehensive information for better understanding of understand of the overall machining process which includes the feature information, its geometry, tolerances, cutting tools data as well as its machine technology.

Since STEP-NC potentials have attracted a lot of research interests in the recent years, it could may become reality and give a lot of benefits such as ease of use in terms of programming data which will be used on different types of CNC machines or vendors, and it also would save consumers or manufacturing industry in terms of cost, manufacturing time and delivery and also will enhanced profit for the manufacturing industry.

1.4 Objectives of the Study

While there are many machining optimization parameters that have been developed and tabulated, an area that has been overlooked is to find the best or suitable parameters of speed rate and cutting speed for machining Aluminum Alloy 6061. Thus, the choice of optimized cutting parameters becomes very important to control the required surface quality.

At the same time, the emergence of STEP-NC found to be a right solution towards optimization and knowledge utilization during machining. Therefore, the objective of the study is:

i. To determine optimum cutting parameters for better machining performance utilizing high-level data (STEP-NC).

1.5 Scope of Study

In the course of this study, some scope has been identified to achieve the research objectives and as a passing reference in this study. With the research specialization, this study can be done better and more organized. Among the scope of this study are:

i. Utilize high-level data (STEP-NC) for development of smart CNC turning environment

ii. Analyze machining performance of an Aluminum Alloy 6061 workpiece material for better surface quality such as surface roughness

iii. Identify suitable cutting parameters such as cutting speed, feed rate, depth of cut and workpiece dimension

iv. Conduct experimental analysis based on design of experiments (MINITAB) to suit smart turning environment.

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