

Machining Parameters and Materials Removal Rate in End Milling Operation Using CNC Machine

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Abstract

Materials removal rate is central in machining operations. The machining parameters -speed, feed rate and depth of cut are the primary factors that must be considered when carrying out machining operations. For a computerized numerical machine tool (CNC) there is the need to demonstrate how these factors affect the materials removal rate. A drilling operation in a aluminum work piece was used to investigate this effect. Various speed -1000, 1200,1400 rpm; feed rate 200, 300, 400 mm/sec. and depth of cut 1.0, 15, 2.0 mm was experimented on the work piece to observe how the materials removal rate will be. Results show materials removal rate up for speed of 1000 rpm, 400mm/rev. feed rate, 2.0 depth of cut as 754.08 and for speed of 1200 rpm, 400 mm/rev, 2.0 depth of cut as 904.80 and finally at the speed of 1400 rpm, 400 mm/rev and 2,0 mm depth of cut as 1055.52. The F- value for the three parameters was 0.001 validating the results.

Keywords: CNC machine, depth of cut, end milling, feed rate, materials, removal rate spindle speed.

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I. Introduction

Machining is any process in which a given piece of material is cut and processed into a designed shape and seize by a controlled material removal process in the form of chips. It is a material subtraction process. For multiple operations and repeatability. CNC is the best choice as it could machine and produce complex designed parts with the same accuracy and tolerance.

The CNC technology emerged in the early 1970s several years after the invention of numerical control machine tools (NC). The NC machine can be defined as an operation of machine tools by means of specialty coded instructions to the machine control system [1]. CNC Technology is an integrated synergy between computer programming, mechanical, electrical, computer and software engineering. It is a Mechatronic machine.[1] referred a CNC machine as soft wired. This is because logical functions are stored on a computer chip as software instructions. Hence programmes and codes can be easily modified for various results, outcomes, and design in the memory register. The flexibility of the CNC machine contributes widely to the use of this technology in variety of machining operations. About 95% of CNC systems today are electronically controlled. Today most of the CNC machines rely on electricity as the chief power source [2].

Modern CNC systems are highly automated and use both as CAD and CAM software in manufacturing operations. The CAD software is used in the design of the mechanical parts and CAM software translates the part design into specific commands of the machine to produce a component. The motion of the simple CNC system is principally in two axes, the X and Y axea with the spindle that moves in the Z axis. The position of the tool is

driven by direct drive stepper motors to provide accurate movement. CNC systems have wide area of applications in modern machining and manufacturing, some of these applications are in mills, lathe, plasma cutting, water jet cutting and 3D printing.

The benefits of CNC machine greatly exceed those of conventional machining. The relatively high capital expenditure is therefore acceptable because payback is shifted [3].

Hence, the resultant implementation of CNC across the metal cutting industry has resulted in conventional machine tools being restricted to limited applications. The features of CNC system can be mainly in three groups which are mechanical system. Electrical and electronic systems and the transmission system. Other systems present in a CNC machine are the lubrication systems, coolant systems, work holding systems and chip removal system.

Material removal dates to historic times, where the early man learnt to make tools for basic activities for farming, shelter and hunting. The early man indulged either in wood carving or metal forging in making of tools. One can invariably say that the prehistoric man was involved in machining. The term machining has evolved over the centuries, as man developed and improved on different methods of metal cutting and production of machine tools. In the 18th century a machining at this time was referred as the traditional machining processes such as boring, turning, milling, drilling, broaching, and sawing etc,

Development of modern machine tools is closely related to industrial revolution [4]. The introduction of water, steam, and later electricity as useful sources of energy lead to the production of power-driven machine tools which rapidly replaced manually driven tools in many applications [5]. Due to this advance in new energy sources industry encountered significant development in metallurgy of alloy steels as cutting tool materials, the machine tool industry encountered significant development. A major original contribution to the new industry came from John Wilkinson. He considered a precision machine for boring engine cylinder, thereby overcoming a problem associated with the first machine tools, which used power by steam [5].

It can be said that the first recognized machine tool was the boring machine of John Wilkinson. Another English Henry Maudsley developed the first crew cutting lathe around 1899. Maudsley's machine added a mechanized tool carriage with feeding and threading operations could be performed with much greater precision than any means before [4].

1.1 Machine Tool

A machine tool is power driven machine for making articles of a given shape. Size and accuracy according to blueprint by removing metal from workpiece in the form of chips [6]. Machine tools are factory equipment utilized in the production of other machine tools, instruments, and machines.[7] further states that machine tools generally are used for two purposes- produce certain form and produce furnished surface. Machine tools can be classified in various ways depending on area of application, general purpose. Types of motions, weight, accuracy, processing operation, etc.,[6] classifies machine tools into nine groups according to the type of processing operations they can perform or tools they employ. The classifications are lathe; drilling and boring; milling, shapers, planers, and slotters; grinding; gear and thread cutting machine; combination machine; cutting off machines and miscellaneous machines.

Machine tool must meet basic requirements for their effective utilization. The machine tool is expected to meet the following requirements: ability to produce desired shape and size, required accuracy and surface finish, high productivity, ease in operation and maintenance, good ergonomics, aesthetics and low cost of manufacturing.

Material removal is a group of processes that involves shaping a given workpiece into a desired shape. The most important branch of the family is conventional machining, in which a sharp cutting tool is used to mechanically cut the material to achieve the desired geometry [4]. These processes of materials removal apply various methods based on the components to be produced and the material used. Machining is the most versatile and accurate form of manufacturing processes as various shapes can be produced from these operations. [8] states

That machining is the essential activity of a manufacturing organization and milling is one of them. [9] described machining as a subtractive process that is used for removing material controllably from a piece of raw material. Machine operation is a system. It is a system that consists of the workplace, cutting tool, machine tool and the production. [10] described the three categories of machining processes which are cutting processes, abrasives processes, non-traditional machining processes Milling operations can be best described as a conventional cutting process.

1.2 Milling

Machining is the essential activity of a manufacturing organization and milling is one of them [8]. Milling machines have evolved significantly since the 100 years old definition to today's modern machines that can perform complex simultaneous 5+ axes operations and man oeuvres requiring computerized numerical control

[11]. The capability of machining parts to produce precise sizes and shapes and creating a large variety of features has made milling one of the most used processes in industry. Whitney is credited with developing the first milling machine in the United States around 1818[4]. Milling is a machining operation in which a work piece is fed past a rotating cylindrical tool with multiple cutting edges. The process evolves removing metal by feeding the work piece past a rotating multipoint cutter. The rotating cutting tool called as milling cutter is a multipoint cutting tool having the shape of a solid of revolution with cutting teeth arranged equally spaced either on the periphery or end face [6]. In milling the axis of rotation of the cutting tool is perpendicular to the direction of the feed. This orientation differentiates milling from drilling. All the operations performed on CNC milling machine is controlled by process parameters and optimum cutting condition is established to get the desired results [12].

Milling operation is done with a cutter having one or more teeth. Milling cutters are made in various forms to perform certain classes of work and they may be classified as : plain milling cutters, side milling cutters, face milling cutters, angle milling cutters, end milling cutters, fly cutters, T-slot milling cutters, formed cutters, metal slitting saw. [8] described a milling cutter as a multiple point tool having the shape of a solid of revolution with cutting teeth arranged either on the periphery and ends. Peripheral tooth may be straight or parallel to the cutter axis, or they may be helical, sometimes referred as spiral teeth [8].

Milling operations can be basically classified into two-face milling and peripheral milling. In face milling, the axis of the cutter is perpendicular to the surface being machined and machining is performed by cutting edges on both the end and outside periphery of the cutter. In peripheral milling the machine surface and the axis of the cutting tool are parallel. The operation is performed by the cutting edges on the outside periphery of the cutter.

Milling machine is a machine capable of a simultaneous cutting motion, using an end mill as the primary cutting tool along at least two axes at the same time [1]. Milling machines use long workpiece tables with slots, for clamping workpiece fixtures, the cutting is usually executed by longitudinal power feed [13]. Milling machines can be used for machining various surfaces-flat surface, contoured surface, complex and irregular areas can be machined using milling machine.

[1] classified milling machines into three categories-by axes orientation, number of axes, tool changer. Milling machine have two basic configurations based on the motion of the spindle. Milling machines where the spindle motion is up and down is called vertical mills. Horizontal mills are machines where the motion of the spindle is in and out. On axes classification. There are two or three axes or more depending on the manufacturer. On tool changer classification, the machines may be equipped with a multitool magazine or carousel. Some have a fully automatic changer and a pallet changer. Milling machine can also be classified into the following categories: knee and column, bed type, planer, tracer mills and CNC milling machines. Most of the modern milling machines manufactured today are not traditional milling machines, these machines can perform many metal operations such as boring, drilling, reaming, profiling and many more.

Milling machining centres are highly automated machine tools capable of performing machining operations using computer numerical control and with less human intervention [1]. These advanced machines have special in-built features such as adaptive controls, automatic loading and unloading, robotic interface and high-speed machining features. With this special feature, machine centre could be distinguished from conventional machines. Milling is one of the machining operations that could be performed on the machine centre. Machine centre specifications can be best described by the manufacturer of the machine tool. Machine centre are basically classified into three: vertical machining centre (VMC); horizontal machining centre (HMC) and universal machining centre (UMC).

1.3 Numerical Control Machines

Numerical control machines emerged in the mid -20th century. It can be traced to the year 1952, the US Air force, Massachusetts Institute of Technology in Cambridge, MA, USA and the John Parsons [1]. The NC machines were developed in the 1940's. The development of the NC machine technology had begun the second industrial revolution in the machine tool industry as automation was incorporated in the production of machine components. These systems had fixed automatic systems and were designed to produce specific products, best represented by the automobile industry, which produced passenger cars at high production rate and low cost [10]. Numerical controls were designed with fixed logical control functions and for these were termed hardware because they could interpret programmes but could not alter or make changes to the programme. The components of numerical control machines include-part programme, machine control unit and machine processing unit,

Part programme is a set of commands inputted to the machine control unit and to be executed in by the processing equipment. [11] described the NC code as a universally accepted plain text set of standard commands that a NC controller is able to interpret to actuate machining. Each command specifies a position of motion that is to be accomplished of the work head relative to the work part [4]. The part programme is prepared by a part

programmer. A part programmer is a skilled person with knowledge of NC and conversant with the technology of the NC machine.

Machine control unit is modern NC technology is a microcomputer that stores and executes the programmes by converting each command into action by processing equipment, one command at a time [4]. MCU are mainly divided into two components. They are the software and hardware. The software components include the control system software, algorithms etc. The hardware components include the microcomputers, mechanical components, and feedback control elements.

The processing equipment accomplishes the sequence of processing steps to transform the starting work into a completed part. The MCU controls the operation of the processing equipment. This equipment operates under the instructions from the part programme [4].

1.4 CNC System

Computerized numerical control (CNC) uses internal microprocessor. This computer contains memory registers storing a variety of routines that can manipulate logical functions [1]. The CNC system can be described as advancement in the NC machines. The eruption in numerical control of machine tools was achieved due to the advancement of microchips. Computers and electronics. The CNC machine has brought significant development to metal manufacturing industry. The greatest advantage of the system is its flexibility.

The CNC can be classified into two based on feedback control system and motion control system. The feedback control system can be open loop control system and close loop control system. On the motion, it be point to point contouring and continuous path contouring. Point to point allow control is used to initiate straight line motion. Continuous contouring enables the machining of different contours.

1.4 CNC Programming

CNC programming utilizes a special code commonly referred to as the G -code or the G and M codes. This language conforms to the EIA standards which was set in the 1960's. The official name of the G-code is RS-274D. The G-code programming language was developed when machine controls had very little memory [14]. This coded instruction is called data. The CNC programme contains sequence of codes which instructs the controls of a machine tool in the machining of a designed component. Various machines have different formats but most of the instructions are similar. Differences in CNC machines exist mostly from different manufacturers.

1.5 CNC Programming

CNC programming requires careful planning before a machining operation is carried out. Before a part design is to be machined steps must be considered and properly evaluated. Proper planning yields both good machine programme and machined part. Programme planning steps are determined generally by the nature of the part to be machined. Programme planning should always start with part drawing. The engineering drawing of a part to be machined acts as a blueprint and provides the programmer with the technical details of the design. The drawing intimates the programmer with the dimensions, sizes, tolerances, and surface finish of the designed part. After completing the evaluation of the part drawing and materials, parts complexity is considered as complex part design could benefit from CAD And CIM SOFTWARE. Part programme could be manually done or through computerized programming. Manual programming requires the programmer to have an in depth understanding of programme development calculations and verification of all data provided by the designer. For accuracy and efficiency, programmes could be developed using CAD/CAM/CIM software. This software eliminates basic errors that could have been made in manual programming. In further planning of CNC programme, material specification must be carefully considered. Evaluation of the material should be made as some material may be raw or already pre- machined. The material size, type, shape and condition should be known. Material uniformity and machinability are also important aspects of planning. In the case of material uniformity production batch and specification of the material should be reviewed. Special characteristics such as size, hardness, toughness etc should be evaluated. In machinability the federate, constant surface speed, cutting speed and peripheral speed are reviewed. The speed and feed rates are usually provided by tooling companies in special charts. These charts aid the programmer in cases where the material to be machined is unknown.

1.6 Tooling Selection and Part setup

Tooling setup involves the selection and usage of the most suitable cutting tool and holders that are economical in machining operation. A programmer must have a good knowledge of the cutting tool which can be used for a specific operation. Part setup and tools is necessary and must be efficiently done to improve productivity of operation. In Part setup, supporting tools, work holding devices, tool changers, offset settings must be analyzed

by the programmer so as to achieve effective and efficient machining sequence and the number of operations required by specific tools.

1.7 Machining Sequence

This refers to the order of machining operations. This operations sequences must follow a logical order. Machining operation must be carefully evaluated to determine a programme of machine sequence. In general programmes should be planned such that the cutting tool once selected must do as much work as possible [1].

1.8 Technological Decisions

CNC programming requires necessary technological decisions. The selection of cutting tools, power rating, feed rate, spindle speeds, application of lubricants influence the programme design. To improve on quality of machined part, these factors must be considered.

1.9 CNC Programming Structure

CNC programme is sequence of coded instructions for machining a part. These instructions are called part programmes. The structure of the programme is divided into four. Each of these terms are important and act as a guide to the machine controls. These four elements of CNC programmes are: character, word, block, and part programme. Character is the smallest unit of a CNC programme. It can be written in three forms, either as digit, letter or symbol, example 2. F. Word is a unit of instruction to the control unit. Words are alphanumeric characters. Example of word is G01, N2. Each word in a programme is written in horizontal lines. Any word in series of at least two characters that define a single instruction. A block contains words. A block contains multiple instructions which are inputted into the control system. CNC programmes are usually programmed in blocks of five words. Blocks must be separated from each other. Example of a block is N23G01Y6.25F200. Part programme is a sequence of blocks in a logical order for a machining process. Part programme could be either a main programme or a sub programme. Main programmes are written using ISO codes.

N-Sequence number

G- Preparatory codes

X-X axis

Y-Y axis

Z-Z axis

F- Feed rate

M- Miscellaneous

S- Spindle function

T- T001 function

CNC milling machine has so many advantages:

- i. CNC machine improves machining accuracy.
- ii. Enables complex task and details to be achieved.
- iii. CNC machines increase safety in machining.
- iv. Boost setup and change over time.
- v. Reduce setup and change over time.
- vi. CNC machines are versatile.
- vii. CNC machines provide room for design retention.

Its disadvantages are:

- i. CNC machines are very expensive to acquire than manually operated machines.
- ii. Fewer workers are required to operate the machines as compared to manually operated machines.
- iii. Investment in CNC machines can lead to unemployment as the machines render the use of conventional machine obsolete.

[15] described the common failures that occur in a CNC machine system are mainly in the mechanical systems, electrical/ electronic system, and the transmission systems. The failures in the mechanical system may occur in mechanical structure, overload, irregular feeding, large impact and damage to the feed drives, guide ways and motion parts of the machine. The failures in the electrical systems can occur from damage to the relays, contractors, switches, control buttons, limit switches, etc. Failures in the transmission system may occur from damage to the hydraulic and pneumatic systems components, leakages in the oil pipes and connections, damage to the oil reservoirs, pressure gauges etc.

1.10 CNC Performance Evaluation

In the modern machining the challenge is mainly focused on quality in terms of surface finishing. Surface texture is concerned with the geometry irregularities. The quality of surface is most significant for any product. The surface roughness is affecting things such as for contact causing surface friction, wearing, holding the

lubricant etc. There are many factors which affect the surface roughness and material removal rate, that is tool (material, nose radius, geometry, tool vibration), work piece (hardness, mechanical properties) cutting condition (speed, feed, depth) etc. New products have been generally designed to be produced on milling machining. It is not sufficient to device a feasible procedure for manufacture of desired component. The procedure must be economically justified. Cutting conditions may be established which give satisfactory result.

Multi-pass operations are generally used to machine stocks that cannot be removed in a single pass. Some turning operations like external step turning and boring, and some of the milling operations such as face milling and deep shoulder milling in which a significant amount of stock material is removed are good examples of the operations which are commonly required to be machined using multi-pass operations. Determination of the optimal cutting parameters like the number of passes, dept of cur for each pass, speed and feed rate considered as crucial stage of multi-pass machining as in the case of all chip removal processes and especially in process planning. The effective optimization of these parameters affects dramatically the cost and production time of machined components as well as the quality of the final product.

the work piece and the edge of the cutting tool. The relative movement in the machining

II. Materials and Methods

An aluminium bracket was designed using computer aided design software and solid works. A Mach3 software was used for the CAM simulation of the aluminium bracket. A simple G and M code programme was written to produce the mechanical component. The cutting tool used in machining this piece was an end mill HSS high speed steel. This component was produced using various cutting speed, feed rate and depth of cut.

2.1 Cutting Speed and Feed

The process of metal cutting or machining of metal work piece is influenced greatly by the relative velocity between operations is produced by the combination of rotary and translator movement either of the work piece or of the cutting tool or both. The translator displacement of the cutting edge of the tool along the work surface during a given period is called the feed, while the rate of transvers of the work surface past the cutting edge is designated as cutting speed. The presence of these motions example feed and cutting speed permits the exertion of the process of cutting continuously.

In machine tools with rotary priming cutting motion, the cutting speed is given as:

$$V = \frac{\pi DN}{60} \quad \text{Equation 1}$$

where V is the cutting speed, D is the diameter of the workpiece and N is the cutter rotational speed in rpm.

2.2 Material Removal Rate

The material removal rate (MRR) is defined as the material removed per unit time. Its unit ia mm^3/sec .

$$MRR = Vfd \quad \text{Equation 2}$$

where V is the speed, f is the feed (mm) and d is the depth of cut (m)

Table 1 is the table of machining parameters used for the research.

Table 1: Machining Parameters at Different Levels of End Milling Operation Using CNC Machine

Factors	Unit	Levels			Variation
		1	2	3	
Spindle speed	rpm	1000	1200	1400	200
Feed rate	mm/rev	200	300	400	100
Depth of cut	mm	1.0	1.5	2.0	0.5

A factorial experiment was designed for the research as shown in Table 2.

Table 2: CNC Factorial Experiment Design Using Aluminium

Runs order	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	1000	200	1.0
2	1000	300	1.0
3	1000	400	1.0

4	1000	200	1.5
5	1000	300	1.5
6	1000	400	1.5
7	1000	200	2.0
8	1000	300	2.0
9	1000	400	2.0
10	1200	200	1.0
11	1200	300	1.0
12	1200	400	1.0
13	1200	200	1.5
14	1200	300	1.5
15	1200	400	1.5
16	1200	200	2.0
17	1200	300	2.0
18	1200	400	2.0
18	1400	200	1.0
20	1400	300	1.0
21	1400	400	1.0
22	1400	200	1.5
23	1400	300	1.5
24	1400	400	1.5
25	1400	200	2.0
26	1400	300	2.0
27	1400	400	2.0

III. Results and Discussion

3.1 Results

Table 3 shows the results of the materials removal rate obtained from factorial experiment.

Table 3: CNC Factorial Experiment Design Using Brass and Aluminium

Runs order	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Material Removal Rate (MRR) mm^3/sec
1	1000	200	1.0	188.52
2	1000	300	1.0	282.78
3	1000	400	1.0	377.04
4	1000	200	1.5	282.78
5	1000	300	1.5	424.17
6	1000	400	1.5	565.56
7	1000	200	2.0	335.08
8	1000	300	2.0	565.56
9	1000	400	2.0	754.08
10	1200	200	1.0	226.20
11	1200	300	1.0	339.30
12	1200	400	1.0	452.40
13	1200	200	1.5	339.30
14	1200	300	1.5	508.95
15	1200	400	1.5	678.60
16	1200	200	2.0	489.52
17	1200	300	2.0	678.60
18	1200	400	2.0	904.80
18	1400	200	1.0	263.88
20	1400	300	1.0	395.82
21	1400	400	1.0	527.76
22	1400	200	1.5	395.82
23	1400	300	1.5	593.82
24	1400	400	1.5	791.64
25	1400	200	2.0	572.89
26	1400	300	2.0	791.64
27	1400	400	2.0	1055.52

Table 4 shows the variance for the machining parameters.

Table 4: Analysis of Variance for Materials Removal Rate

Source	DF	Adj SS	Adj MS	F-Value	F-Value
Spindle speed	2	144660	72330	25.64	0.0001
Feed rate	2	504510	252255	89.43	0.0001
Depth of cut	2	531851	265925	94.28	0.0001

Error			
Total	20	56414	2821
	26	1237434	

Figure 1 presents the mean materials removal rate with the spindle speed. The residual plots for material removal rate are shown in Figure 2.

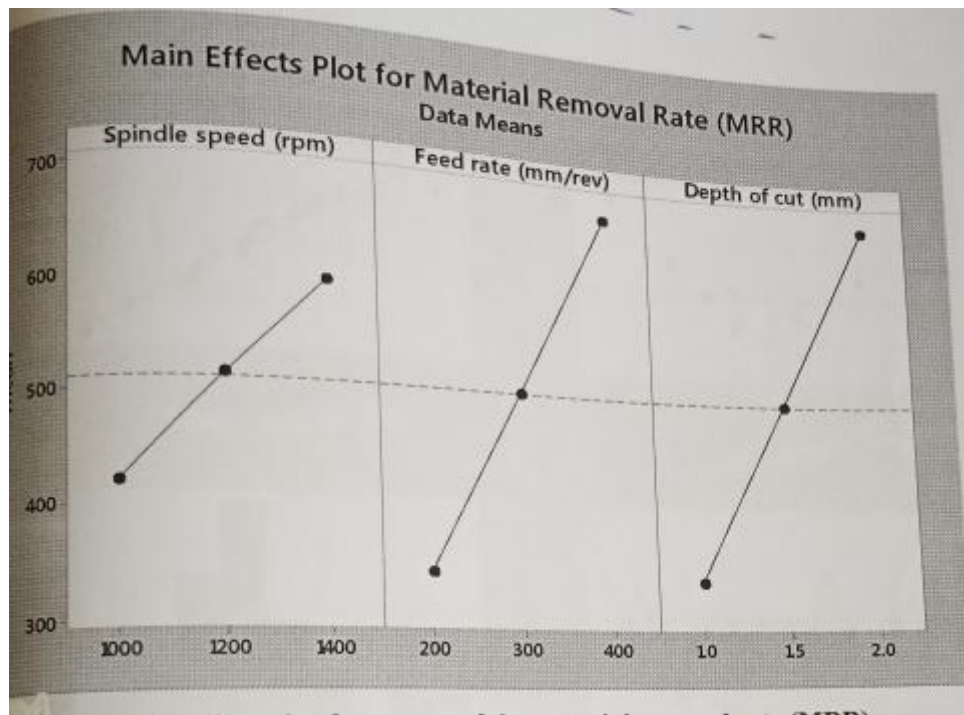


Figure 1: Mean Materials Removal Rate with speed, feed rate and depth of cut

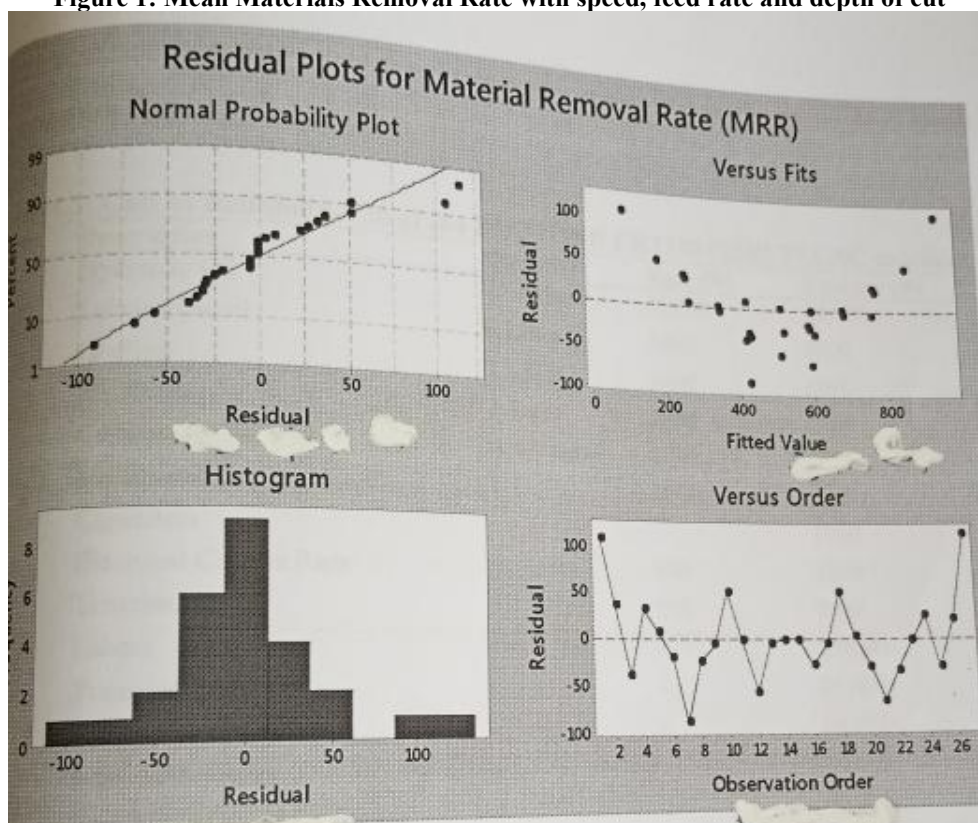


Figure 2: Residual Plots for Materials Removal Rate

3.2 Discussion

From Figure 1 the materials removal rate increases with increase in speed, feed rate and depth of cut. The residual plots in Figure 2 was used to evaluate the data for the problems like non normality, non-random variation, non-constant variance, higher relationships, and outliers. The residual plots follow an approximate straight line in normal probability. This shows clear a pattern, hence there is no error due to time or data collection order.

To study the significance of the process variables towards MRR, analysis of variance was performed at a confidence interval of 95% - a significance level of 0.05. This showed that, spindle speed, feed rate and depth of cut with p-values of 0.0001, 0.0001 and 0.0001 respectively, implying that the machining parameters used for the performance evaluation of the CNC machine is statistically significant at 0.005 for MRR.

IV. Conclusion

At a speed of speed of 1000 rpm, 400mm/rev. feed rate, 2.0 depth of the materials removal rate was 754.08. Also for speed of 1200 rpm, 400 mm/rev, 2.0 depth, MRR was 904.80 and rose to 1055.52 at the speed of 1400 rpm, 400 mm/rev and 2,0 mm depth of cut, with The F- value of 0.001. The research has demonstrated that the materials removal rate of CNC is highly influenced by spindle speed, feed rate and depth of cut

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