

Performance Analysis of CNC Milling Machine using Graph Theory

Navin Vashisth

M. Tech Student

Department of Mechanical Engineering

*YMCA University of Science & Technology, Faridabad, India-
121006*

Mukesh Gupta

Assistant Professor

Department of Mechanical Engineering

*YMCA University of Science & Technology, Faridabad, India-
121006*

Abstract

Milling is the machining process of using rotary cutters to remove material from a workpiece advancing (or feeding) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. All the operation performs on CNC milling machine is controlled by process parameters and optimum cutting condition is established among parameters to get the desired results. This Study is to establish the relation between the process parameters of CNC milling machine, behavioural aspect in different cutting condition and their dependency on other process parameter. Graph theory and permanent matrix concept is used to evaluate the dependency matrix to the performance analysis of CNC milling machine.

Keywords: CNC Milling, Performance Parameter, Graph Theory

I. INTRODUCTION

Modern CNC milling consist of a table that moves in the Y-axis, and a tool chuck that moves in X and Z (depth). The position of the tool is driven by motors through a series of step-down gears in order to provide highly accurate movements, or in modern design, direct-drive stepper motors. As the controller hardware evolved, the mills themselves also evolved. One change has been to enclose the entire mechanism in a large box as a safety measure, often with additional safety interlock to ensure the operator is far enough from the working piece for safe operation. Mechanical manual controls disappeared long ago. CNC like system are now used for any process that can be described as a series of movement and operations. This include laser cutting, welding, friction stir welding ultrasonic welding, flame and plasma cutting, bending, spinning, pinning, gluing, fabric cutting, sewing, tape and fiber placement, routing, pick and placing and sawing.

The machining process is controlled by several parameters which affect the machine performance and accuracy. Heat affection zone is developed when tool comes in contact with workpiece which leads to tool wear and rough cutting environment, cutting forces, spindle power, feed leads to higher vibration and higher vibration during machining process leads to rough surface finish, noise, chatter and positional inaccuracy. Feedback devices are used in machine to control the position and accuracy of machine. It may be open loop feedback or close loop feedback devices. Lower accuracy of feedback devices leads to inaccuracy in machining position and geometry of workpiece material is affect. Due to continuous movement of ball screws for bed movement and due to dirty environment of machining areas, heat affected zone is developed due to which the positional accuracy, machine performance is affected, movement noise and other, position control, cutting forces, material removal rate, feed, speed, depth of cut. Cutting forces occurred during machining at tool workpiece interface which leads to vibration of machine due to which the accuracy and machine efficiency decrease and MRR and surface finish is affected. These parameters affect the overall machine performance. Graph theory and matrix method is used to find out the dependency matrix and variable permanent matrix and analysis of variation by changing the diagonal elements dependency.

II. PARAMETER EVALUATION AND DEPENDENCY

Performance of machine is dependent of several parameters out of which few are critical parameters and few are dependent parameters. The performance depends on the critical parameters and critical parameters depend on the dependent parameters. Based on the literature survey and books reference, the critical parameters and dependent parameters are evaluated. It is found that the MRR is depends on Vibration, feed, speed, depth of cut, cutting force, fuzzy control, coolant and ball screw heating. [13]

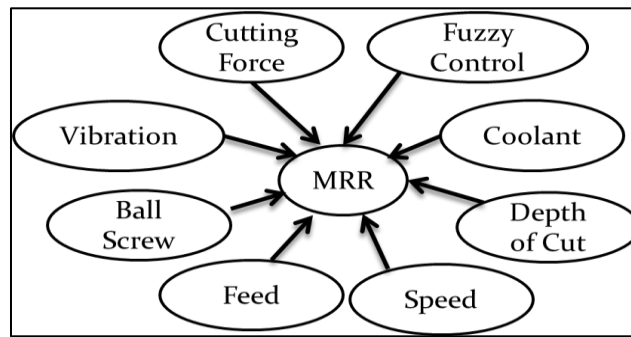


Fig. 1: Relation between MRR and Related Parameter [13]

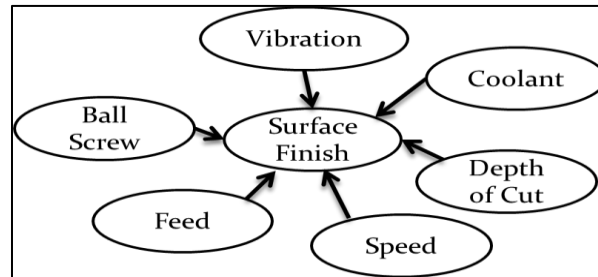


Fig. 2: Relation between Surface finish and Related Parameter [13]

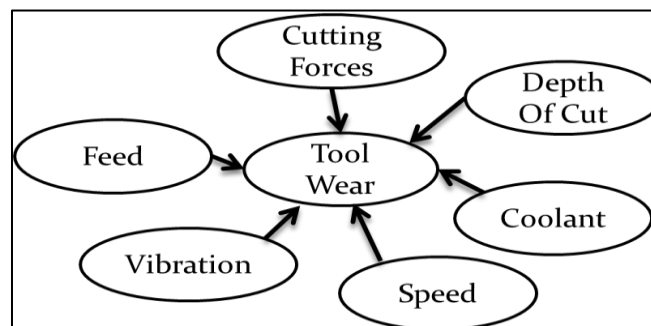


Fig. 3: Relation between Tool Wear and Related Parameter [13]

III. GRAPH THEORY AND MATRIX EVALUATION

A. Development of Graph Theoretic Model:

Graph theoretic and matrix model consists of digraph representation, matrix representation and permanent representation. Digraph representation is useful for visual analysis. Matrix model is useful for computer processing. Permanent multinomial function characterizes abstract CNC Performance uniquely. Permanent value of multinomial represents the effect of critical parameters on Machine performance by a single number/index, which is useful for comparison, ranking and optimum selection. The systematic application of graph theoretic methodology is discussed below.

B. System Digraph:

A system digraph is prepared to represent the system factors of the CNC Machine in terms of nodes and edges. Let nodes represent behavioural factors and edges represent their interactions. It represents CNC Performance – behavioural measure of characteristics or factors (B_i 's) through its nodes and dependence of factors (b_{ij} 's) through its edges. B_i indicates the inheritance of factors and b_{ij} indicates degree of dependence of j th factor on i th factor. In the digraph b_{ij} is represented as a directed edge from node i to node j . The digraph permits to show the proposed system factors and interactions between factors. In particular three factors identified form the system digraph. The three performance parameter factors –

$B_1 = \text{MRR}$, $B_2 = \text{Surface Roughness}$, $B_3 = \text{Tool Wear}$
 $B = \text{Variable Parameter Index}$

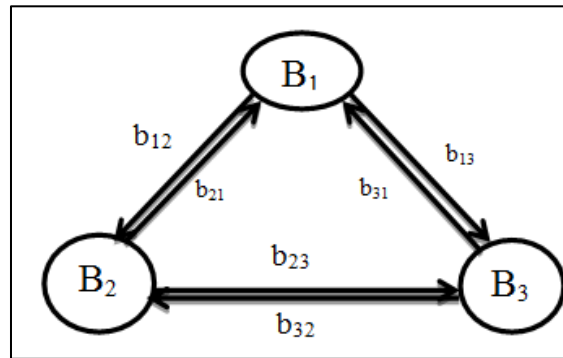


Fig. 4: Critical Parameter Dependency Digraph

C. Variable Permanent System Structure Matrix (VPSSM) for Machine Performance:

Application of the permanent concept leads to a better appreciation of the complete structure, in general. The variable permanent system structure matrix (VPSSM) for the Machine is as represented by the expression (5.6). The determinant of the VPSSM will be with the positive and negative signs. Therefore, Variable Permanent System Structure Function (VPSSF) is used in place of determinant for the evaluation of VPSSM. Evaluation and formulation of VPSSF is explained in the next section.

Overall behavioural effect is maximum when the behavioural effect of all the factors is maximum. Since, total quantitative information is not obtained in VCM-B, VPM-B is defined for the system in general (assuming interactions among all factors) as

$$B = \begin{matrix} & \begin{matrix} 1 & 2 & 3 \end{matrix} & \text{Factor} \\ \begin{matrix} B_1 \\ b_{21} \\ b_{31} \end{matrix} & \begin{bmatrix} B_1 & b_{12} & b_{13} \\ b_{21} & B_2 & b_{23} \\ b_{31} & b_{32} & B_3 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} \end{matrix} \quad 3.1$$

The permanent of matrix equation (3.1) is multinomial and is called variable permanent behavioural function (VPF-B), also known as permanent of B (per B). This permanent function is a standard matrix function and is used and defined in combinatorial mathematics. This is evaluated by standard procedures and is same as determinant of VCM but with all signs positive.

D. Quantification of Bi's and bij's:

Quantification of Performance (i.e. Bi's) is carried out on the lines of per B. Each factor is identified as a subsystem and graph theoretic approach is applied in each subsystem. Behavioural subsystem permanent characteristic matrix is evaluated for permanent function considering various factors affecting the subsystem. The various factors affecting subsystems are identified. The dependencies of factors at subsystem level are visualized through digraphs. These digraphs lead to the inheritance of factors at system level through matrix and measures. The corresponding variable permanent matrices are then derived for each subsystem (ss) and permanent function of each VPM (ss) is evaluated. The permanent functions of these matrices will lead to inheritance of behavioural factors.

Thus, graph theoretic approach may be applied at every level. In order to avoid complexity, suitable scale may be used to assign value at subsystem level or sub subsystem. If all the factors are not equally important, suitable weights may be assigned. Table suggests assignment of numerical values to factors. To get the complete value of multinomial, the off diagonal elements in VPM-B are to be assigned numerical values. As already discussed, these off diagonal elements represent interdependencies among Performance factors for CNC Milling Machine. However, this dependence among factors at system level (or subsystem level) cannot be measured directly and values can be assigned only after proper interpretation through proper analysis of all the variables and dependency of these variables by practical results and application. [20]

Table - 1
Quantification of CNC Performance Factors

Sr. No.	Qualitative Measure of CNC Milling Machine	Assign Value for
1	Exceptionally Low	1
2	Very Low	2
3	Low	3
4	Below Average	4
5	Average	5
6	Above Average	6
7	High	7
8	Very High	8
9	Exceptionally High	9

Table - 2
Quantification of CNC Performance factor Interdependency

Sr. No.	Qualitative Measure of Interdependency	b_{ij}
1	Very Strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very Weak	1

E. Graphical Representation of Systems Diagram:

System digraph is prepared based on the experimental analysis done through literature survey and research papers published in the field of CNC Milling machine performance and factors affecting the machine performance and their dependency on process parameters or other parameters.

1) System Diagram for MRR:

Based on the literature survey and other books references, relationship between the sub parameters is established and it is found that vibration, cutting forces and heating in ball screw is affected by feed, speed, depth of cut, fuzzy control and coolant. These parameters are affected by each other's also. Based on this analysis digraph for MRR is prepared and established the relationship between all the related parameters.

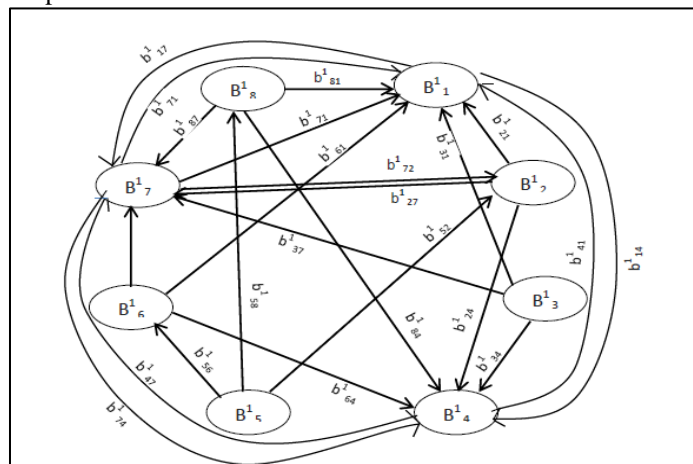


Fig. 5: Digraph for Subsystem 1

- B^1_1 = Vibration
- B^1_2 = Coolant
- B^1_3 = Speed
- B^1_4 = Heating In Ball Screw
- B^1_5 = Fuzzy Control
- B^1_6 = Depth Of Cut
- B^1_7 = Cutting Force
- B^1_8 = Feed

2) System Diagram for Surface Roughness:

Similarly the relationship is established between Surface roughness related parametrs and it is found that vibraion and cutting forces affect each other and rest other parametrs affect these two parameters. Based on this analysis digraph is prepared for surface roughness.

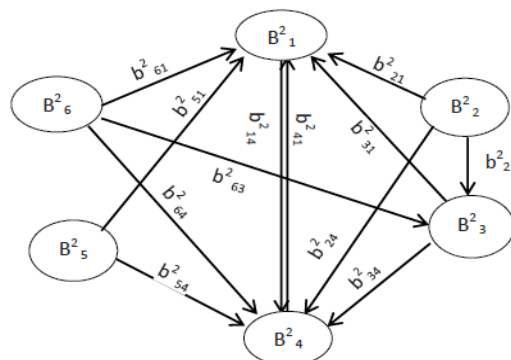


Fig. 6: Digraph for Subsystem 2

- B^2_1 = Cutting Force
- B^2_2 = Depth of Cut
- B^2_3 = Coolant
- B^2_4 = Vibration
- B^2_5 = Speed
- B^2_6 = Feed

3) *System Diagram for Tool Wear:*

Similarly the relationship is established between Tool wear related parametrs and it is found that vibraion and cutting forces affect each other and rest other parametrs affect these two parametrs. Based on this analysis diagram is prepared for Tool wear

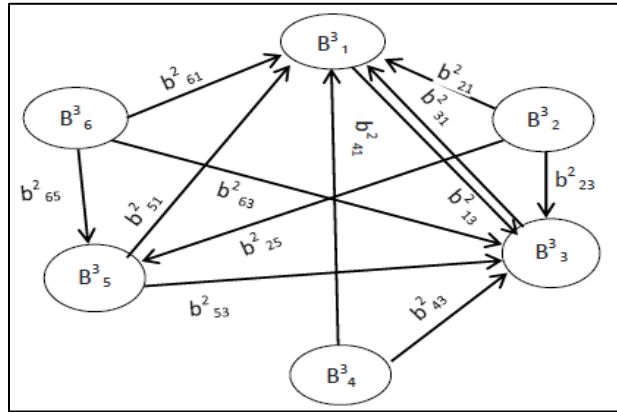


Fig. 7: Digraph for Subsystem 3

- B^3_1 = Vibration
- B^3_2 = Depth of Cut
- B^3_3 = Cutting Force
- B^3_4 = Speed
- B^3_5 = Coolant
- B^3_6 = Feed

F. Matrix Representation for System and Subsystem:

Based on the diagram 1 shows above and the relationship established between the subsystem the variable permanent matrix for MRR is prepared below in which diagonal elements shows the effect of that dependent arameter on MRR and non diagonal elements show the relationship between these subsystem or dependent parameters.

$$\begin{matrix}
 & \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{matrix} & \text{Factor} \\
 \text{VPM } B^1 = & \begin{bmatrix}
 B^1_1 & 0 & 0 & b^1_{14} & 0 & 0 & b^1_{17} & 0 \\
 b^1_{21} & B^1_2 & 0 & b^1_{24} & 0 & 0 & b^1_{27} & 0 \\
 b^1_{31} & 0 & B^1_3 & b^1_{34} & 0 & 0 & b^1_{37} & 0 \\
 b^1_{41} & 0 & 0 & B^1_4 & 0 & 0 & b^1_{47} & 0 \\
 0 & b^1_{52} & b^1_{53} & 0 & B^1_5 & b^1_{56} & b^1_{57} & 0 \\
 b^1_{61} & 0 & 0 & b^1_{64} & 0 & B^1_6 & b^1_{67} & 0 \\
 b^1_{71} & 0 & 0 & b^1_{74} & 0 & 0 & B^1_7 & 0 \\
 b^1_{81} & 0 & b^1_{83} & b^1_{84} & 0 & 0 & b^1_{87} & B^1_8
 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \end{matrix}
 \end{matrix} \quad (3.2)$$

Similarly based on the diagram 2 shows above and the relationship established between the subsystem the variable permanent matrix for Surface Roughness is prepared below in which diagonal elements shows the effect of that dependent parameter on Surface Roughness and non diagonal elements show the relationship between these subsystem or dependent parameters.

$$\begin{matrix}
 & \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 \end{matrix} & \text{Factor} \\
 \text{VPM } B^2 = & \begin{bmatrix}
 B^2_1 & 0 & 0 & b^2_{14} & 0 & 0 \\
 b^2_{21} & B^2_2 & b^2_{23} & b^2_{24} & 0 & 0 \\
 b^2_{31} & 0 & B^2_3 & b^2_{34} & 0 & 0 \\
 b^2_{41} & 0 & 0 & B^2_4 & 0 & 0 \\
 b^2_{51} & 0 & 0 & b^2_{53} & B^2_5 & 0 \\
 b^2_{61} & 0 & b^2_{63} & b^2_{64} & 0 & B^2_6
 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix}
 \end{matrix} \quad (3.3)$$

Similarly based on the diagraph 3 shows above and the relationship established between the subsystem the variable permanent matrix for Tool wear is prepared below in which diagonal elements shows the effect of that dependent parameter on Tool wear and non diagonal elements show the relationship between these subsystem or dependent parameters.

$$\text{VPM } B^3 = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 \end{matrix} & \text{Factor} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix} & \begin{bmatrix} B_1^3 & 0 & b_{13}^3 & 0 & 0 & 0 \\ b_{21}^3 & B_2^3 & b_{23}^3 & 0 & b_{25}^3 & 0 \\ b_{31}^3 & 0 & B_3^3 & 0 & 0 & 0 \\ b_{41}^3 & 0 & b_{43}^3 & B_4^3 & 0 & 0 \\ b_{51}^3 & 0 & b_{53}^3 & 0 & B_5^3 & 0 \\ b_{61}^3 & 0 & b_{63}^3 & 0 & b_{65}^3 & B_6^3 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix} \end{matrix} \quad (3.4)$$

Based on experimental results and analysis of all the factors by expert reviews it is find out that the value of dependency parameters for MRR from table no 2 are $B_1^1=5, B_2^1=7, B_3^1=8, B_4^1=8, B_5^1=3, B_6^1=8, B_7^1=3, B_8^1=7, b_{14}^1=4, b_{17}^1=3, b_{21}^1=2, b_{24}^1=4, b_{27}^1=4, b_{31}^1=3, b_{34}^1=4, b_{37}^1=2, b_{41}^1=4, b_{47}^1=1, b_{52}^1=3, b_{53}^1=2, b_{56}^1=2, b_{57}^1=2, b_{61}^1=4, b_{64}^1=3, b_{67}^1=4, b_{71}^1=4, b_{74}^1=2, b_{81}^1=3, b_{84}^1=3, b_{87}^1=4. [3][7][12][14][15][21][23]$

$$\text{VPM } B^1 = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{matrix} & \text{Factor} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \end{matrix} & \begin{bmatrix} 5 & 0 & 0 & 3 & 0 & 0 & 3 & 0 \\ 2 & 6 & 0 & 4 & 0 & 0 & 4 & 0 \\ 3 & 0 & 7 & 4 & 0 & 0 & 2 & 0 \\ 4 & 0 & 0 & 7 & 0 & 0 & 1 & 0 \\ 0 & 3 & 2 & 0 & 3 & 2 & 2 & 0 \\ 4 & 0 & 0 & 3 & 0 & 7 & 4 & 0 \\ 4 & 0 & 0 & 2 & 0 & 0 & 3 & 0 \\ 3 & 0 & 0 & 3 & 0 & 0 & 4 & 6 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \end{matrix} \end{matrix} \quad (3.5)$$

The value of variable permanent matrix for MRR for given values which is calculated by grapher software is 1434130 Similarly variable permanent matrix for Surface Roughness ia calculated for the below dependent value which is taken from experimental results.

$B_1^2=5, B_2^2=7, B_3^2=8, B_4^2=8, B_5^2=3, B_6^2=8, b_{14}^2=4, b_{21}^2=4, b_{23}^2=2, b_{24}^2=4, b_{31}^2=3, b_{34}^2=3, b_{41}^2=2, b_{51}^2=2, b_{54}^2=3, b_{61}^2=4, b_{63}^2=2, b_{64}^2=4. [4][7][10][16][19][22][26][29]$

$$\text{VPM } B^2 = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 \end{matrix} & \text{Factor} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix} & \begin{bmatrix} 5 & 0 & 0 & 4 & 0 & 0 \\ 4 & 6 & 2 & 4 & 0 & 0 \\ 3 & 0 & 7 & 3 & 0 & 0 \\ 2 & 0 & 0 & 7 & 0 & 0 \\ 2 & 0 & 0 & 3 & 3 & 0 \\ 4 & 0 & 2 & 4 & 0 & 6 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix} \end{matrix} \quad (3.6)$$

The value of variable permanent matrix for Surface Roughness for given values which is calculated by grapher software is 32508

Similarly Variable permanent matrix for Tool Wear is Given Below. The value of dependency is as follows.

$B_1^3=5, B_2^3=7, B_3^3=8, B_4^3=8, B_5^3=3, B_6^3=8, b_{13}^3=3, b_{21}^3=4, b_{23}^3=4, b_{25}^3=2, b_{31}^3=4, B_{41}^3=2, b_{43}^3=2, b_{51}^3=2, b_{53}^3=3, b_{61}^3=4, b_{63}^3=2, b_{65}^3=4. [2][5][9][16]17[27][31]$

$$\text{VPM } B^3 = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 \end{matrix} & \text{Factor} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix} & \begin{bmatrix} 7 & 0 & 3 & 0 & 0 & 0 \\ 4 & 6 & 4 & 0 & 2 & 0 \\ 4 & 0 & 7 & 0 & 0 & 0 \\ 2 & 0 & 2 & 7 & 0 & 0 \\ 2 & 0 & 3 & 0 & 3 & 0 \\ 4 & 0 & 2 & 0 & 4 & 7 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{matrix} \end{matrix} \quad (3.7)$$

The value of variable permanent matrix for Tool Wear for given values which is calculated by grapher software is 53802 Now for calculating the variable parameter value of B, the values of $B_1=1434130$ (eq 5.11), $B_2=32508$ (eq 5.12), $B_3=53802$ (eq 5.13) and the values of dependency of critical parameters $b_{12}=2, b_{13}=4, b_{21}=3, b_{23}=3, b_{31}=3, b_{32}=4$

$$B = \begin{matrix} & \begin{matrix} 1 & 2 & 3 \end{matrix} & \text{Factor} \\ \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} & \begin{bmatrix} 1434130 & 2 & 4 \\ 3 & 32508 & 3 \\ 3 & 4 & 53802 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} \end{matrix}$$

G. Variable Permanent Value Variations Calculation:

Now if we change the diagonal element of any of the subsystem of the main matrix the value of the permanent function changes in the same or different proportion as per their dependency of sub parameter on the permanent function. This shows the dependency of performance of CNC milling machine on individual factors.

1) *Variable Permanent Value Variation Due to MRR Related Parameters:*

It is observed that the MRR is decreased day to day after commissioning the new machine that means the diagonal dependency of sub parameters decreased day by day. That means RPM, feed, speed, Depth of cut also decreased day by day that reduces the vibration, cutting forces and other parameters.

The vibration in cnc milling machine reduces when the feed, depth of cut and cutting forces reduces. Due to reduction in these parameters, the value of dependency of the vibration is reduces from 5 to 4 in diagonal. The effect of that reduction direct affect the permanent value of MRR and which leads to direct impact on the Performance of CNC machine. After reduction the dependency value of vibration from 5 to 4 it is calculated that the value of permanent function changes from 2.508×10^{15} to 2.229×10^{15} which affect the overall system up to approx. 8.5 %.

Similarly the value of other parameter is also changes and find out the effect of all the sub parameter on permanent function. The below table shows the value of sub parameters, parameter index values for sub parameter permanent index value for B and the % impact of all the dependent parameters.

Table – 3
Variable Permanent Value Variation W.R.T MRR Related Parameters

System	Sub System	Index Value	Parameter Index value For Sub parameters	Parameter Index value for B	% impact on parameter index value
B ¹ (MRR)	B ₁ ¹	5	1434130	2.508x 10 ¹⁵	
		4	1312420	2.295x 10 ¹⁵	8.5
B ₂ ¹	B ₂ ¹	3	1190700	2.082x 10 ¹⁵	16.9
		6	1434130	2.508x 10 ¹⁵	
		5	1195110	2.094x 10 ¹⁵	16.5
B ₃ ¹	B ₃ ¹	4	956088	1.672x 10 ¹⁵	33.3
		7	1434130	2.508x 10 ¹⁵	
		6	1229260	2.149x 10 ¹⁵	14.3
B ₄ ¹	B ₄ ¹	5	1024380	1.791x 10 ¹⁵	28.5
		7	1434130	2.508x 10 ¹⁵	
		6	1291250	2.258x 10 ¹⁵	9.9
B ₅ ¹	B ₅ ¹	5	1148360	2.008x 10 ¹⁵	19.9
		3	1434130	2.508x 10 ¹⁵	
		2	1323120	2.434x 10 ¹⁵	2.9
B ₆ ¹	B ₆ ¹	1	1124354	2.103x 10 ¹⁵	16.2
		7	1434130	2.508x 10 ¹⁵	
		6	1229260	2.145x 10 ¹⁵	14.4
B ₇ ¹	B ₇ ¹	5	1024380	1.791x 10 ¹⁵	28.5
		3	1434130	2.508x 10 ¹⁵	
		2	1285410	2.273x 10 ¹⁵	11.344
B ₈ ¹	B ₈ ¹	1	1136684	2.138x 10 ¹⁵	19.688
		6	1434130	2.508x 10 ¹⁵	
		5	1195110	2.090x 10 ¹⁵	16.66
B ₈ ¹	B ₈ ¹	4	956088	1.672x 10 ¹⁵	33.33

2) *Variable Permanent Value Variation Due to Surface Roughness Related parameters:*

Similarly the same analysis is developed for Surface Roughness but surface roughness can be increased or decreased depending on the cutting conditions or customer requirement so the analysis is developed in both side to find out the percentage changes. The following table shows all the variable parameter values and the percentage changes.

Table - 4
Variable Permanent Value Variation W.R.T Surface Roughness Related Parameters

System	Sub System	Index Value	Parameter Index value For Subparameters	Parameter Index value for B	% impact on parameter index value
B ² (Surface Roughness)	B ² ₁	7	43092	3.324x 10 ¹⁵	32.53
		6	37800	2.916x 10 ¹⁵	16.26
		5	32508	2.508x 10¹⁵	
		4	27216	2.099x 10 ¹⁵	16.3
		3	21924	1.691x 10 ¹⁵	32.57
	B ² ₃	8	43344	3.344x 10 ¹⁵	33.3
		7	37926	2.926x 10 ¹⁵	16.6
		6	32508	2.508x 10¹⁵	
		5	27090	2.090x 10 ¹⁵	16.6
		4	21672	1.691x 10 ¹⁵	32.5
	B ² ₃	9	41796	3.224x 10 ¹⁵	28.54
		8	37152	2.866x 10 ¹⁵	14.27
		7	32508	2.508x 10¹⁵	
		6	27864	2.149x 10 ¹⁵	14.31
		5	23220	1.791x 10 ¹⁵	28.58
B ² ₄	9	40068	3.091x 10 ¹⁵	23.24	
	8	36288	2.799x 10 ¹⁵	11.6	
	7	32508	2.508x 10¹⁵		
	6	28728	2.216x 10 ¹⁵	9.84	
	5	24948	1.924x 10 ¹⁵	23.28	
B ² ₅	B ² ₅	5	36180	2.956x 10 ¹⁵	8.97
		4	33344	2.726x 10 ¹⁵	6.72
		3	32508	2.508x 10¹⁵	
		2	30672	2.308x 10 ¹⁵	3.98
		1	28836	2.182x 10 ¹⁵	5.02
	B ² ₆	8	43344	3.443x 10 ¹⁵	37.2
		7	37926	2.926x 10 ¹⁵	16.6
		6	32508	2.508x 10¹⁵	
		5	27090	2.207x 10 ¹⁵	12
4	21672	1.672x 10 ¹⁵	33.3		

3) Variable Permanent Value Variation Due to Tool Wear Related Parameters:

Similar study is developed for Tool wear. As time increased the tool wear is also increased. Thus the variable permanent function value is also changes. The following table shows the parameter dependency and variable permanent value changes as we changes the diagonal element values.

Table - 5
Variable Permanent value variation w.r.t MRR Related Parameters

System	Sub System	Index Value	Parameter Index value For Sub parameters	Parameter Index value for B	% impact on parameter index value
B ³ (Tool Wear)	B ³ ₁	9	66150	3.083x 10 ¹⁵	22.9
		8	59976	2.796x 10 ¹⁵	11.48
		7	53802	2.508x 10¹⁵	
	B ³ ₃	8	71736	3.344x 10 ¹⁵	33.3
		7	62769	2.926x 10 ¹⁵	16.6
		6	53802	2.508x 10¹⁵	
	B ³ ₃	9	69150	3.083x 10 ¹⁵	26.9

		8	61976	2.796×10^{15}	15.48
		7	53802	2.508×10^{15}	
	B^3_4	9	69174	3.224×10^{15}	28.5
		8	61488	2.866×10^{15}	14.27
		7	53802	2.508×10^{15}	
		B^3_5	5	62471	3.180×10^{15}
	4		58746	2.718×10^{15}	8.3
	3		53802	2.508×10^{15}	
	B^3_6	9	69174	3.224×10^{15}	28.5
		8	61488	2.866×10^{15}	14.27
		7	53802	2.508×10^{15}	

IV. RESULTS AND CONCLUSION

Based on the discussion in the previous chapter in which we have discussed about the variable permanent value and the relationship of variable permanent with critical parameter and dependent parameter.

A. Variable permanent value variation w.r.t MRR Related Parameters

Based on table 5.3, MRR and variable Permanent function variation is calculated as we changes the diagonal elements values because of parameter variation and cutting conditions. The variable permanent value variation changes up to 16.66 % as the value of diagonal element for Feed changes from 5 to 4. Similarly permanent value variation changes up to 14.5% as the diagonal element value of Speed is decreases from 7 to 6. The variation of variable permanent values which is affected by dependent variables is as follows:-

Feed > Speed > Coolant > Depth of Cut > Cutting Forces > Vibration > Heating in ball screw > Fuzzy Control.

B. Variable permanent value variation w.r.t Surface Roughness Related Parameters

Similarly based on table 5.4, Surface Roughness and variable Permanent function variation is calculated as we changes the diagonal elements values because of parameter variation and cutting conditions. Surface roughness may increases or decreases depending upon the condition or customer requirement. The variable permanent value changes up to 16.67 % as the value of diagonal element for feed changes from 6 to 7 and variable permanent value changes up to 12 % as the value of diagonal element for feed changes from 6 to 5. Similarly the variable permanent value changes up to 16 % as the value of diagonal element for depth of cut changes from 6 to 7 and variable permanent value changes up to 16 % as the value of diagonal element for feed changes from 6 to 5. The variation of variable permanent values which is affected by dependent variables is as follows:-

Feed > Depth of Cut > Cutting Forces > Coolant > Vibration > Speed

C. Variable permanent value variation w.r.t Tool Wear Related Parameters

Based on table 5.5, Tool wear and variable Permanent function variation is calculated as we changes the diagonal elements values because of parameter variation and cutting conditions. The tool wears increases as time increases in cutting operation. The variable permanent value variation changes up to 16.66 % as the value of diagonal element for depth of cut changes from 6 to 7. Similarly permanent value variation changes up to 15.48% as the diagonal element value of Cutting forces is increases from 7 to 8. The variation of variable permanent values which is affected by dependent variables is as follows:-

Depth of Cut > Cutting Forces > Speed > Feed > Vibration > Coolant.

REFERENCES

- [1] Amit Joshi, Pradeep Kothiyal(2012), "Experimental Investigation Of Machining Parameters Of Cnc Milling On Mrr By Taguchi Method", International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.7 No.11
- [2] B.C Rutara,(2008)," Roughness modeling and optimization in CNC end milling using response surface method: effect of workpiece material variation" Int J Adv Manuf Technol 40: pp 1166-1180
- [3] Bharat Chandra Routara, Saumya(2010), "Optimization in CNC end milling of AISI 304 Steel with multiple surface roughness's characteristics" Sadhana Vol. 35, Part 5, pp. 619-629
- [4] G. Euan, E. Ozturk(2013), "Modeling Static and Dynamic Cutting Forces and Vibrations for Inserted Ceramic Milling Tools, 14th CIRP Conference on Modeling of Machining Operations (CIRP CMMO), Procedia CIRP 8, pp 564 – 569
- [5] Hedi Yangui, Bacem Zghal(2010), "Influence of Cutting and Geometrical Parameters on the Cutting Force in Milling", Procedia Engineering 29 (2012) : pp 2645 – 2657
- [6] IbrahimMaher(2014), "Investigation of the effect of machining parameters on the surface quality of machined brass (60/40) in CNC end milling—ANFIS modeling.", MSTC08, 16-17 Dec, KLCC, Malaysia, pp 593-598

- [7] Ivan Sunit Rout(2014), "The effect of heat generation by friction in the ball screw nut system on the precision of high speed", IOSR Journal of Engineering (IOSRJEN)" Vol. 04, Issue 05,pp 06-12
- [8] Kantheti Venkata Murali Krishnam Raju(2006), "Optimization of Cutting Conditions for Surface Roughness in CNC End Milling", International journal of precision Engineering and Manufacturing Vol. 12, No. 3, pp. 383-391
- [9] KwangieOhl,etal (2013), "Identification of thermal characteristics in the Ball screw assembly", International Journal of Innovative Research in Science, Engineering and Technology", Vol. 2, Issue 5,pp1748-1756
- [10] Mandeep Chahal, Vikram Singh(2012), "Cutter Path strategies effect on the range of process parameters for optimization of Surface Roughness & Cutting forces in CNC Milling" International journal of research in aeronautical and mechanical engineering, 57(2), vol. 3, pp. 45-53
- [11] Meenu Sahu, komesh Sahu (2014), "Optimization of Cutting Parameters on Tool Wear, Workpiece Surface Temperature and Material Removal Rate in Turning of AISI D2 Steel" International Journal of Advanced Mechanical Engineering, ISSN 2250-3234 Volume 4, Number 3, pp. 291-298
- [12] Mohmmod Aziz Muhammed,(2003), "Heat Generation effect on precision ball screw" Vol. 5, Issue 3,pp1628-1637
- [13] Navin Vashisth, Mukesh Gupta, et al (2015), "Critical analysis of performance factors of CNC Mailling machine", National conference of Machine Intelligence and Research advancement, Vol 1, Issue 3, pp: 345-356.
- [14] Nitin Aggrawal(2012), "Surface Roughness Modelling with machine parameters (Speed, Feed, Depth of Cut)", MIT International Journal of mechanical engineering, vol 2, no 1, pp 55-61
- [15] P. Chockalingam, Lee Hong Wee(2012), " Surface Roughness and Tool Wear Study on Milling of AISI 304 Stainless Steel Using Different Cooling Conditions" International Journal of Engineering and Technology Volume 2 No. 8, pp. 652-661
- [16] PoTsang B. Huang, et al (2014), "An intelligent neural-fuzzy model for an in-process surface roughness monitoring system in end milling operations", "Springer Science+Business Media New York
- [17] PoTsang, B. Huang(2014), "An intelligent neural-fuzzy model for an in-process surface roughness monitoring system in end milling operations" International Journal of Advanced Manufacturing Technology 40: pp 1064–1072
- [18] R. Daud, N.K.Hasfa(2009), "Prediction of Chatter in CNC Machining based on Dynamic Cutting Force for Ball End Milling" Proceedings of the International MultiConference of Engineers and Computer Scientists, Vol II IMECS 2009
- [19] R. Ramesh, et al(2009), "Automated intelligent manufacturing system for surface finish control in CNC milling using support vector machines", pp 1-56
- [20] Rao RV (2006d), "Machine group selection in a flexible manufacturing cell using digraph and matrix methods", International Journal of Industries System Engineering 1(4), pp. 502–518
- [21] Sandeep Grover, V.P. Agrawal (2006), "Role of human factors in TQM: A graph theoretic approach", An International Journal, Vol. 13 No. 4,,pp. 447-468
- [22] Sharifah Noor Shahirah(2007)"Cutting force of end cutting tool milling machining", "Int J Adv Manuf Technol (2013) 67:1765–1776 DOI 10.1007/s00170-012-4607-0
- [23] Tian-Syung Lan (2010)"Tool Wear Optimization for General CNC Turning Using Fuzzy Deduction". Engineering, 2010, 2, 1019-1025 doi:10.4236/eng.2010.212128 Published Online December
- [24] V. S. Thangarasu, G. Devaraj(2012), "High speed CNC machining of AISI 304 stainless steel; Optimization of process parameters by MOGA", International Journal of Engineering, Science and Technology, Vol. 4, No. 3, pp. 66-77
- [25] Vijaya Krishna Teja, N. Naresh (2013), "Multi-Response Optimization of Milling Parameters on AISI 304 Stainless Steel using Grey-Taguchi Method", International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 8
- [26] Vytautas Ostasevicius,(2013), "Study of Vibration Milling for Improving Surface Finish of Difficult-to-Cut Materials", Strojniški vestnik - Journal of Mechanical Engineering 59.6, 351-35.
- [27] Wani MF, Gandhi OP (1999), "Development of maintainability index for mechanical systems". Reliab Eng Syst Saf 65, pp. 259–270
- [28] Wen-Hsiang Lai,(2010), "Modelling of Cutting Forces in End Milling Operations", "Tamkang Journal of Science and Engineering, Vol. 3, No. 1, pp. 15-22
- [29] Wu Baohai (2009), "Cutting force prediction for circular end milling process", "Chinese Journal of Aeronautics,26(4): 1057–1063", pp 1-117
- [30] Xie Dong, Zhu Jian(2012), "Fuzzy PID Control To Feed Servo System of CNC Machine Tool" Procedia Engineering 29 pp 2853 – 2858
- [31] Yao Xiong , Jun Wu(2013), "Machining process parameters optimization for heavy-duty CNC machine tools in sustainable manufacturing" International Journal of Advanced Manufacturing Technology DOI 10.1007/s00170-013-4881-5
- [32] Zhong LJ, Yu AB, Yu SY, Du HY (2006), "Machinability evaluation of engineering ceramics with digraph method", Key Eng Mater 304, pp. 256–260