Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 8, August -2015

Evaluation of factors affecting cutting forces with CNC Milling using Graph Theory and Matrix Approach

Mandeep Chahal, Sandeep Malik

Asst. Professor at Department of Mechanical Engineering, HCTM, Kaithal, Haryana, India
Student at HCTM, Kaithal, Haryana, India

Abstract- *Machinability aspect is of considerable importance for efficient process planning in manufacturing. In this paper, graph theoretic approach (GTA) is proposed to evaluate the cutting force during CNC milling. Cutting force is considered as a machinability attribute during CNC milling to evaluate the effect of several factors and their subfactors. Factors affecting the cutting force and their interactions are analyzed by developing a mathematical model using digraph and matrix method. Permanent function or machinability index is obtained from the matrix model developed from the digraphs. This index value helps in quantifying the influence of considered factors on cutting force. In the present illustration, factors affecting cutting force during CNC milling are grouped into five broad factors namely work material, machine tool, cutter runout, penetration strategies, and tool geometry to be machined. GTA methodology reveals that the machine tool has highest index value. Therefore, it is the most influencing factor affecting cutting force.*

Keywords- *Graph theory, Index value, CNC Milling, Cutting Force*

1. INTRODUCTION

CNC Milling system serve as an alternative to EDM for making dies or moulds from the hardened tool steels. It produces the die faster and is also more accurate, because fewer steps result in reduced error stacking. It can result in significantly lower manufacturing costs and times when compared with existing production processes and its performance is characterized by a lot of the machining factors. End milling is the widely used operation for metal removal in a variety of manufacturing industries including the automobile and aerospace sector where quality is an important factor in the production of slots, pockets and moulds/dies (Mike et al, 1999; John and Joseph, 2001).

The use of computer numerical control (CNC) machining centers has expanded rapidly through the years. A great advantage of the CNC machining center is that it reduces the skill requirements of machine operators. One of the most important yet least understood operation parameters of a machining operation is the cutting force. In general, this force is thought of as a 3D vector that is represented by three components, namely, the power component, the radial component and the axial component in the tool coordinate system (Zorev, 1966). Of these three components, the greatest normally is the power component, which is often called the cutting force. This simplification will be used through the body of this paper. As this force is of high importance, one might think that theoretical and experimental methods for its determination have been developed and are thus available in the literature. Unfortunately, this is not the case. When it comes to a possibility of theoretical determination, the foundation of the force and energy calculations in metal cutting is based upon the over simplified orthogonal force model known as Merchant's force circle diagram or a condensed force diagram (Komanduri, 1993; Merchant,2003).

Thus, much effort has been devoted to developing indirect force-measurement tools. When it comes to experimental determination of the cutting force, there are at least two problems.

1. First and foremost is that the cutting force cannot be measured with reasonable accuracy although this fact has never been honestly admitted by the specialists in this field. To appreciate the issue, one should consider the results of the joint program conducted by The International Academy for Production Engineering, and National Institute of Standards and Technology (NIST) to measure the cutting force in the simplest case of orthogonal cutting (Ivester, 2004). The experiments were carefully prepared (the same batches of the workpiece (steel AISI 1045), tools, etc.) under the supervision of National Institute of Standards and Technology (NIST) and replicated at four different most advanced metal cutting laboratories in the world. Interestingly, although extraordinary care was taken while performing these experiments, there was significant variation (up to 50%) in the measured cutting force across these four laboratories. If less care is taken and no laboratory conditions are available then the accuracy of cutting force measurement be much would worse.

2. Second, many tool and cutting inserts manufacturers do not have adequate dynamometric equipment to measure the cutting force. Many dynamometers used in this field are not properly calibrated because the known literature sources did not present proper experimental methodology for cutting force measurements using piezoelectric dynamometers (Astakhov and Shvets, 2001).

Out of the various CNC industrial machining processes, milling is one of the vital machining operations. Milling is a common metal removal operation in industry because of its ability to remove material faster with a reasonably good surface quality.

The matrix approach is useful in analyzing the graph models expeditiously to derive the system function and index to meet the objectives. Moreover, representation of graph by a matrix offers ease in computer processing (Jangra et al. 2002). This paper reveals the utilization of graph theoretic approach (GTA) to determine the factors affecting cutting force with CNC Milling. Various factors, sub-factors and their interdependencies that affect the cutting force is prepared by a digraph and demonstrated by a matrix. A numeric value named as index value (MI) has been calculated to evaluate the cutting force. A detailed literature review has been done to determine the various factors and sub-factors that affect the cutting force under different machining methods. Experimental results and the methodology based on graph theory to evaluate the Index value have been discussed in the later sections.

2 LITERATURE REVIEW

In order to achieve the objectives of this research a literature review was conducted. The literature involved information on Graph theory and Matrix method used in various field of science and technology and also on the behavior of cutting force during machining.

Lou et al. (1999) carried out experimentation to evaluate that feed rate was the most significant machining parameter used to predict the SR in the multiple regression models. Toh (2006) investigated and evaluated the different cutter path orientations when high-speed finish milling hardened steel, and the results demonstrated that vertical upward orientation has been generally preferred in terms of workpiece SR. Zhang et al. (2007) suggested that Milling has been one of the most widely used metal removal processes in industry and milled surfaces are largely used to mate with other parts in die, aerospace, automotive and machinery design as well as in manufacturing industries. Heinz A Preisig (2007) Suggested A Graph-Theory-Base Approach to the Analysis of Large-Scale Plants On-line balancing of mass and energy in a large-scale plant.

Gologlu and Sakarya (2008) studied that Milling of machining parts could be accomplished by employing different cutter path strategies (step over), which were one direction, back and forth and spiral cutter path strategies. Viktor P. Astakhov and Xinran Xiao (2008). Huang et al. (2012) developed a hybrid graph theory and GA approach to process planning for a prismatic part within the context of CAPP. Jaime Cerda Jacobo et al. (2012) provide A Graph-based Method to Solve the Economical Dispatch Problem Disregarding Slack Variables One of the greatest challenges to confront Nonlinear Programming Problems; it is the selection of the active and non active set of constraints of the system.

Srishti Sabharwal and Suresh Garg(2013). Determining cost effectiveness index of remanufacturing: A graph theoretic approach Remanufacturing is a powerful product recovery option which generates products as good as new ones . Rajesh Attri and Sandeep Grover (2013). Application of preference selection index method for decision making over the design stage of production system life cycle The life cycle of production system shows the progress of production system from the inception to the termination of the system. During each stage, mainly in the design stage, certain strategic decisions have to be taken.

Vinay Babu Gada et al. (2013) In the present study, an attempt has been made to investigate the effect of primary cutting parameters (cutting speed, feed and depth of cut) and tool overhang length on cutting forces and chatter starting point lengths in finish turning of EN8 steel, EN24 steel, Mild steel and aluminium.

Nikhil Dev et. al (2014). Provide A systematic approach based on graph theory and matrix method was developed ingeniously for the evaluation of reliability index for a Combined Cycle Power Plant (CCPP). In present work CCPP system is divided into six subsystems. Consideration of all these subsystems and their interrelations are rudiment in evaluating the index. Reliability of CCPP is modelled in terms of a Reliability Attributes Digraph.

Vishal S. Sharma et al. (2014) were Investigated the tool geometry effect and penetration strategies on cutting forces during thread milling. The application of thread milling is increasing in industry because of its inherent advantages over other thread cutting techniques. The objective of this study is to investigate the effect of milling cutter tool geometry on cutting forces during thread milling. The proposed method can compare the performance of milling cutters in spite of the different number of tooth. The best thread milling cutter among the studied tools was determined from the cutting forces point of view. Furthermore, this study also pinpoints the best penetration strategy that provides minimum cutting forces. Lower cutting force variations will lead to fewer vibrations of the tool which in turn will produce accurate part.

Based on the detailed literature related to the machining of tool steels and other hard materials, various factors and sub-factors have been identified which affect the cutting force during machining with CNC Milling. Table1 summarize these factors and sub-factors.

Problem Identification

1. Literature review reveals that researchers have carried out most of the work with AHP (analytic hierarchy process), ANN (artificial neural network), DOE (design of experiment), Taguchi method and RSM (Response surface methodology) but very limited work has been reported with Graph theory and Matrix approach.
2. Very limited work has been reported to evaluate the cutting force on CNC Milling by using graph theory and matrix approach.
3. Most of the researchers have applied Graph Theory to evaluate the surface roughness and MRR. Here I am applying Graph Theory to evaluate cutting force during CNC Milling.

3 GTA

The beginning of Graph theory is said to have in 1736 when EULER considered the Konigsberg bridge problem. Subsequently, the graph theory has been applied in various fields of engineering such as physics, chemistry, mathematics, electrical engineering, sociology, computer technology (net working), economics, operation research, etc.

Graph theoretic approach (GTA) is a systematic methodology for conversion of qualitative factors to quantitative values and mathematical modeling gives an edge to the proposed technique over conventional methods like cause-effect diagrams, flow charts etc. Graph theory serves as a mathematical model of any system that includes multi relations among its constituent elements because of its diagrammatic representations and aesthetic aspects. GTA is a three stage unified systems approach (Deb, 2000).

(i). Modeling of systems in terms of nodes and edges gives a structural representation to the system and results in a directed graph. This representation is suitable for visual analysis and understanding the interrelationships among various nodes.
(ii). For further analysis, digraph representation is converted to matrix form, which makes it suitable for computer processing. However the matrix representation is not unique as changing the labeling of nodes can change it.
(iii). Analysis of matrix model results in permanent function model, which is in the expression form. The permanent function model analyzes various combinations among the factors and interrelationships. Simplified permanent function expression is represented in terms of a single numerical index.

Using graph theoretic approach, several attempts have been made to solve the industrial problems involving multi variables having interaction among them (Wani and Gandhi, 1999; Rao and Gandhi, 2002, 2006; Grover et al., 2004; Jangra et al., 2011).

3.1 Methodology

The various steps involved in graph theoretic approach are enlisted in sequential manner as below:
1.Identify the various sub-systems affecting the main system.
2.Logically develop a diagraph between the system/sub-system depending upon their
interdependencies.
3. Develop a variable permanent function matrix at the sub-system level on the basis of digraph developed in step 2. Matrix representation of the alternative selection criteria digraph gives one-to-one representation. A matrix called the equipment selection criteria matrix. This is an M in M matrix and considers all of the criteria (i.e. A_i) and their relative importance (i.e. a_{ij}). Where A_i is the value of the i-th criteria represented by node n_i and a_{ij} is the relative importance of the i-th criteria over the j-th represented by the edge e_{ij} (Rao, 2007; Faisal et al., 2007).

The value of A_i should preferably be obtained from available or estimated data. When quantitative values of the criteria are available, normalized values of a criterion assigned to the alternatives are calculated by v_i/v_j, where v_i is the measure of the criterion for the i-th alternative and v_j is the measure of the criterion for the j-th alternative which has a higher measure of the criterion among the considered alternatives. This ratio is valid for beneficial criteria only. A beneficial criteria means its higher measures are more desirable for the given application. Whereas, the non-beneficial criterion is the one whose lower measures are desirable and the normalized values assigned to the alternatives are calculated by v_j/v_i.

$$CS\ \text{Matrix} = \begin{bmatrix} A_1 & a_{12} & a_{13} & a & a & a_{1.m} \\ a_{21} & A_2 & a_{23} & \cdots & \cdots & a_{2.m} \\ a_{31} & a_{32} & A_3 & \cdots & \cdots & a_{3.m} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \vdots & \ddots & \cdots & \cdots & \cdots & \vdots \\ a_1 & a_1 & a_1 & \cdots & \cdots & A_m \end{bmatrix}$$

4.Using the logical values of the inheritances and interdependencies, obtain the permanent functions at the system/subsystem level. The off- diagonal elements of the matrix representation may be obtained from the graphs, knowledge database interpretation or from the excerpts of the expert's opinion.

5. Evaluate the permanent of the variable permanent function at the system/sub-system level. Obtaining alternative selection criteria function for the matrix. The permanent of this matrix, is defined as the alternative selection criteria function.

Table 1. Factors and sub factors affecting cutting forces

S. no.	Factors	Sub-factors	References
1.	Work material	Temperature, hardness, Tensile strength	joseph (1995)
2.	Cutter runout	Uncut chip thickness, shear angle, Friction angle	Min Wan et al.(2014)
3.	Tool Geometry	Tool extension length, rack angle, Deflection of cutting tool	Renjith V B et al.(2013)
4.	Penetration strategies	Straight penetration(sp), half revolution Penetration(hrp), quarter revolution penetration(qrp)	Vishal S.Sharma et al.(2014)
5.	Machine tool	Cutting speed, feed rate, depth of cut, Tool overhang length	Mr.Vinay Babu Gada, et al.(2013)

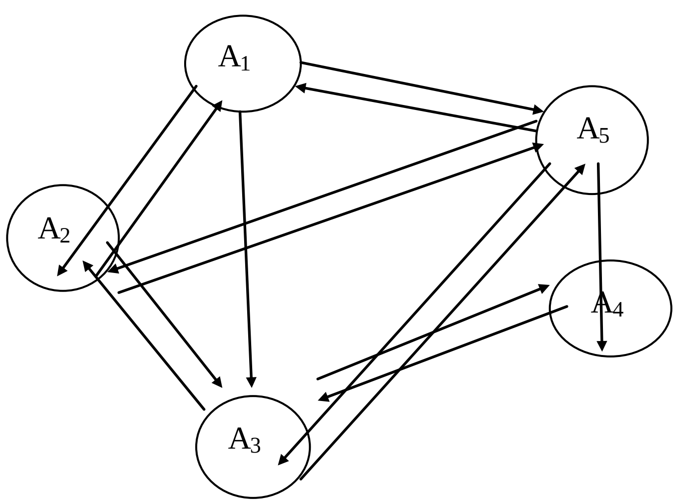

Fig. 1 Digraph representing interdependence among factors 1 work material 2 cutter runout, 3 tool geometry, 4 penetration strategies, 5 machine tool

$$\mathrm{VPM} = B = \left(\begin{array}{cccccc} A1 & A2 & A3 & A4 & A5 & \\ A_1 & a_{12} & a_{13} & a_{14} & a_{15} & A1 \\ a_{21} & A_2 & a_{23} & a_{24} & a_2 & A2 \\ 0 & a_{32} & A_3 & a_{34} & a_{35} & A3 \\ 0 & a_{42} & a_{43} & A_4 & 0 & A4 \\ A_{51} & a_{52} & a_{53} & a_{54} & A_5 & A5 \end{array}\right) \qquad (1)$$

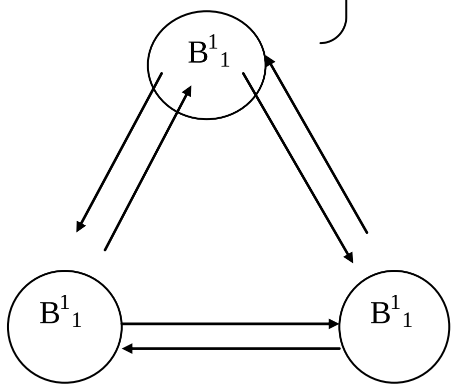

Fig. 2 Digraph representing sub-factors affecting work-piece: 1 temp. 2 hardness 3 tensile strength

Table 2. Quantification of factors affecting cutting forces

Qualitative measure of factors	**Assigned value/inheritance**
Exceptionally low	1
Very low	2
Low	3
Below average	4
Average	5
Above average	6
High	7
Very high	8
Exceptionally high	9

Table 3. Quantification of interdependence/off diagonal elements

S. no.	**Qualitative Measure**	a_{ij}
1	Very strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very weak	1

Table 4. Results of air hardened die steel(H-11)

S. no.	Temp.(^{0}C)	Hardness(HRC)	Tensile strength (Mpa)
1	510	56.5	2,120
2	540	56.0	2,005
3	565	52.0	1,855
4	595	45.0	1,540
5	650	33.0	1,060

Results are taken from joseph (1995)

3.5 Index value for work material (A1)

Sub factors affecting work material and their interactions have been illustrated with the help of digraph as in Fig.2

Table 5. Inheritance of sub-factors for work material (diagonal elements)

S. no.	Temperature(B^1_1)	Hardness (B^1_2)	Tensile strength (B^1_3)
1	6	5	7
2	7	6	7
3	9	7	6
4	5	7	4
5	4	7	4

Table 6. Index Value for work piece for different combination

Subsystem with different sub factor combination	$(A_1)_1$	$(A_1)_2$	$(A_1)_3$	$(A_1)_4$	$(A_1)_5$
Index value	483	585	680	380	344

The superscript represents the factor and the subscript represents the sub factors affecting factor (work-piece). Experimental data proposed by Joseph (Joseph and Tool Materials 1995) has been used to evaluate the inheritance of diagonal elements. The results show the significant effect that temperature has on hardness and tensile strength of die steels.
At higher temperatures, the die steels start losing their hardness and tensile strength. The inheritance of sub-factors has been assigned value in range of 1–9 as shown in Table 5 with the help of Table 2.

The VPM for each sub-system based on digraph showing their inter-relationship have been developed and based on detailed literature review, the numeric values of interdependences between sub-factors (non-diagonal elements) have been taken from Table 3.
Value of permanent function for work material (A1) can be calculated using Eq.3.

$$VPM = A_1 = \begin{pmatrix} 1 & 2 & 3 & \\ B^1_1 & 3 & 2 & 1 \\ 5 & B^1_2 & 2 & 2 \\ 5 & 4 & B^1_3 & 3 \end{pmatrix} \quad (3)$$

Higher values of index reflect the best conditions of cutting force, because at 565^{0}C the die steel maintains optimum hardness and tensile strength (Table 6).

3.6 Index value for Cutter runout (A2)

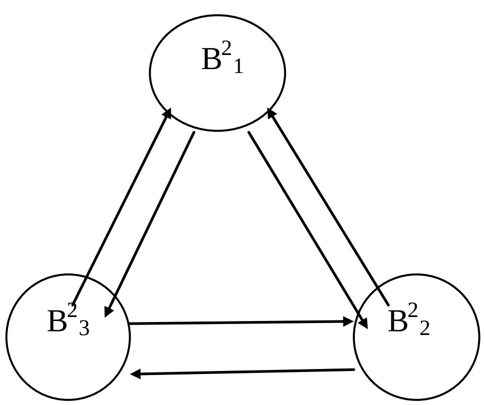

Fig.3. Digraph representing sub-factors affecting cutter runout: 1 uncut chip thickness, 2 shear angle 3 friction angle

Min Wan et al.(2014) was stated that the accurate determination of cutting force coefficients is essential for reliable prediction of cutting force in milling process. A unified and simple method is proposed to develop unified instantaneous cutting force model for flat end mills with variable geometries. By transforming the cutting forces measured in Cartesian coordinate system into a local system on normal plane, novel procedures and algorithms are presented to establish the instantaneous models of shear stress, shear angle and normal friction angle involved in the cutting force coefficients. The advantage of the new method lies in that the models developed from a few tests.

Table 7. Experimental result for uncut chip thickness in milling

Sr. no.	Uncut chip Thickness	friction angle	shear angle
1	0.05	0.5	0.2
2	0.06	0.6	0.4
3	0.07	1.0	0.6

Results have been taken from Min wan et al. (2014)

Sub factors related to cutter runout and their interactions have been illustrated with the help of digraph as in Fig. 3. The superscript represents the factor and the subscript represents the sub factor affecting factor (cutter runout). Based on the need, inheritance values have been assigned to sub-factors affecting cutter runout (Table 8). The VPM for each sub-system based on digraph showing their inter-relationship have been developed and based on detailed literature review, the numeric values of interdependences between sub-factors (non-diagonal elements) have been taken from Table 3.

Value of permanent function for cutter runout (A2) can be calculated using Eq. 4.

$$VPM = A_2 = \begin{bmatrix} & 1 & 2 & 3 & \\ & B^2_1 & 3 & 2 & 1 \\ 5 & B^2_2 & 4 & 2 & \\ & 3 & 4 & B^2_3 & 3 \end{bmatrix} \quad (4)$$

Table 8. Inheritance of sub-factors in cutter runout (diagonal elements)

Uncut chip thickness	inheritance (B^2_1)	friction angle	inheritance (B^2_2)	shear angle	inheritance (B^2_3)
0.05	4	0.5	5	0.2	6
0.06	7	0.6	6	0.4	8
0.07	7	1.0	6	0.6	6

Table 9. Index value for cutter run out

Subsystem with different Sub factor combination	$(A_2)_1$	$(A_2)_2$	$(A_2)_3$
Index value	380	680	566

It is found that shear angle increases along with the increase of instantaneous uncut chip thickness, whereas normal friction angle decreases.

Higher index value $(A_2)_2$, illustrates that friction angle have been preferred in case of cutter runout on CNC Milling (Table 9).

3.7 Index value for tool geometry (A_3)

Sub factors affecting tool geometry and their interactions have been illustrated with the help of digraph as in Fig. 4

The superscript represents the factor and the subscript represents the sub factor affecting factor (tool geometry). Tool geometry is a function of tool extension length, rake angle and deflection of cutting tool. Based on the application, inheritance values have been assigned to sub-factors affecting tool geometry. Value of permanent function for tool geometry (A3) can be calculated using Eq.5.

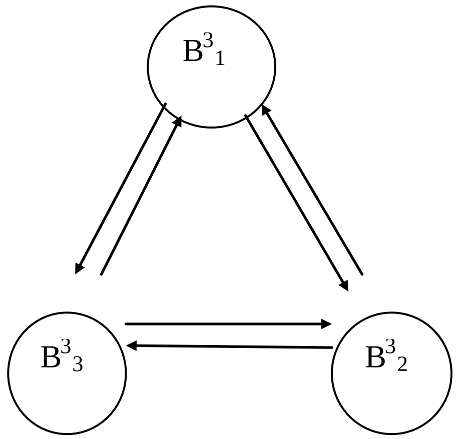

Fig. 4. Digraph representing sub-factors affecting tool geometry: 1. tool extension length 2. rack angle 3. Deflection of cutting tool

$$VPM = A_3 = \begin{pmatrix} & 1 & & 2 & 3 & \\ & B^3_1 & 3 & 4 & 1 & \\ 5 & B^3_2 & 3 & & & 2 \\ & 4 & 3 & B^3_3 & 3 & \end{pmatrix} \qquad (5)$$

Table 10. Experimental results for tool geometry

S. no.	Rake angle (degree)	Tool extension length (mm)	Deflection (mm)
1	10	30	0.04791
2	15	35	0.06248
3	0	25	0.0123

Results have been taken from Renjith V B et al. (2013)

Table 11. Inheritance of sub factors in tool geometry (diagonal elements)

Rack Angle	Inheritance (B^3_1)	Tool extension length	Inheritance (B^3_2)	Deflection	Inheritance (B^3_3)
10	4	30	5	0.04791	5
15	5	35	6	0.06248	6
0	7	25	6	0.0123	8

Table 12. Index Value for tool geometry

Subsystem with different Sub factor combination	$(A_3)_1$	$(A_3)_2$	$(A_3)_3$
Index value	387	507	711

Putting the value of diagonal elements, index under different combinations can be calculated. Higher value of (MI) indicates that cutter having rake angle of 0 and tool extension length of 25 is usually preferred which give minimum deflection i.e. 0.0123 mm.

3.8 Index value for penetration strategies (A_4)

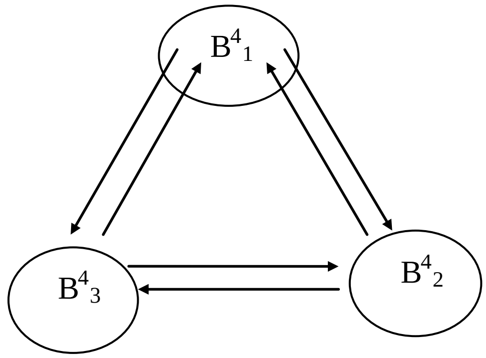

Fig. 5. Digraph representing sub-factors affecting penetration strategies: 1. straight penetration 2. half revolution penetration 3. quarter revolution penetration

The penetration strategies (PS), used in the study, are straight penetration (SP), half revolution penetration (HRP), and quarter revolution penetration (QRP). In SP, the mill engages with the part following a straight line trajectory; there is no Z-axis displacement during this movement. For HRP, the tool follows a half helical path to engage with the part; during this movement, it also travels equal to P/4 in Z-axis. QRP utilizes quarter helical trajectory for engagement with the part and movement in Z-axis. HRP and QRP strategies are employed in industry; the SP strategy is considered for comparisons with them.

the process can be used to machine difficult-to-machine materials such as titanium alloys, tool steels, stainless steels, hardened steels, and other super alloys. The machine used for the experiments was a three-axis vertical machining center (Deckel Maho DMC 65V). Aluminum alloy (AlCu4Mg) was opted for study as it exhibits good machinability characteristics. Solid carbide TiCN-coated thread mills were used for the study. Cutting forces were measured with 9123 Kistler rotating dynamometer and data was processed using DASY Lab acquisition software.

Table 13. Experimental data for full machining and penetration

Sr. no.	D (mm)	Mill	Ps	N_{wt} (N)	RF_{ptp} (N)	RF_{rms}	RF_{rms}/N_{wt} (N)
1	20	T1	FM	1.02	423	196	192
2	20	T1	SP	1.68[a]	653	322	192
3	20	T1	HRP	1.02[a]	490	213	209
4	20	T1	QRP	1.02[a]	451	207	203
5	20	T2	FM	1.67	193	189	113
6	20	T2	SP	2.46[a]	604	350	142
7	20	T2	HRP	1.67[a]	361	213	128
8	20	T2	QRP	1.67[a]	354	204	12

Results have been taken from Vishal S. Sharma et al. (2014)

Table 14 Inheritance of sub factors in penetration strategies (diagonal elements)

SP ($B^4{}_1$)	HRP ($B^4{}_2$)	QRP ($B^4{}_3$)
5	7	9

Vishal S. Sharma et al (2014). Various types of Penetration strategies have been illustrated with the help of digraph as in Fig. 5. Here the superscript represents the factor and the subscript represents the sub factor affecting factor (Penetration strategies) (Tables 10, 11, 12,13, 14).

Value of permanent function for Penetration strategies (A4) can be calculated using Eq. 6.

$$VPM = A_4 = \begin{bmatrix} & 1 & 2 & 3 & \\ & B^4{}_1 & 1 & 2 & 1 \\ 2 & B^4{}_2 & 1 & 2 & \\ & 2 & 2 & B^4{}_3 & 3 \end{bmatrix} \qquad (6)$$

Index value for Eq. (6) is 380.

1.Straight penetration leads to more resultant cutting forces as compared to half revolution penetration and quarter revolution penetration strategies for all the three milling cutters because flute working angle (θ_{twa}) becomes double at the end of penetration strategy.

2.The cutting forces are minimum for quarter revolution penetration because of progressive increase of radial penetration (r_p) and the number of working teeth (N_{wt}).

3.The peak to peak variations of the resultant cutting force is linked to the number or working teeth, and according to this criterion T2 mill appears to be the best among the studied tools.

3.9 Index value for Machine tool (A_5)

Sub- factors affecting machine tool and their interrelationship have been demonstrated with the help of digraph as in Fig. 6.

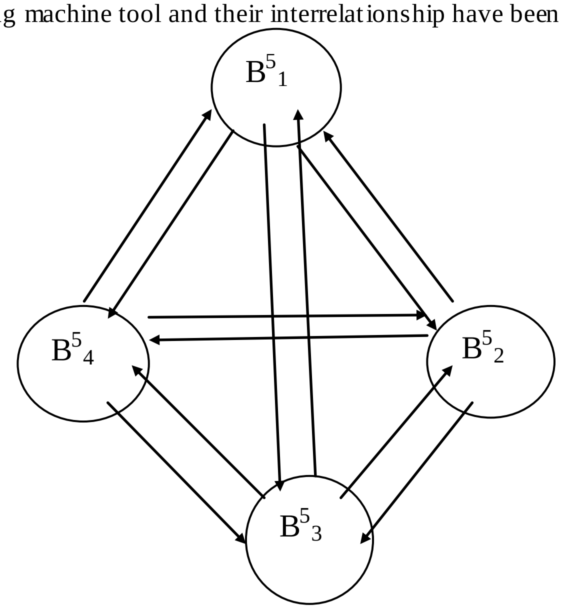

Fig. 6 Digraph representing sub-factors of machine tool: 1 cutting speed 2 feed rate 3 depth of cut 4 tool overhang length

Many engineering components manufactured using casting, forming and other processes often require machining as their end operation. Machining or metal cutting is an important manufacturing process. With the modern trend of machine tool development, accuracy and reliability are becoming prominent features. To achieve higher accuracy and productivity, it requires consideration of dynamic instability of cutting process. When there is a relative motion present between the tool and work piece, the performance of the operations may not be satisfactory. The machine tool vibrations have detrimental effect on tool life which in turn lowers the productivity and increases cost of production.

Fig.7 Five-axis machining center with rotating table and computer interface

Table 15. Operating parameters and their levels used in the experiments:

Work piece material	Cutting speed in(rpm)	Feed rate(mm/rev)	Depth of cut(mm)	Tool overhang length(mm)
EN 24 Steel	7, 14, 22	0.1(constant)	0.1, 0.2, 0.3, 0.4 0.5, 0.6, 0.7	54,57,59,61
EN 8 Steel	7, 14, 22	0.1(constant)	0.1, 0.2, 0.3, 0.4 0.5, 0.6, 0.7	53, 57, 60,63
Mild Steel	7, 14, 22	0.1, 0.138, 0.175 0.2, 0.275, 0.35, 0.5	0.1(constant)	54,57,59,61
Aluminum	7, 14, 22	0.1, 0.138, 0.175 0.2, 0.275, 0.35, 0.5	0.1(constant)	53,54,58,62

Results have been taken from Vinay Babu Gada et al. (2013)

Based on the optimum values of process parameters taken from Table 15, the inheritance values have been assigned to sub-factors of machine tool as in Table 16. Value of permanent function for machine tool (A5) can be calculated using Eq. 7

Table 16. Inheritance of sub factors of machine tool (diagonal elements)

Cutting speed	(B^5_1)	Feed rate	(B^5_2)	Depth of cut	(B^5_3)	Tool overhang length	(B^5_4)
7	6	0.1	6	0.1	5	53	4
14	7	0.2	8	0.2	6	57	5
18	6	0.3	5	0.4	4	59	4
22	5	0.5	6	0.6	4	63	3

Table 17. Index value for machine tool

Subsystem with different sub factor Combination	$(A_5)_1$	$(A_5)_2$	$(A_5)_3$	$(A_5)_4$
Index value	3,496	5,328	2,968	2,616

$$VPM = A_5 = \begin{bmatrix} & 1 & 2 & 3 \\ B^5_1 & 3 & 2 & 1 \\ 4 & B^5_2 & 3 & 2 \\ 3 & 3 & B^5_3 & 3 \end{bmatrix} \qquad (7)$$

Index value indicates that feed rate is the most significant sub factor affecting cutting force, followed by cutting speed ,depth of cut and tool overhang length. (Tables 16, 17).

Table 18 Index Value for under different sub-factor combination

S. no.	Subsystem combination	Index value
1	$(A_1)_1(A_2)_1(A_3)_1(A_4)_1(A_5)_1$	9.43×10^{13}
2	$(A_1)_2(A_2)_2(A_3)_2(A_4)_2(A_5)_2$	4.08×10^{14}
3	$(A_1)_3(A_2)_3(A_3)_3(A_4)_3(A_5)_3$	3.09×10^{14}
4	$(A_1)_4 (A_2)_4(A_3)_4(A_4)_4(A_5)_4$	1.52×10^{14}
5	$(A_1)_5(A_2)_5(A_3)_5(A_4)_5(A_5)_5$	2.40×10^{14}

$$VPM = B^* = \begin{array}{c} \begin{array}{ccccc} A1 & A2 & A3 & A4 & A5 \end{array} \\ \left(\begin{array}{ccccc} A1 & 3 & 2 & 2 & 5 \\ 4 & A2 & 4 & 2 & 3 \\ 0 & 3 & A3 & 4 & 4 \\ 0 & 2 & 4 & A4 & 0 \\ 2 & 1 & 2 & 3 & A5 \end{array}\right) \end{array} \begin{array}{c} A1 \\ A2 \\ A3 \\ A4 \\ A5 \end{array} \quad (8)$$

Now, the need is to calculate the MI of the complete system. The VPM is used and the value of diagonal elements has been determined by the results obtained for each sub factor. MI has been calculated under different subsystem combinations. Value of permanent function for Cutting force (A) can be calculated using Eq. 8.

Higher index value of sub-system corresponds to substantial influence on the cutting force. Machine tool subsystem has the highest index value, so it is the most important factor corresponding to cutting force. Higher index value of subsystem combination demonstrates that feed rate is the most crucial machining parameter influencing cutting force, followed by cutting speed and depth of cut

4. RESULTS AND DISCUSSION:-

Index value is helpful in evaluating the important parameters affecting Cutting Force at both system and sub-system level. Graph theory technique can be used to evaluate the weak and the strong factors and sub-factors. In present work, work-piece, cutter runout, tool geometry, penetration strategies and machine tool have been taken as factors affecting Cutting force. Firstly, the tensile strength, temperature and hardness of wok piece have been worked out and the inter-relationship have been developed at sub-system level and based on index values, the optimum values of tensile strength, hardness and temperature have been taken for work piece to carry out experimentation. Similarly, impact of friction angle, shear angle and uncut chip thickness on cutter runout have been evaluated and based on index values of $(A_2)_2$ and $(A_3)_3$, it has been found that shear angle increases along with the increase of instantaneous uncut chip thickness, whereas normal friction angle decreases.

Higher index value $(A_2)_2$, illustrates that friction angle have been preferred in case of cutter runout on CNC Milling to achieve good surface finish values. experimentation has been conducted by Mr.Vinay Babu Gada et al (2013) are used to determine the range of machining parameters like feed rate, depth of cut, cutting speed and tool overhang length. Results reveal that machine tool is the most important factor at the system level and machine tool index value illustrates that feed rate is the most vital parameter affecting cutting force, followed by cutting speed, tool overhang length and depth of cut at the sub-system level. At last, Index value is calculated for complete system. Combination 2 reveals the best results in terms of cutting force and hence is the most preferred combination of sub-factors to achie optimum cutting force.

5.CONCLUSIONS:-

To determine cutting forces, graph theory proves to be a capable system that can compare the parameters at both system and subsystem level and helps in quantifying the influence of various factors and sub-factors. By using this technique, the evaluation of the weak and the strong factors and sub factors is done. Graph theory provides flexibility in terms of number of factors, sub-factors and help in predicting the most influencing interactions between sub-factors. By using this, machinability can also be evaluated in terms of quality characteristics like material removal rate, surface roughness, dimensional accuracy etc. In nutshell, it is concluded that cutting force index can be a very effective tool for achieving optimum solutions to production problems.

6. SCOPE FOR FUTURE WORK

1. Using this methodology, machinability of any material can be evaluated and compared under the influence of any number of factors and subfactors.
2. Similar to this methodology, machinability can be evaluated in terms of other machining performances such as surface finish, dimensional precision, tool life, etc.

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