OPTIMIZATION OF MACHINING PROCESSES BY USING CRITERIA OF MAXIMUM PRODUCTIVITY AND MINIMUM COST

by

AEAD M. AHMED

(0940510393)

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Author's full name ...AEAD M. AHMED........................

Date of birth ...22th / DECEMBER / 1979 ....…………......

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LIST OF SYMBOLS

Term	**Description**	**Units**
$\sum_{j=1}^{p} t_{ej}$	Time Losses Referred to One Part Due to Reliability of Machine Tool Units Containing Mechanical Electrical, Hydraulic, etc. Treatment	min/part
$\sum_{i=1}^{k} t_{ci}$	Losses Referred to One Part Due to Reliability of Cutting Tools That Changed After Limit Time of Wearing or Occasional Braking	min/part
$\sum_{j=1}^{s} t_{org.j}$	Time Losses Due to Managerial and Organizational Problems of *S*	min/part
$\sum_{i=1}^{d} t_{t.i}$	Time Losses Referring to One Product Due to Technical Problems of a Machine	min/part
$\sum_{i=1}^{r} t_{ci}$	Time Losses Referred to One Part Due to Reliability of *r* Tools	min/part
$\sum_{i=1}^{r} t_{ci}^{*}$	Time Losses Due to Reliability of *r* Tools at New Cutting Speeds	min/part
$\sum_{j=1}^{p} t_{uj}$	Time Losses Referring to One Part Due to the Reliability of *P* Machine Units	min/part
a	Safety Distance	mm
B	Ratio of the Failure Rates of Mechanisms of Auxiliary Motions to Machine Motions	
B_g	Burden Rate of Tool Grinder	MYR/min
B_m	Overhead Charge of the Machine	MYR/min
C	Taylor's Coefficient of the Cutter Work	
C_l	Cost of Loading, Unloading	MYR/part
C_m	Machining Cost	MYR/part
C_p	Total Machining Cost Per Part	MYR/part
C_s	Cost of Setting Up for Machining, material and	MYR/part

	nonproductive cost	
C_t	Cost of Tool-Related Expenses Per One Piece	MYR/part
d	Depth of Cut	mm
D	Diameter of the Part to be Machined	mm
f	Feed Rate	mm/rev
k	Coefficient of Change in the Machining Mode	
L_g	Labor Cost of Tool Grinder Operator	MYR/min
L_m	Labor Cost of Production Operator Per Hour	MYR/min
l_p	The Length of the Part Being Machined	mm
M	Average Time of Cutter Replacement	min
m^*	Mean Time Between Failures Under the Condition of Change in Processing Mode	min
Mr	Ratio of the Failure Rates of the Machine Tool Machining Motion Mechanism	
N	Index of the Type of Cutter Material	
n_m	Number of the Revolutions of the Spindle	
N_p	Number of Part Machined Per Tool Grind	
Q	Productivity Rate of Automatic Machine Tools	parts/min
T	Tool Life or Cycle Time	min
t_a	Auxiliary Time	min/part
t_c	Time Losses Referred to One Product Due to Failures of the Cutter	min/part
T_c	Time Required to Change Tool	min
$t_{c.p}$	Time of Cutting Process	
t_e	Time Losses Referred to One Product Due to the Reliability	min/part
T_g	Time Required to Grind the Tool	min
t_i	Time Losses Due to Repair	min/part
T_l	Time Involved In Loading and Unloading the Part	min/part

t_m	Machining Time	min/part
$t_{m.l}$	Longest Machining Time of the Multi-Cutting Process	min/part
t_{mo}	Total Machining Time	min/part
V	Cutting Speed	m/min
W	Power Factor of Hyperbolic Function	
z	Number of Products Machined Per Observation Time	
z^*	Number of Products Produced Per Work Time of a Machine Tool Under the Condition of Change in Processing Mode	
θ	Observation Time	min
θ_i	Idle Time	min
θ_{org}	Idle Time Due to Managerial and Organizational Problems	min
θ_t	Idle Time Due to Technical Failures of the Machine	min
θ_u	Time Losses Due to P Mechanisms	min
θ_w	Machine Work Time	min

LIST OF ABBREVIATIONS

Term	**Description**	**Units**
AI	Artificial Intelligence	
AISI	American Iron and Steel Institute	
ANN	Artificial Neural Networks	
CBN	Cubic Boron Nitride	
CVD	Chemical Vapor Deposition	
GA	Genetic Algorithm	
GP	Geometric Programming	
HRC	Rockwell Hardness	
KT	Crater Wear	mm
LGP	Linear Goal Programming Technique	
MRR	Material Removal Rate	mm^3/min
NLGP	Non-Linear Goal Programming Technique	
PVD	Physical Vapor Deposition	
VB	Flank Wear	mm

Pengoptimuman Proses Pemesinan Melalui Nilai Tara Kadar Pengeluaran Maksimum Dan Kos Minimum

ABSTRAK

Dalam bidang pembuatan, proses pemesinan dengan menggunakan norma-norma produktiviti maksimum dan kos yang minimum adalah diikat. Dalam banyak kes, peningkatan mod pemesinan membawa kepada peningkatan dalam produktiviti dan kos pemesinan turut meningkat. Tesis ini merumuskan satu set model matematik yang membolehkan penetapan produktiviti maksimum dan parameter kos yang minimum pada peralatan mesin. Tiga pendekatan matematik baru telah dibangunkan untuk mencapai matlamat ini. Dalam pendekatan pertama, produktiviti maksimum diberi sebagai fungsi yang semakin meningkat pada kelajuan pemotongan (x) masa adalah 0.93. Pendekatan kedua memberi tumpuan kepada mengoptimumkan proses pemesinan pelbagai alat dengan tindakan serentak. Di sini, produktiviti maksimum pada faktor (k) ialah 1.28 untuk mengubah kelajuan pemotongan telah diperolehi. Manakala dalam pendekatan ketiga, produktiviti maksimum dan kos yang minimum untuk alat pelbagai tunggal dan dibentangkan. Persamaan berguna dalam model untuk meramalkan mod pemprosesan yang akan memberi produktiviti maksimum dan kos yang minimum. Dengan menaip ungkapan matematik maju di MATLAB, produktiviti alat mesin dikira. Kerja-kerja ini telah dilakukan di bawah keadaan kering. Keputusan menunjukkan kelajuan pemotongan yang optimum (V_{opt}) pada produktiviti maksimum bagi alat memotong tunggal untuk keluli kelajuan tinggi dan karbida sebagai teori. Manakala dengan menaip diameter bahan kerja adalah 25mm, kedalaman pemotongan 2mm dan makanan kadar 0.21mm/rev, yang dicapai uji kaji, kelajuan pemotongan yang sesuai untuk HSS bahan-bahan yang diuji ialah 50 m/min. manakala kelajuan pemotongan yang optimum memotong proses pemesinan alat daripada bahan-bahan yang berbeza sebagai teori produktiviti maksimum bagi tersusun karbida adalah 95 m/min. manakala bagi alat memotong pelbagai bahan-bahan yang sama produktiviti maksimum teori diperolehi pada 80 m/min. manakala kelajuan pemotongan yang optimum untuk memotong alat proses pemesinan pelbagai bahan-bahan yang sama sebagai percubaan untuk produktiviti maksimum pada 75 m/min. Walau bagaimanapun, peningkatan rejim pemesinan membawa kepada peningkatan dalam kedua-dua kos pemesinan dan produktiviti. Dalam pendekatan kos yang minimum, yang merupakan kelajuan pemotongan yang betul bahan-bahan yang diuji adalah 46 m/min. Nilai julat mudah kelajuan multi-cutting untuk kedua-dua produktiviti dan kos yang diperolehi dalam kerja-kerja ini adalah 40 hingga 90m/min. Dan pelbagai yang baik memotong kelajuan 40 hingga 60 m/min untuk mendapatkan kos yang minimum. Rangkaian sesuai kelajuan model matematik pemotong untuk produktiviti alat tunggal dan multi-memotong untuk kekerasan pertengahan kerja sekeping bahan adalah 35 hingga 69 m/min, 50 hingga 90m/min, masing-masing Walaupun kedua-dua set data teori dan eksperimen menunjukkan kelakuan yang sama, terdapat sedikit penyelewengan dalam diterima bagi dua nilai set data.

Optimization of machining processes by using criteria of maximum productivity and minimum cost

ABSTRACT

In manufacturing, the machining process by using norms of the maximum productivity and minimum cost is knotted. In many cases, the increase of machining modes leads to an increase in productivity, and the machining cost also increases. The present thesis formulates a set of mathematical models that enable the setting of maximum productivity and minimum cost parameters on machine tools. Three new mathematical approaches have been developed to achieve this objective. In the first approach, maximum productivity is given as a function of the increase of cutting speed at (x) time equal 0.93. The second approach focuses on optimizing multi tool machining process with simultaneous actions. Here, the maximum productivity at (k) factor, which is 1.28 of changing the cutting speed, has been derived. Whereas in the third approach, maximum productivity and minimum cost for single and multi tools are presented. The equations are useful in modeling and predicting the processing mode that will give maximum productivity and minimum cost. By keying in the developed mathematical expressions in MATLAB, the productivity of the machine tool is calculated. This work has been carried out under dry conditions. The results give the optimum cutting speed (V_{opt}) at maximum productivity for a single cutting tool for high speed steel and carbide as a theoretical. Whereas by keying a diameter of work piece is 25mm, depth of cut 2mm and feed rate 0.21mm/rev, which are achieved experimentally, the proper cutting speed for HSS of the tested materials is 50 m/min. whereas the optimum cutting speeds of cutting tool machining process of the different materials as a theoretical of maximum productivity for cemented carbide is 95 m/min. whilst for the multi cutting tool of the same materials the maximum theoretical productivity is obtained at 80 m/min. whereas the optimum cutting speeds for the multi cutting tool machining process of the same materials as an experimental for maximum productivity at 75 m/min. However, increasing the machining regimes leads to an increase in both of machining cost and productivity. In the minimum cost approach, which is a proper cutting speed of the tested materials is 46 m/min. The convenient range values of multi-cutting speed for both productivity and cost obtained in this work is 40 to 90m/min, and a favorable range of cutting speed is 40 to 60 m/min to get the minimum cost. The appropriate range of cutting speed of the mathematical model for the productivity for single and multi -cutting tool for intermediate hardness of work piece material is 35 to 69 m/min, 50 to 90m/min, respectively. Although both theoretical and experimental data sets show similar behavior, there are slight deviations within acceptable range for the two data set values.

CHAPTER 1

INTRODUCTION

1.1 Background

Machined metals and alloys are classified to be soft or hard, wrought or cast, brittle or ductile, with a low or high melting point. Most of the components in the engineering world are produced by a machining process regardless of the size or shape. In order to produce any component type, different machining operations such as turning, milling, drilling and boring, are to be used. There are different parameters to be considered during the machining process for a tool; among them is the cutting speed, which could be reached to a high value of 3500 m/min in Alumina, or very low as in some carbon alloys, which can be a few centimeters per minute. The cutting time may be extended to several hours or can be interrupted in fractions of a second, depending on the cutter type (Malkin, 1989).

Metal cutting machining processes comprise many unsolved problems that should be resolved in order to obtain reliable data with respect to the economics of manufacturing some analytical models that are well-described were able to predict the tool life through changes in the machining, there are also well-known mathematical equations that calculate the minimum machining cost depending on the changes in the machining regimes, thereby optimizing the machining process. However, known equations of metal cutting processes, tool life and minimum machining cost, which is one of the main indices of machining economics, Groover, (2006); De-Garmo et al. (2002); Beddoes et al. (1999); Bralla, (2007) and Flores et al. (2007). Researchers do not consider the very important aspects of machine tool output that are influenced by the change in machining regimes. However, indices of the productivity rate of machine tools and machining costs logically depend on the failures of cutters, Freiheit & Hu, (2002); Jones et al. (2004) and Isakov, (2004)

Metal cutting processes are industrial processes in which the metal parts are shaped by removing unwanted materials. According to Weller (1984) the wide range of cutting speed gives manufacturers a many materials can be choose for their machining process. In these operations, metal is removed as a plastically deformed chip, and a fairly unified physical analysis can be carried out by using orthogonal and oblique cutting models.

Wilson (1971) and Chryssolouris (1991) proposed that abrasive wear occurs on grinding and honing processes. To add, abrasive wear also occurs in nontraditional machining processes such as electro discharge, ultrasonic, electrochemical and laser machining. In abrasive processes, small chips are removed from the metal. The chips then stick to the cutting tool. In nontraditional processes, the metal is removed on a much smaller scale by thermal, electrical, and chemical processes compared to the amount removed in traditional machining processes.

Chang (1988) proposed that metal-cutting process can also be applied to nonmetallic work materials such as polymer, wood, and ceramics. Because there is a difference in the thermo mechanical properties between the cutting tool and the nonmetallic work-piece materials, the process is also considered as a machining process.

The turning operation is one of the most common operations employed in experimental work on metal cutting. The work-piece materials are held in the chuck of the lathe machine, and it will be rotated at a fixed speed that is set by the operator. The hardness of the cutting tool should be high compared to the work-piece. The cutting tool passes at a constant feed rate along the axis of the bar that is being machined. Out of this process, the cutting tool starts to cut a layer of metal away to form a cylinder or a surface with a complex profile. The cutting speed (*V*) is the rate at which the uncut surface of the work-piece passes the cutting edge of the cutting tool within the observation time, and it is usually expressed in meter per minute (*m/min).* The feed rate *(f)* is the distance that the cutting tool is moved in an axial direction at each revolution of the work-piece that is machined, and it is usually expressed in millimeters per revolution (mm/rev). The depth of cut *(d)* is the thickness of the metal that has been removed from the work-piece material, and it is measured in a radial direction of the product. It is usually expressed in millimeter (mm). The parameters discussed are combined to give the 'metal removal rate' *(MRR)* which is usually given as ($MRR = V * f * d$). The MRR is used to measure the efficiency of the cutting operation (Boothroyd & Knight, 1989).

The cutting speed and feed rate are effectively the most important parameters that can be controlled by the operator to achieve optimum cutting conditions. The depth of cut is usually chosen according to the initial size of the work-piece material and the required size of the final product. The cutting speed is usually within the range of 3 m/min and 200 m/min. For new high speed machining processes that use Alumina alloys cutters, the speed may reach up to 3500 m/min. However, the rotational speed of the chucks spindle of the lathe machine is usually constant during a single operation, and it is expressed as revolution per minute (rpm). The cutting speed along the pass keeps changing due to the variation in the work-piece diameter. At the nose of the tool, the speed is often a bit lower than at the outer surface of the bar, therefore, the cutting speed is considered constant along the tool edge in the turning process.

The feed rate varies between 0.0125 mm /rev and 2.5 mm /rev, depending on the hardness of work-piece material. The depth of cut takes from values close to zero up to 25 mm. It is possible to remove metal from the work-piece material at a rate of more than 1600 cm^3 /min but this value is uncommon. The recommended range of the metal removal rate, which is 80 to 160 cm^3 /min, would normally be considered as rapid (Tounsi & Elbestawi, 2003).

The cutting edge is at the intersection of the rake face and the clearance face or flank of the tool. The tool is designed and held in such a position that the clearance angle is variable but is often in the order of 6 -10^o. The rake face is inclined at an angle to the axis of the work-piece, and this angle can be adjusted to achieve optimum cutting performance for particular tool materials, work materials and cutting conditions. The rake angle is measured from a line parallel to the axis of rotation of the work-piece.

A positive rake angle is one where the rake face dips below the line. Early metal-cutting tools had large positive rake angles, and this caused the cutting edge to be easily damaged. Cutting tools are more robust if they have smaller rake angles, including zero and negative rake angle values. Rake angles can reach up to 15^o, but it is better to have a negative rake angle value of 5^o or 6^o, with the angle between the rake and clearance face to be 90^o. The tool terminates in an end clearance face, which is also inclined at such an angle as to avoid rubbing against the freshly cut surface. The nose of the tool is at the intersection of all three faces and may be sharp, but more frequently there is a nose radius between the two clearance faces (Benedict, 1987).

1.2 Economics of Machining Optimization

Childs et al. (2000) proposed that the ultimate objective of manufacturing engineering is to produce objects at the most economical cost. To do this, the machining process should be optimized to get the minimum possible cost. All aspects of the machine tool technology, manufacturing systems management, and material technology, which influence the process, must be considered. According to Childs et al. (2000) the purpose is not to develop detailed recommendations for best practice, but to show how these three factors interact to create an improvement. Isakov (2004) listed the various costs associated with the machining process, namely:

- Manpower cost, C_l, - measured in currency per unit time, generally by the number of hours that the operator is employed. Handling cost is also included here. Handling cost arises because of the time spent in the loading and unloading of tools and work-piece materials, in which time the machine tool is kept idle. Operators may also be required to attend to other jobs, of which the machine is kept idle, too.
- Machine tool operating (overhead) cost C_m - which includes machine depreciation and other costs associated with the running of the machine tool such as amount of power consumed, maintenance overhead and consumables such as lubricants. This may also include the other overhead costs, such as buildings, land and administrative overheads.

Combining the above costs in the overall overhead cost C_o

$$C_\circ = C_m + C_l \tag{1.1}$$

In addition, there is also the tool cost, which is the price of the tool used for the given operation.

Kronenberg (1966) presented three optimization criteria that can be considered, and they are the minimization of machine cost, the maximization of production rate, and the maximizing of profit. The three criteria, profit required more information in terms of various costs which may not always be available to the processes' planning department. Hence the other two criteria, namely machine cost and production rate, are more practical in terms of actual planning and implementation.

The costs stated earlier can be demonstrated with a simple turning operation. When the production rate is to be maximized, the cutting speed goes up, resulting in a decrease of the tool life. The reverse is also true. This happens because the earlier optimization does not take into account any constraints on the variables; hence the variables go to the extreme. It is necessary to get more useful values for optimization to be carried out using various constraints on the variables. Some of the possible constraints include maximum cutting power available at the machine tool spindle, maximum force permissible, the surface finish and diametric tolerance to be achieved on the machined surface, limits on cutting speed, feed rate, depth of cut imposed by the machine tool and cutting tool, maximum permissible cutting temperature, maximum permissible chatter, maximum permissible work-piece static and dynamic instability, tool life, and tool fracture.

1.3 Machining Parameters

Cutting speed *(V)* is the largest parameter of the relative to cutting tool or work-piece. In turning, the work-piece rotates, and the speed of the rotation is very important. In contrast, in drilling and milling, it is the cutting tool that rotates, and likewise, this speed is very important. In turning, *V* is given by the surface speed of the work-piece, namely,

$$V = \frac{\pi * D * N}{1000} \tag{1.2}$$

where V (m/min) is the rate at which the uncut surface of the work material passes the cutting edge of the tool. This speed is dependent on the rpm (N_s) and the diameter of the rotating work-piece D (mm). The depth of cut (d) is the distance the cutting tool penetrates into the work-piece. In turning machining process, for example, d is given by $(D1-D2)/2$. The feed rate, (f), is the movement of the tool per revolution. In turning, it is the distance the tool travels in one revolution of the work-piece and is given in units of mm/rev or in/rev.

Efficient machining requires the removal of material to be as fast as possible while producing the required tolerances of the dimensions and surfaces. The metal removal rate in turning is the product of three cutting parameters, namely, *MRR* (cm^3/min) = depth of cut *cutting speed* feed rate, Childs et al. (2000).

$$MRR = v * f * d \tag{1.3}$$

1.4 Problem Statement

It is a well-known fact that manufacturing processes should be set to achieve the highest productivity at the lowest possible cost. However, in reality, productivity and cost are usually inversely proportionate to one another. In order to get the highest productivity, the cost of production goes up, too. In order to get higher productivity of a machining process, the cutting speed, the feed rate, and the depth of cut are usually increased. However, increasing these three parameters invariably lead to a decrease in the tool life. A worn-out tool will affect the quality of the end product. Hence, the tool must be replaced often. When the replacement cutting tool is carried out, the machining work must stop, thereby decreasing the productivity of the process. At the same time, tool replacement does not come in cheap. Tools cost money, resulting in an increase in the cost of manufacturing. A machining regime is characterized by the following