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DETERMINATION OF THE OPTIMUM MACHINING PARAMETERS BY USING THE MULTIPLE MEASUREMENT APPROACH

[1] M. Özgürler, [2] B. Durmuþoðlu and [1] N. Sönmez
[1] Yýldýz Technical University, 80750 Beºiktaº, Ýstanbul, Turkey
[2] Ýstanbul Technical University, 80750 Maslak, Ýstanbul, Turkey

Abstract: Currently the 75 % of the metal products obtained in the metal processing industry are produced by machining methods. Due to the importance of the subject, many detailed studies are being undertaken in the related fields. The frequently encountered problems in the machining processes are the selection and determination of the cutting and propagation parameter values, tool geometry, material of the piece to be produced, cutting medium and the cutting equipment. Briefly, a proper and suitable selection of these parameters is achieved by providing a database for the machining operation, which is determined to be suitable to the present working conditions of the plant.
Keywords: Machining parameters, tool life, surface roughness

1. INTRODUCTION

This paper aims to find optimum cutting conditions for a widely used steel Ck 60. To do this a series of experiment have been performed on this material. Optimum cutting conditions are to be determined based on following criterions.

Surface Roughness: Directly affects the machined workpiece quality.

Tool Life: Owing to its effect on tool cost and tool change time, it affects the manufacturing time.

Material Removal Rate: Directly affects the manufacturing time.

While considering these criterions it is desirable to minimize surface roughness, maximization of tool life and to maximize material removal rate. But these requirements seem conflicting with each other. For instance, increasing the material removal rate will increase the tool wear and surface roughness. Therefore the aim is to optimize the solution. To achieve that, classical optimization methods can not be used. For this reason a multi-criterion decision making approach is to be utilised to obtain a final solution[1].

2. EXPERIMENTS PERFORMED

Workpiece material used in experiment:
CK60 (220 BSD) steel is used as workpiece material with different diameters in experiments. These workpieces are labeled with letters as A, B, C, D, E, F, G, H, I, J, K and L. Dimensions of workpiece A is given below in Figure 1. To measure hardness of workpiece materials a ring shape portion is removed from tailstock side of workpieces before starting experiments.

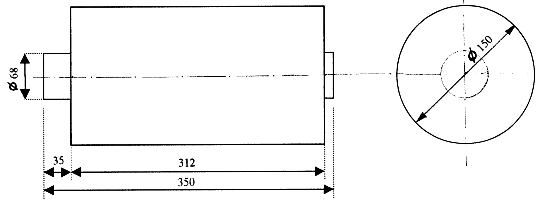

Figure 1. workpiece material dimensions

2.1 Cutting Tool:

As a cutting tool material P10 (%55WC+%36 (TIC+TAC) + %9 Co) inserts have been used [2]. Insert type is SNMG 12 04 08 (DIN 4988/150). Insert dimensions are shown as follows [3].

ISO	l (mm)	s (mm)	r (mm)	d_1 (mm)	m (mm)
SNMG 12 04 08	12,7	4,76	0,8	5,16	2,301

2.2 Description of tool holder used in the experiment: PSSNR/L 32 25-12 [4].

Cutting tool angles:

X	***a***	***b***	***c***
45^o	8^o	90^o	-8^o

Cutting edges of inserts to be used for tool life experiment are numbered from 1 to 12 as to be with experiment number performed.

2.3 Determination of Metal Cutting Parameters for Experiment

For mechanically clamped turning tools, standard tool life changes in between 5 to 30 min [5]. Cutting speed values are selected for T=15 min. tool life and VB=0.4 mm width tool wear in our experiment (Table 1) [2]. Determined cutting speeds can be shown as $V_{15,VB=0.4}$. In the experiment for tool life criteria tool wear VB=0.4 mm (free surface wear) and maximum tool wear VB_{max}= 0.6 mm are chosen [6,7].

Experiment Systematic:

Metal cutting conditions obtained in the experiment are shown in Table-1.('v' as cutting speed, 'a' as cutting depth, 's' as feed). Inserts to be used in life time experiment are labeled from 1 to 12. Cutting conditions in Table-1 are obtained employing an insert for each experiment set. Experiment is completed and tool life is recorded for each case when free surface wear reaches VB=0.4 mm or maximum tool wear VB_{max}= 0.6 mm. Then surface roughness value is measured for each workpiece using the equipment whose technical data are presented in Annex 3.

Table-1 shows T(tool life) and Ra(surface roughness) value obtained from the last part machined by each insert in addition to v, a and s values. Besides chip volume related with v, s,a is also presented for each case.

As seen from Table 1 experiment has been performed between ranges stated below:

120 v 240; 0.1 s 0.3; 0.5 a 2

The values in Table-1 are taken as basis in formation of objective equation. By converting Table-1 to logarithmic scale Table-2 can be obtained.

Table 1. According cutting parameters founded tool life and surface roughness in experimental studies

Test No	**v (m/min)**	**a (mm)**	**s (mm/ r)**	**q (mm^2)**	**V (mm^3/min)**	**T (min)**	**Ra m**
1	125	1.5	0,18	0.27	33750	24.06	2.4
2	125	1.,5	0,22	0.33	41250	18.5	3
3	125	2	0,28	0.56	70000	29.53	8
4	160	2	0,18	0.36	57600	17.48	2.8
5	160	1.5	0,22	0.33	52800	18.3	3
6	175	1	0,11	0.11	19250	16.33	3.5
7	175	1.5	0,18	0.27	47250	16.45	5
8	175	2	0,14	0.28	49000	25.04	2.8
9	213	2	0,18	0.36	76680	14.01	2.8
10	213	1.5	0.14	0.21	44730	16.8	3.6
11	235	1.5	0.14	0.21	49350	11.31	4
12	235	1	0.11	0.11	25850	9.63	2

Table 2. Logarithmic scale of values in Table-1

Test No	**LnV**	**LnS**	**Lna**	**LnRa**	**LnT**	**LnV**

	X_1	X_2	X_3	Z_1	Z_2	Z_3
1	4.83	0.59	2.71	0.88	3.18	10.43
2	4.83	0.79	2.71	1.1	3.16	10.63
3	4.83	1.03	3	2.08	3.39	11.16
4	5.08	0.59	3	1.03	2.86	10.96
5	5.08	0.79	2.71	1.1	2.91	10.87
6	5.16	0.1	2.3	1.25	2.79	9.87
7	5.16	0.59	2.71	1.61	2.8	10.76
8	5.16	0.34	3	1.03	3.22	10.8
9	5.36	0.59	2.71	1.28	2.64	10.96
10	5.36	0.34	2.71	1.1	2.82	10.71
11	5.46	0.34	2.71	1.30	2.43	10.81
12	5.46	0.1	2.3	0.69	2.26	10.16
Total	61.77	6.19	32.57	14.54	34.46	128.12

Objective function coefficients are found by applying Multi Regression Analysis to values presented in Table-2. Coefficients are determined as follows:

Ln Ra=-1,47+0,44Lnv+0,96 Ln(10s)-0,035 Ln(10a) (1)
Ln T = 8,50-1,37Ln v-0,38 Ln (10s)+0,60 Ln (10a) (2)
Ln V = 3,70+0,79 Lnv+0,90 Ln (10s)+0,90 Ln (10a) (3)

Constrains are as follows:

120 v 240 (m/min.) (4)
0,1 s 0,3 (mm/ r) (5)
0,5 a 2 (mm) (6)
Ra 3,25 (µm) (7)
T 15 (min) (8)

Average surface roughness Ra (equation 4) is one quarter of Rt' maximum surface roughness. Rt has a straight relation with cutting speed and reverse relation with tool nose radious, r. Under this condition maximum possible s value makes Ra 3,25. As seen in equation 8, minimum acceptable value of tool life is taken as 15 min.

To show constrain equation as objective equation, equation 1, 2 and 3 should be converted to logarithmic scale. By doing this below equations are obtained:

4,79 ln v 5,46 (9)
0 ln(10s) 1,10 (10)
1,61 ln(10a) 3,0 (11)
lnRa 1,18 (12)
lnT 2,71 (13)

If lnRa and lnT values are substituted in equation 1 and 2, constrains 14 and 15 can be obtained. In this way all constrains are expressed in terms of v, s and a.

0,44lnv+0,96ln(10s)-0,035ln(10a) 2,65 (14)
-1,37lnV-0,38ln(10s)-0,60ln(10a) -5,79 (15)

3. SOLUTION OF MULTI-CRITERION LINEAR PROGRAMMING MODEL

Now metal cutting problem is treated as multi-criterion linear programming model. To simplify formulation, the following base assumption is assumed:

Z_1=lnRa	X_1=lnv
Z_2=lnT	X_2=ln(10s)
Z_3=lnV	X_3=ln(10a)
$Z=(-Z_1,Z_2,Z_3)$	$X=(X_1,X_2,X_3)$

Z_1 represents minimisation of surface roughness. Knowing that if objective functions are examined, one can notice that Z_1 is used as maximisation of $-Z_1$ to express the same equation. If these assumptions are substituted in objective functions, following equations are obtained:

Z_1=-1.47+0.44X_1+0.96X_2-0.035X_3 (16)
Z_2=8.50-1.37X_1-0.38X_2+0.60X_3 (17)
Z_3=3.70+0.79X_1+0.90X_2+0.90X_3 (18)

Z equations will be maximized under following constrains,

4.79 X_1 5.48 (19)
0 X2 1.10 (20)
1.61 X3 3.0 (21)
0.44X_1+0.96X_2-0.035X_3 2.65 (22)
1.37X_1+0.38X_2+0.60X_3 5.79 (23)

Extreme points of possible range and their objective values are as follows:

Point	v	s	a	Ra	T	V
1	**120**	**0.1**	**0.5**	1.77	7.5	7578
2	120	0.1	**2**	1.70	63	25858
3	**240**	**0.12**	2	3.35	12	44954

Ra 3.35 .... 1.77
T 7.5 63
V 7578 44954

Extreme points are non-dominated points. As can be seen from here, possible range and agreement range are equivalent for each objective. In other words, there is a strong conflict between objectives because of non-dominated points.

This multi-criterion linear programming model is settled using multi-criterion simplex method [8,9]

4. SOLUTION OF THE MODEL SETTLED BY COMPOSITE OBJECTIVE FUNCTIONS

It is necessary to assign a weighed value for composite objective functions which is one of vector optimization methods. Criterions for these values should reflect relative importance and they can be summarized under one measure. It is possible to select a value with or without dimension. The value without dimension is selected in this case.

Solution step are the following:

1. selection of desired levels
2. formulation of composite objective function
3. definition of optimum solution
4. evaluation of the final solution; if necessary return to step 1.

The values obtained from experiment shall be substituted in the following equations;

$$U= \overset{1}{\underset{k=1}{á}}\ {}_k\ y_k(x) \quad (24)$$

$$á_k=A_k-n_k/M_kn_k \quad (25)$$

$$y_k(x)=z_k(x)-n_k/M_k-n_k \quad (26)$$

Abbreviations are as follows,

U : composite objective function
X : independent variable vector
y_k : dimensionless form of z_k objective
l : expected objective number
$á_k$: dimensionless weighted value of z_k objective
M_k : maximum value of k objective in non-dominated range
n_k : minimum value of k objective in non-dominated range
A_k : desired value of k objective

For the last operation desired levels are;

Ra=2 µm T=20 min. V=25000 mm^3/min.

Knowing these, composite objective function defined in second step (equation 24) is re-arranged as follows;

$$U=\sum_{k=1}^{1}[A_k-n_k/M_k-n_k]\,[z_k(x)-n_k/M_k-n_k]$$

$$U=\left[\frac{\ln(2)-\ln(3.25)}{\ln(1.26)-\ln(3.25)}\right]\cdot\left[\frac{-1.47+0.44X_1+0.96X_2-0.035X_3-\ln(3.25)}{\ln(1.26)-\ln(3.25)}\right]$$

$$+\left[\frac{\ln(20)-\ln(7.5)}{\ln(63)-\ln(7.5)}\right]\cdot\left[\frac{8.50-1.37X_1-0.38X_2+0.60X_3-\ln(7.5)}{\ln(63)-\ln(7.5)}\right]$$

$$+\left[\frac{\ln(25000)-\ln(7578)}{\ln(44954)-\ln(7578)}\right]\cdot\left[\frac{3.70+0.79X_1+0.90X_2+0.91X_3-\ln(7578)}{\ln(25000)-\ln(7578)}\right]$$

It is possible to obtain final composite objective function after performing necessary calculations
$U=-1.62-0.31X_1-0.32X_2+0.17X_3$

If this function is maximised under perscribed contrains, following results are found.

X1= 4.79	**V=120 m/min**	**Ra=1.9 μm**
X2=0	**s=0.1 mm/rev.**	**T=63 min.**
X3=3.4	**a=3 mm**	**V=26478 mm^3/min.**

If assembly criterion method was applied for the experiment instead of composite objective function method, the same results were obtained.

5. CONCLUSION

For today's metal cutting applications the most important problem is to select optimum cutting speed, feed rate, cutting tool shape and type, cutting fluids and machine tools for a given workpiece material. Although there are some tables prepared for this purpose available, the results obtained from usage of data are subjected to discussion. Also the tables recommend values only for limited parameters like workpiece material with cutting tool and cutting speed and so on. Therefore, it can be summarised that these tables could not optimize all the parameters such as product quality, cutting cost, tool life at the same time. Thus it is essential to determine to what goal the output to be obtained from cutting conditions will serve especially in case of critical applications. After determining expected level, cutting conditions are derived from standard tables, and then using multi-criterion decision making analysis final values that can be used in practice are found.The performed experiment serves to this purpose. In the experiment, to find optimum cutting conditions solution techniques such as multi-criterion decision making analysis, multi-criterion simplex method, composite objective function and assembly criterion method have been utilised. If the results obtained from these methods are compared, it is seen that second and third methods give the same results whereas first one finds a closer results with relatively far objectives.

Cutting condition values selected from standard tables are not able to optimize these three objectives in once. For instance in experiment 2, the lowest value of surface roughness is attained, tool life is T=18'30" and chip volume is V=41250mm^3/min. In the same way in experiment 8, the highest value of tool life is attained, surface roughness is Ra=2.8μm and chip volume is V=49000mm^3/min. For this experiment, surface finish increases relative to the former. In experiment 9, the highest value of chip volume is attained, surface roughness increases to Ra=3.6μm and tool life decreases to T=14'01".

As shown above, cutting condition values selected from standard tables could optimise only one parameter in each experiment. However this fact conflicts with the necessity of optimum resource usage. To reach this goal approach explained in this paper should be utilesed in a widely manner and the approach should be accepted as a base in cutting condition determination.

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AUTHORS: Univ.Assoc. Prof. Dr. Mesut ÖZGÜRLER, Department of Industrial Engineering, Univ.Prof. Dr. Niºan SÖNMEZ, Department of Metallurgical and Material Science Engineering, Yýldýz Technical University, 80750 Besiktas, Ýstanbul, Turkey, Univ.Prof. Dr. Bülent DURMUÞOÐLU, Department of Industrial Engineering, Ýstanbul Technical University, 80750 Maslak, Ýstanbul, Turkey, Phone Int ++90 212 259 70 70 (2801) or ++90 212 2 61 86 74, E-Mail: nisan @yildiz.edu.tr