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FULL FACTORIAL EXPERIMENT FOR PRODUCTION OPTIMIZATION

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Abstract—**The paper focuses on the use of the fuzzy sets to optimized the production (specifically, CNC turning). When determining the cutting conditions, it is necessary to respect the aspect of approaching the accuracy required for optimal conditions for achieving the workpiece quality, as well as the cost of its production. It is obvious that these aspects work contrary to each other; the higher dimensional accuracy of the workpiece resulting from the determination of optimal cutting conditions, means higher costs and vice versa. When we contemplate the effect of economic / cost optimization of machining processes in the context of microeconomic theory, the option of a cost criterion may be ineffective under certain assumptions of business strategy implementation. A typical feature of mechanical engineering is its mechanical precision with which there are repeatedly achieved nominal IT dimensions that are affected by the way of machining and surface roughness Ra. The first main purpose of the paper is to demonstrate that fuzzy-logic method can be a useful tool for multicriteria optimization of cutting conditions. The second main purpose is the determination of fuzzy sets using design of experiments methods. The paper was elaborated in the frame of solving project P403/12/1950.**

Keywords— **design of experiments, factorial experiment, cutting conditions, fuzzy logic, surface roughness of workpiece**

I. Introduction

At present, when machining there are, besides technological considerations, also economic analyses and calculations as an integral part of technical preparation. An economic side of the production process then represents a key aspect in conditions of prevailing **difussion competition**. Difussion competition is characterized by equal distribution of inner energetic and tangible sources with all competitors of a given industry with the same availability of external sources. It means that no competitor has better access to any of the sources. Under this situation, there is the only one source of competitive advantage more efficient use of technological potential which is at the disposal of a particular company. In effect, this efficiency is carried out through lowering the consumption of material, work, production time and energy in order that production costs are minimalized. This cost minimalization of variable production costs makes the background for the creation of a sufficiently high profit spread, not only for creating reserves of necessary financial sources for the recovery of the production device, but also for creating a means by which we will finance the development and innovation of contemporary technological progress. Nevertheless, it is possible to start from conventional cost itemization when machining, i. e. from the minimalization of partial costs which are as follows:

- Unit (average) costs for machine work (related to one workpiece),
- Unit costs for extra work,
- Unit costs for the exchange / adjustment of a worn-out tool,
- Unit material costs.

The biggest cost item is represented according to [2], [4] by costs for machine work $\boldsymbol{N_{SP}}$. The calculation is based on time costs for machine work $\boldsymbol{n_t}$ (for instance in CZK/minute) and from the costs related to one cutting blade life $\boldsymbol{n_b}$ (for instance in CZK).:

$$N_{SP} = t_A \times n_t + z \times n_b \quad (1)$$

Where cutting blade life $\boldsymbol{T_b}$ is possible to be determined for instance by Tailor relation which expresses this cutting blade life in the dependence on cutting speed $\boldsymbol{v_C}$:

$$T_b = \frac{c_T}{{v_C}^m} \quad (2)$$

Where $\boldsymbol{c_T}$**,** $\boldsymbol{m}$ are constants which are determined experimentally/empirically and are dependent (with certain depth of the cut and feed) on the character of a machined material (especially on its machinability).

The choice of a machine from the point of view of a **produced batch** size belongs to other conventional procedures contributing to reaching a sufficiently high profit spread during the production. It usually includes a decision-making process which from two and more processing equipments (usually having at disposal various degree of automation) decides the cheapest use in the production. When taking into consideration the batch produced in order to determine the costs, we start from so called **marginal batch** $\mathbf{d_K}$. The marginal batch determines the critical amount of workpieces in a batch, when the total costs CN_1 for the batch production, with the usage of the first machine equal the total costs for the batch production of the second machine CN_2. If the total costs for the production of the batch $\boldsymbol{CN}$ contain $\boldsymbol{q}$ amount of workpieces, we determine the total costs as the sum of variable $\boldsymbol{v}$ and fixed costs $\boldsymbol{FN}$:

$$CN = v \times q + FN$$

(3)

Then it is possible for the critical amount of workpieces in the produced batch to be determined according to the relation:

$$q_{KR} = \frac{FN_2 - FN_1}{v_1 - v_2}$$

(4)

At the same time, fixed costs represent the sum of costs for machine adjustment, machine depreciation (purchasing), costs for managing programme creation, etc. The average variable costs represent the costs for machine work, costs for exchange, and tool adjustment, etc. related to one workpiece. This critical amount of workpieces in a batch then determines from what amount of items it is economically advantageous to substitute a certain machine by the machine with a higher degree of automation (for instance a universal lathe by a turret type semi-automatic lathe, or a turret type semi-automatic lathe by an automatic lathe).

When optimizing cutting conditions, it is possible to use the so-called **gradual method**, when first of all, according to [2] we determine the cutting depth. When finish machining, the cutting depth a_p is equal to the size of the whole machining allowance. Roughing allowance is determined by the size of the whole allowance decreased by finish machining allowances and by allowances for other finishing operations. Then it is possible for chosen a_p to determine the optimum size of the feed f from lifting conditions, which are not the function of the cutting speed. One of the limiting conditions can be according to [1],[4] for instance, maximum allowable intensity of tangential force F_{Zmax}, which has the form:

(5) $$\frac{F_{Zmax}}{c_{Fz}} = a_p^{x_{Fz}} \times f^{y_{Fz}}$$

Where c_{Fz}, x_{Fz}, y_{Fz} are empirical constants. For optimum values T, a_p, f the optimum cutting speed **v** is determined from the complex Taylor relation:

$$v = \frac{c_v}{h^{Xv} \times s^{Yv} \times \sqrt[m]{T}}$$

(6)

In the last step, it is necessary to verify that the performance of processing equipment enables the use of optimum cutting conditions.

In the second case, when optimizing cutting conditions, **production standards of cutting conditions** are ordinarily used. Production standards (they represent tabular processing of the relation (6), start from the tool cutting life. Both mentioned ways prefer the economic nature of a machining process, and surface roughness Ra represents a limiting condition (such as feed size, optimum cutting depth, component of cutting force Fy and cutting speed).

At present, besides the economic nature of a production process, it is necessary to take into consideration resultant characteristics of a product (a workpiece forming part of a resultant product). At the same time, nowadays, there are heavy demands placed on the product in the field of reliability, service life and the efficiency of final assembly. The surface quality is considered to be a decisive factor in achieving the above mentioned characteristics. For instance, one of the main components of the surface quality – its roughness (surface microgeometry) is, according to [8], responsible for the accuracy of a particular mechanism running, size, operational wear, notch impact strength/notch toughness, lubricating conditions, corrosion resistance, noisiness, time of running in, electrical resistance and transfer of heat. From the point of view of constructional demands, surface roughness represents an important condition of the exchangeability of components in mass production [2]. At the same time, a reached value of roughness and its character is the function of a chosen machining procedure, cutting conditions, the state of the tool and workpiece material, tool geometry, effectiveness of heat removal by cooling, toughness of systems: machine – jig or workpiece – tool, etc. During the process of machined component surface creation, the literature [4] recognizes the theoretical and real surface unevenness. The theoretical deviation of the surface is determined in case of the validity of the prerequisite that unevennesses on a machine surface have a distinctive arrangement, which is the result of mutual geometrical and kinematic effects of a tool and a workpiece. Then this theoretical form of unevennesses according to [2] could be specificied under the following idealized prerequisites:

- Machined material is not plastically deformed,
- Tool edge creates smooth geometrical curves while in motion, and kinematic conditions are constant during production operation,
- System of machine-tool-workpiece is perfectly tough.

The real surface is different from the theoretical one as far as the size and the shape of microunevennesses are concerned. This difference is especially caused by material and technological influences. Material influences are caused by the fact that machining operation is the process of plastical deformation, which is dependent on cutting conditions. Vibrations of a tool and a machined component, irregularity of a tool blade (caused by its wear or by the change of cutting environment – the type of cutting liquid) can be included among technological influences. Among materialized indicators of the difference between the theoretical and real roughness of a machined surface, there can be included the type of a chip. The chip which is not continuous, indicates a technological problem having a negative impact upon the roughness and dimensional and shape equality of the workpiece (for instance because of the variation of cutting force or tool vibrations).

II. Methodology

In general, surface roughness is the function of four variables: cutting depth (**a_p** [mm]), feed (**f** [mm/ot]), cutting speed (**v** [m/min]) and point radius of the tool (r_ε [mm]). If we choose the tool, the point radius of the tool is given, for instance $_\varepsilon$ = 1mm and remaining variables represent guiding variable parameters of the machining process. If we have to determine cutting conditions for finish machining of the diameter 80 mm to 78 h7s roughness, which can be reached on the given processing equipment (however at the worst Ra = 3,2 µm), we can use fuzzificated rules for reaching the maximally possible surface quality. If we want to reach general optimization, it is necessary first of all to describe a dynamic behavior of the system which is to be optimized. Owing to the complexity and indefiniteness in functional interactions among remaining variable factors ***a_p*, *f*, *v***, it is advantageous for this dynamic system to be described by means of expert rules with the usage of a vague description instead of a complex mathematical model [3]. Here there will be shown the advantage of a fuzzy-linguistic and logic model which enables the matching of numerical values (i. e. fuzzification) with the verbal characteristic of the input variable. That is why the following part of the article will characterize the input-output relation between variable inputs while turning h, s, v and output surface roughness Ra with the usage of fuzzy rules which use linguistic variables instead of a complicated mathematical model.

A two-step process of creating the procedural knowledge base about the workpiece roughness dependence on cutting conditions v, s, h is based on the following process.

In the first step we carry out the assigning of variable values h, s, v to the so called relevance fuzzy set - fuzzification. With these free variables, we first of all implement a fuzzy set/ (input) which will comprise free subsets:

$$I = \{MA, ST, VE\} \quad ; \tag{7}$$

where: **MA** means small value, **ST** medium value and **VE** large value of a fuzzy set element I. At the same time the fuzzy set **I** is created by all elements a_p, f, v and further, by the functional values of these inputs ***$\mu_I(x)$***. The functional values of inputs are determined by the function of a relevant fuzzy set of inputs. This function is usually defined in the interval from zero to one, it means that for any value of the input X there exists the functional value ***$\mu_I(x)$*** in the interval <0,1>. X is, in the theory of fuzzy logic, according to [3] called the universum (i. e. universal designation of the input. In our case, it represents the designation for a_p, f, v).

So, we can write that universum X is composed of the elements x, where:

$$x = \{a_p, \text{f}, \text{ v}\} \quad ; \tag{8}$$

and the function of a fuzzy set I: $\mu_I(x) \in \langle 0,1 \rangle$. (9)

By the record, the fuzzy set I (inputs) is defined as an arranged pair of input universum X and functions.

Now it is necessary to determine so called function of relevance (membership). The function of relevance represents the creation of the rule according to which we will assign average variables *a_p, f, v* to the fuzzy set $I = \{MA, ST, VE\}$. For the guiding variable **cutting depth size a_p** the fuzzy set *I* will be implemented, where the input is a half value of finish machining allowance and the output of the fuzzification of the variable **a_p** is $\mu_I(a_p)$, which achieves free values: MA, ST, VE .

$$I = (a_p, \mu_I(a_p)) \;\; ; \;\; a_p = \{\,0{,}5\;\; 1\;\; 1{,}5\;\; 2\;\; 2{,}5\, mm\} \;\; ; \;\; \mu_I(a_p) = \{MA, ST, VE\}. \tag{10}$$

We will implement the fuzzy set **I** for two remaining guiding workpiece roughness variables in the same way.

For feed size f:

$$I = (f, \mu_I(f)) \quad ;$$
$$f = \left\{\, 0{,}10\;\; 0{,}12\;\; 0{,}14\;\; 0{,}16\;\; 0{,}18\, \frac{mm}{ot} \right\} \quad ;$$
$$\mu_I(f) = \{MA, ST, VE\}. \tag{11}$$

For cutting speed size v:

$$I = (v, \mu_I(v)) \quad ;$$
$$v = \left\{\, 220\;\;\; 230\;\; 240\;\; 250\;\; 260\, \frac{m}{\min} \right\} \quad ;$$
$$\mu_I(v) = \{MA, ST, VE\}. \tag{12}$$

After implementing the fuzzy set **I** for all free guiding variables, it is possible to proceed to the fuzzification itself. This procedure is illustrated in the figure 2.1.

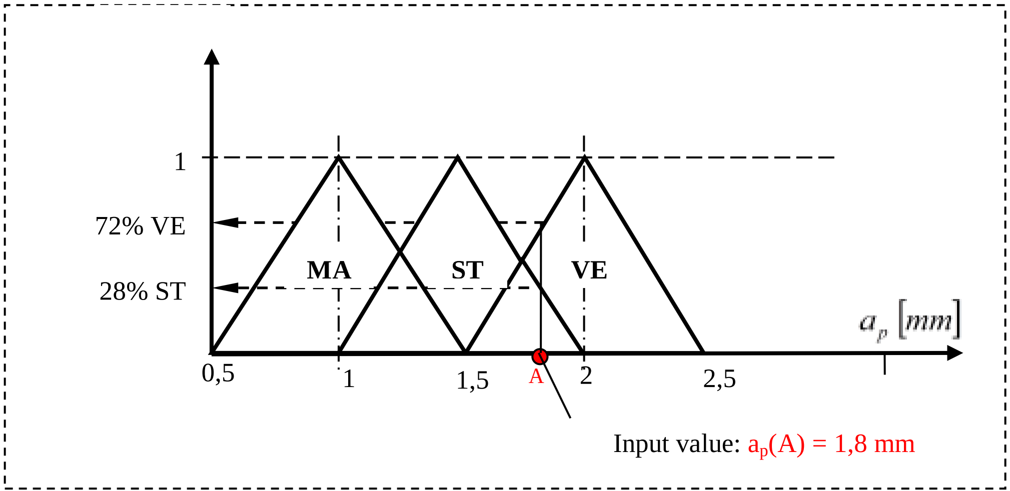

Fig. 2.1 Fuzzification of cutting depth a_p (mm)

Figure 2.1 illustrates the assignment of point values of the criteria for the cutting depth ap to the fuzzy set represented by the three subsets (MA, ST, VE). This assignment is done by the method of the so-called relevance (membership) function estimate in a parametric way. Its principle is based on the expert estimation of three points (parameters) of the input function for each subset. Parameter, which is the leftmost, is excluded from the fuzzy set (for a subset of MA it is the point [0.5, 0]). It is natural for the material and its normative class workability that the minimum allowance for finish machining is 2 mm. It would be an inefficient production to choose a minimum cutting depth of less than 1 mm. The second point that we determine is one that certainly belongs to the fuzzy subset. For our case of a subset of MA it is the cutting depth value belonging to the top of the "triangle", therefore the point [1, 0]. If this point definitely belongs to the fuzzy set, we can guarantee 100% membership rate, i. e. in the range of our scale by the value of 1. This means that for the input value, in our case 1 mm, the fuzzified value μI (ap) = 1 is assigned. This yields a top of the fuzzy subset of MA ([1, 1]). The third parameter that is specified is the point that is still included into the fuzzy subset. In our case, it is [1.5, 0]. Following that determination, we can define the fuzzy subset of MA. Its geometrical interpretation represented by the triangle MA is obtained by combining the three identified parameters, i. e. points [0.5, 0], [1, 1] and [1.5, 0].

In an analogous way, as shown in Figure 2.1, we would find the other two subsets ST and VE. The practical question is, in what other way than an expert way it is possible to determine the position of centroids of the fuzzy set, respectively the range of these fuzzy sets. References [x] offer the solution by means of the weight functions.

The weight values w_{MA}, w_{ST}, w_{VE} were received from the ratios of central points (centroids) for single output fuzzy sets. If the fuzzy set MA value of weight function equals one (i. e. $w_{MA} = 1$), then remaining two weight functions (w_{ST}, w_{VE}) will be calculated from the ratios of centroids of these sets to the centroids of the MA set. The position of centroids on the horizontal coordinated axe for fuzzy set of MA is equal to 1.25 points (weight function for the fuzzy set of MA was equal to 1. At the same time, the ratio of weight function to the value of a relevant centroid should be the same (constant) for all fuzzy sets. If we express this condition in a mathematical way, we get:

$$\frac{w_{MA}}{centroid\,(MA)} = \frac{w_{ST}}{centroid\,(ST)} = \frac{w_{VE}}{centroid\,(VE)} = const \quad ; \qquad (13)$$

From this it follows:

$$centroid\,(ST) = \frac{w_{ST}}{w_{MA}} \times centroid\,(MA) = ; \qquad (14)$$

$$centroid\,(VE) w_{VE} = \frac{w_{VE}}{w_{MA}} \times centroid\,(MA) = \quad . \qquad (15)$$

Such generally conceived weighting functions can then be transformed into interval units (variables), by means of which the relevant fuzzificated variable is characterized. More sophisticated methods can be seen in the use of methods for the design of experiments, specifically using the Full Factorial Experiment (FFE). The following procedure is indicated to determine the fuzzy set ST (middle) for the cutting speed v. Here we use the idea that the entire range of input values corresponding to this set should have, due to the interaction with other significant factors (cutting depth ap, feed f) such a variability of output values (here the surface roughness), which would not exceed a predetermined reliability interval (here chosen at 95%). If we verified that all values within the interval of the fuzzy set have little interaction, that means that we can use all the values from the fuzzy set, and thus we can optimize the production process according to another criterion (for example the economic one, with the cost optimization of production given by the durability of the turning knife blade). If we verify that the change of fuzzy set interaction for the cutting speed v of the set ST is not important between the extreme points of this set, then we can use the whole range of values of this fuzzy set to optimize the manufacturing process without the system reduction of the output quality of the workpieces. These two extreme points define this set ST i. e. the value of v = 230 m / min (minimum value) and v = 250 m / min (maximum value).

To compare changes in interaction of the fuzzy set ST for cutting speed *v*, *feed f* and cutting depth $\boldsymbol{a_p}$, we will carry out the measures of interaction with the values of chosen centroids of these two variable parameters with the set “small“ MA and “big“ VE.

The coded measurement of cutting speed v: -1 corresponds to the level v = 230 m/min, + 1 corresponds to the value v = 250 m/min.

Similarly for the feed s, the coded measurement is : -1 corresponds to the level v = 230 m/min, + 1 corresponds to the value v = 0,12 mm/ot (centroid MA), + 1 corresponds to the value v = 0,16 mm/ot (centroid VE).

For the cutting depth a_p , the coded measurement is: -1 corresponds to the level a_p = 1 mm, a_p = 1 mm (centroid MA), + 1 corresponds to the value a_p = 2,5 mm (centroid VE).

Tab. 2.1 Results from a 2^3 full factorial experiment

Trial (standard order)	Trial (randomized order)	A Cutting speed ***v***	B Cutting depth $\boldsymbol{a_p}$	C Feed ***f***	Response (µm)		Average (µm) B C
1	***4***	***-1***	***-1***	***-1***	***1.757***	***1.745***	***-1 -1 +1 +1*** $A_{B,C(-1)}$ 1.7605
2	3	-1	+1	-1	1.326	1.368	
3	2	-1	-1	+1	1.671	1.720	
4	***1***	***-1***	***+1***	***+1***	***1.802***	***1.738***	
5	***8***	***+1***	***-1***	***-1***	***1.905***	***1.896***	***-1 -1 +1 +1*** $A_{B,C(+1)}$ 1.8135
6	7	+1	+1	-1	1.890	1.963	
7	6	+1	-1	+1	1.878	1.867	
8	***5***	***+1***	***+1***	***+1***	***1.744***	***1.709***	

In this case, the research team has to study the effect of each factor at different conditions of other factor. Interactions occur when the effect of one process parameter depends on the level of the other process. In order to study interaction effects among the process parameters, we need to vary all the factors simultaneously. For this surface optimization process, we have employed a Full Factorial Experiment (FFE) and each triql was replicated twice to observe variation in results within the experimental trials. The results of the FFE are shown in next Table 2.1.

The relative difference between average response $A_{B,C(+1)}$ and $A_{B,C(-1)}$ can be computed using the following equation:

$$RD = \frac{A_{B,C(+1)} - A_{B,C(-1)}}{\frac{A_{B,C(+1)} + A_{B,C(-1)}}{2}} = 0.29658 = 3\,\% < 5\%\ significance\ level \qquad (16)$$

(Fuzzy set size is therefore all right)

After verifying sufficiently small changes of the interaction force between the extreme values of the fuzzy set ST for the cutting speed, we can define other fuzzy sets MA and ST symmetrically from the set ST (here it is advisable to check sufficiently "small" change in interactions with other parameters of machining within the given set).

The subsequent step is based on variable inputs; fuzzification for cutting speed, cutting depth and feed. We will assign the membership function along with their graphical interpretations. Fuzzification of feed size is presented in Figure 2.2, fuzzification of cutting speed is illustrated in Figure 2.3.

Fig. 2.2 Fuzzification of feed rate ***f*** (mm/rev)

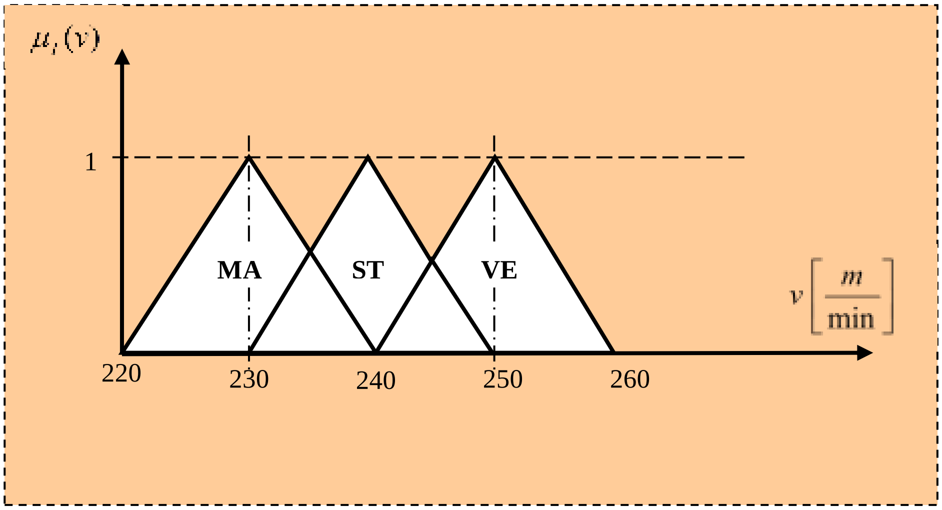

Fig. 2.3 Fuzzification of cutting speed ***v*** (m/min)

A. *Selecting a Template (Heading 2)*

First, confirm that you have the correct template for your paper size. This template has been tailored for output on the US-letter paper size. If you are using A4-sized paper, please close this file and download the file for “MSW A4 format”.

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III. Results and discussion

In the third step, after finding the fuzzy inputs $\mu_I(a_p, f, v)$, these inputs are transferred to the output value in the form of surface roughness Ra - mean arithmetic deviation of the surface (defuzzificated). The defuzzification is carried out in two stages. In the first stage, the value of the achieved roughness in several control points is transferred to a subset representing a certain level of arithmetic median value of absolute deviations in the profile, in the fundamental length Ra. Using the stylus profilometer with electromechanical transfer, graphic recording (profilograph) is obtained, if the case may be, the data on discrete heights and hollows of the profile y (xi) are obtained. If the profilograph of a controlled area was acquired, then the surface roughness expressed by median arithmetic deviation of the profile is calculated according to the relation [8]:

$$Ra = \frac{\int_0^l |y(x)|dx}{l} \tag{17}$$

Where ***l*** is the basic length. Geometric interpretation Ra according to the relation (17) is that it represents the height of the rectangle constructed over the nominal dimensions of the workpiece, whose surface area is equal to the area defined by the median line of the profile and the curve of the actual profile. If we have the discrete values about the heights of inequalities in a controlled area, then we determine the surface roughness according to [8]:

$$Ra = \frac{1}{n} \times \sum_{i=1}^{n} |y(x_i)| \tag{18}$$

Where **n** is the number of measured profile inequalities. Now the calculated value of a particular workpiece surface roughness can be attributed to a number of preferred numbers of roughness. For the assignment to a series of preferred numbers of roughness we will again use the membership function (see Figure 3.1).

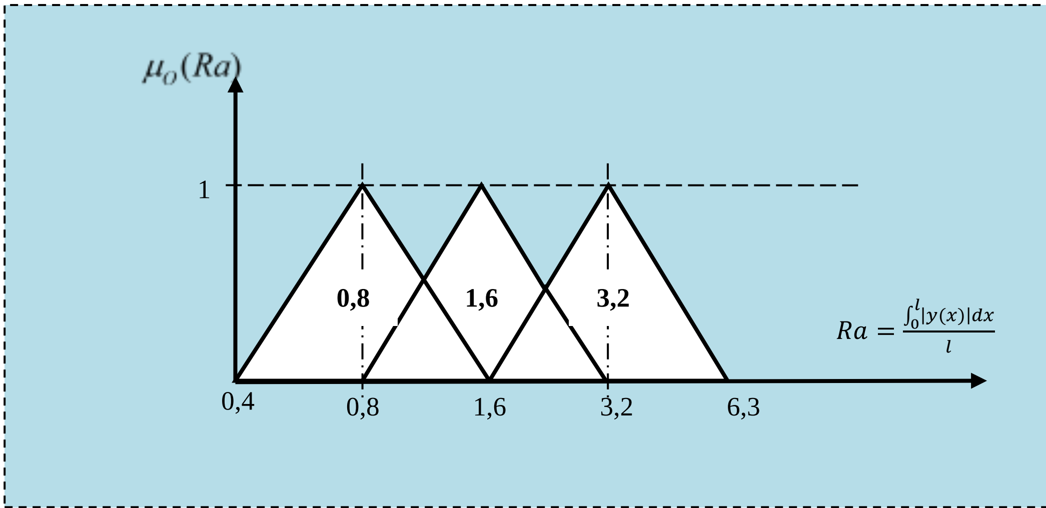


Fig. 3.1 Assigning an arithmetic mean deviation of profile to the chosen number of roughness Ra

According to [5], the optimization of the machining process is based on the criteria of minimum production costs of the selected production unit. Another possible optimization criterion is the size of the maximum material removal. It is necessary to respect certain restrictions - mostly machine performance limitations, restrictions by the maximum allowable torque (in terms of grip strength of machined components), limitations by allowable bending moment (in terms of risk of workpiece pull in unilateral clamping), limitations by the maximum centrifugal force (which causes the reduction of clamping chuck power during its rotation), limitations by allowable cutting force, sliding and passive, limitations by suitable chip creation, by reducing surface roughness and finally limitations by the desired accuracy of a workpiece shape.

If we contemplate the effect of economic / cost optimization of machining processes in the context of microeconomic theory, the choice of cost criterion under certain assumptions of the business strategy implementation may be inappropriate. A typical property of engineering is the accuracy with which there are repeatedly achieved nominal dimensions of IT that are influenced by the way of machining and surface roughness Ra. This typical feature – production precision – has represented machining since its inception during the industrial era in the history of mankind.. Fascination with the economic nature of the machining process (under certain conditions) inappropriately replaces optimization criterion for the constraint.

Taking into consideration that according to Porter [7] there are two opposing strategies: product differentiation and benefits of scale, then during the implementation of the first strategy (differentiation) costs per unit of production will be a rather more limiting restriction (known as target costing) than utility function of optimization. For simplicity, we can as an auxiliary criterion of whether it is more advantageous to choose the product differentiation or benefits of scale (in terms of total sales) choose the price elasticity of the demand ep function:

$$e_p = \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}} \qquad (19)$$

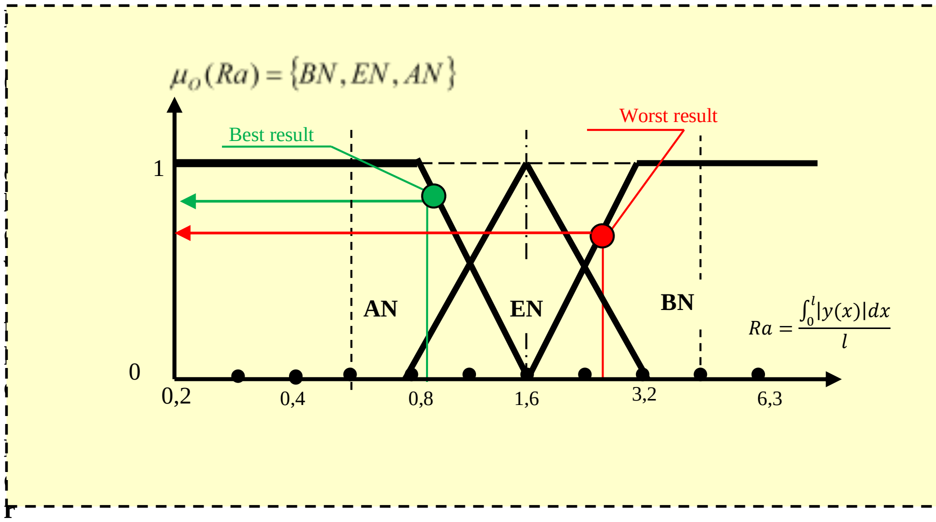
Where **q** is the demanded amount of a product (kit) which is composed of the workpiece, **p** equivalent price of the workpiece to the price of the kit. If the elasticity of the demand function is less than one, it is not necessary to consider the unit costs of the machining process for machining optimization cost function, but only for the restrictive condition. The historical context also shows some support for considering machining economics as one of the restrictive conditions.

The current trend of reducing moral life of engineering products [5] necessarily leads to an increase in the proportion of a small-scale production and thus to limiting the advantages of scale. Therefore, it is possible under certain conditions to focus attention on workpiece quality aspects, which may pose a special-purpose (criterion) function of the machining process. In this case, defuzzification can be used to determine the final surface roughness. This defuzzification enables us to find out how we can predict the output surface roughness of the workpiece in comparison with the normative structure in a setting of cutting conditions. In the fuzzy set the output is the set $\mu_O(R)$, (where O= output), which may take three values:

$$\mu_O(Ra) = \{BN, EN, AN\} \quad , \qquad (20)$$

where:

1. **B**



r mative) means that for a given setting of

Fig. 3.2 Output fuzzy set for the experimental determination of surface roughness

cutting variables: a_p, f, v there exist reasonable prospects to lower the value of surface roughness than that in the normative for the optimization of blade durability. It is this value of the output ($\mu_O(Ra) = BN$) that represents variants which should be excluded from the set of allowable settings of cutting conditions.

2. **EN (=Equivalent to the Normative)** means that with a given settings of cutting conditions we reach the surface roughness Ra value equivalent to the value resulting from the per capita amount. To compare whether this setting is better than the settings in the normative, the comparison of tool life time can serve.

i	Defuzzification inputs			Ra	Defuzzification
	Cutting speed ***v***	Cutting depth a_p	Feed ***f***	$Ra = \frac{\int_0^l \lvert y(x) \rvert dx}{l}$ Response	Output $\mu_O(Ra)$ ⇩
1	ST	MA	MA	0,9233	**AN**
2	ST	MA	ST	1,3780	**EN**
3	MA	MA	VE	2.4450	**BN**
4	VE	MA	MA	1,1570	**AN**
5	ST	MA	VE	1,9233	**EN**
6	VE	MA	MA	1,0803	**AN**
7	VE	MA	VE	1,7830	**EN**
8	MA	MA	MA	1,6510	**EN**
9	VE	MA	ST	1,2240	**EN**
10	238 m/min	1 mm	0,12 mm/ot	1,4710	Values from normative, blade 20×20 P10, machineability 14b, T=45min

AN (=Above the Normative) signals that for a given setting of cutting

conditions, we can predict better surface roughness than in the case of cutting parameters settings by normative. It is this defuzzicated subset that represents alternative solutions from which we can expect some improvement leading to vague optimization of machining, according to the criterion of the surface roughness (the achievable production technology). The outputs of fuzzification are variables that take values BN, EN, AN. For this output set $\mu_O(Ra)$ we must form the rules, valid between defuzzificated input (the values of criteria from fuzzy sets (Ra acquired from profilograph) and the output (the output fuzzy set $\mu_O(Ra)$ in the form of BN, EN, AN. To express these rules, a conditional statement by implication is commonly used (IF) and conjunction (AND). The output is characterized by conjunction THEN. The number of these rules is given by the number of combinations k that can be done with three inputs, n = 3: each input may take three

Fig. 3.1 Orthogonal results in a constant cutting depth of 1 mm

values, h = 3 (BN, EN, AN).

$k = h^n$; in our case for ***n = 3*** and ***h = 3*** is

$$k = 3^3 = 27\ rules \quad (21)$$

Creating the rules is governed by the vague description of states BN, EN, AN and furthermore, these rules are determined in an experimental way.

igure 3.1 shows the defuzzification of single measured roughness and comparison for which combination of cutting conditions we can expect the best result in surface roughness. Although to some extent of values, higher speed may have a positive impact on the resulting surface roughness, here medium speed (240 m / min) proved to be more convenient. This can be explained by the fact that there may be through a subset of VE reached the limit of cutting speed, which affects whether when working, there is a point or surface contact between the knife and the workpiece. Due to the high temperatures caused by high cutting speed, the yield stress may have been exceeded, and plastic deformation of the contact layer of the workpiece (workpiece material to flow) may have occured.

IV. Conclusion

In determining the cutting conditions, the aspect of the required precision approximation to the optimal conditions and the viewpoint of costs incurred for this activity, must be respected. It is obvious that these aspects work against each other: greater accuracy means higher costs and vice versa. The accuracy rate of closing to the optimum conditions depends on the nature of production (individual, small batch, batch, mass). The higher the number of parts produced under the same conditions, the greater are the costs associated with more the advanced way of finding optimal conditions. According to the accuracy and complexity, it is possible to state basic ways of determining cutting conditions in order: an experimental basis (e. g. fuzzy logic method), according to tables and nomograms, according to the normatives, by the calculation.

Submitted methodology for fuzzy logic optimization of cutting conditions was experimentally tested. The size of fuzzy sets checked for sufficiently "small" interactions of set marginal values changes within the interaction with other machining parameters, using methods of Full Factorial Experiments. As a tool, Cermet (titanium carbonitride) - type NX2525, which has a very good wear resistance and chemical stability, was used. As a machining tool, a high-speed CNC lathe ECOC SJ-20 was used. It is not very common in the CR, but in terms of output machined surface roughness shows, according to the study [11] better results than a well-known MAZAK QUICK TURN 15N.

In the benchmarking study, the significant difference in the surface roughness in optimum cutting conditions and comparative (standard) conditions given by the difference value of Ra 0.6666 µm compared to Ra 0.9233 µm was measured. The purpose of this paper was to demonstrate that fuzzy methodology may be an appropriate tool for multicriteria optimization of cutting conditions, especially in adaptive optimization of ACO systems. Furthermore, there has been introduced a still unpublished methodology for verifying the size of fuzzy sets using the methods of designing experiments to ensure that any value of the fuzzy sets will have no significant effect on the change in interaction with other fuzzificated variables and in this way, the measurable consistency of expert system to support production process management.
It is advisable to incorporate this methodology in the direction of further development of CNC machine tools, which is [6]: increasing accuracy (geometric precision of machine work, geometric and dimensional accuracy of the workpiece), increasing the quality (of machined surfaces, positive influence of waviness and surface integrity) increase in manufacturing output, increasing reliability (of the machine and its functions to ensure the stability of the manufacturing process), increasing efficiency (minimizing unit costs for machines), and reducing negative environmental impacts (minimization of energy requirements).

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