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A hybrid empirical-neural network approach to the determination of optimal cutting conditions*

F. Čuš [a], B. Mursec[b], T. Ploj[b], U. Zuperl[a]

[a]Faculty of Mechanical Engineering, University of Maribor
Smetanova 17, 2000 Maribor, Slovenia

[b]Faculty of Agriculture, University of Maribor
Vrbanska 30, 2000 Maribor, Slovenia

In the contribution, a hybrid empirical and neural network based approach to complex optimization of cutting parameters is proposed. The empirical module OPTIS selects the optimum cutting conditions from commercial data bases with respect to minimum machining costs by taking into account the technological cutting process limitations. The neural network module describes the multi-objective technique of optimization of cutting conditions by means of the artificial neural networks (ANN) taking into consideration the technological, economic and organizational limitations. To reach higher precision of the predicted results a mathematical-neural optimization algorithm is developed and presented to ensure simple, fast and efficient optimization of all important turning parameters. In the end of the paper the comparison of the determined cutting conditions by empirical and neural approach was made.

1. INTRODUCTION

The optimization of cutting parameters is the key component in planning of machining processes. However, deep analysis of cutting involves certain costs, particularly in case of small series. In case of individual machining it is particularly necessary to shorten as much as possible the procedure for determination of the optimum cutting parameters, otherwise the cost of analysis might exceed the economic efficiency which could be reached if working with optimum conditions. For the process of the single objective optimization several different techniques have been proposed, such as the differential calculus, regression analysis, linear programming, geometric and stochastic programming, computer simulating.

While most hitherto researches are based on the single-objective optimization, there have been some successful attempts also with the multi-objective optimization. In many real applications the makers face on regular basis the problem of simultaneous optimization of several objectives. Those objectives are often conflicting and incomparable.

The operation of turning is defined as a multiple-objective optimization problem with limitation non-equations and with three conflicting objectives (production rate, operation cost, quality of machining). All the above mentioned objectives are represented as a function of the cutting speed, feed rate and depth of cutting [1].

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2. PROGRAMME OPTIS FOR EMPIRICAL OPTIMIZATION OF CUTTING CONDITIONS

The contribution proposes a programme OPTIS for optimization of cutting conditions from commercial data bases with respect to minimum machining costs by taking into account the cutting process limitations. From this limitation of the machining costs the OPTIS calculates the related cutting conditions. So far, this has not been ensured by the programmes [2].

2.1. Functioning of the programme OPTIS

The cutting conditions are indicated over an interval from the smallest to the greatest ones: $v_{\min} \le v \le v_{\max}$, $f_{\min} \le f \le f_{\max}$, $a_{\min} \le a \le a_{\max}$. The cutting speed, feeding and cutting depth increases over the intervals with a certain step.

The OPTIS first calculates the machining costs for all combinations of cutting conditions and then it classifies them into the smallest to the greatest ones. Then successively (from lowest to highest machining costs), it verifies also all limitations. The first combination of cutting conditions, that satisfies the limitations, is the best one for the respective tool maker. In case of several tool makers the program first selects for each of them the best cutting conditions. Then from these best cutting conditions obtained it determines those that are optimal for a given case. In the conclusion of the calculation the programme OPTIS records the minimum machining cost and cutting speed *v*, feeding *f* and cutting depth *a* in case of minimum machining cost by taking into account all the limitations.

2.2. Theoretic solving of set problem

Solving of the problem is effected first mathematically. Mathematically the problem is very exacting and difficult to solve. Therefore we decided on the programme solution of the problem, where the minimum of the nonlinear function of costs is searched for:

$$k = k(a, f, v) = PR \cdot \left(\frac{t_r}{z_1} + t_d \right) + PR \cdot \frac{V}{a \cdot f \cdot v} + \frac{V}{a \cdot f \cdot v \cdot T} \cdot (PR \cdot t_m + C_n) \tag{1}$$

The power required for metal removal must be smaller than the power of the machine tool:

$$P = P(a, f, v) = \frac{F_c \cdot v}{\eta} = \frac{(b \cdot k_{c1x1} \cdot h^{1-z}) \cdot v}{\eta} = \frac{a \cdot k_{c1x1} \cdot (f \cdot \sin\kappa)^{1-z} \cdot v}{\sin\kappa \cdot \eta} \le P_{EM} \tag{2}$$

The moment of the cutting force must not exceed the maximum permissible moment of the machine:

$$\frac{(b \cdot k_{c1x1} \cdot h^{1-z}) \cdot D}{2 \cdot 10^3} \le \frac{P_K \cdot 60}{2 \cdot \pi \cdot n_s} \tag{3}$$

In order to reach the required quality of surface the feeding must not exceed:

$$f \le \sqrt{\frac{R_a \cdot r}{31{,}25}} \tag{4}$$

3. A NEURAL NETWORK APPROACH TO THE DETERMINATION OF OPTIMAL CUTTING CONDITIONS

3.1. Architecture of network and its adaptation to optimization problem

The multi-layer feed forward neural network has proved to be an excellent universal approximator of non-linear functions. If it is capable of approximating any nonlinear function, than it is possible to represent with it any manufacturer's implicit multiattribute function [3]. The ANN needs three input neurons for three parameters: *v*, *f* and *a*. If the values *v*, *f* and *a* are not at the same scale, all data must be normalized. The output from the neural network is a real value *k*, therefore only one output neuron is necessary (Figure 1).

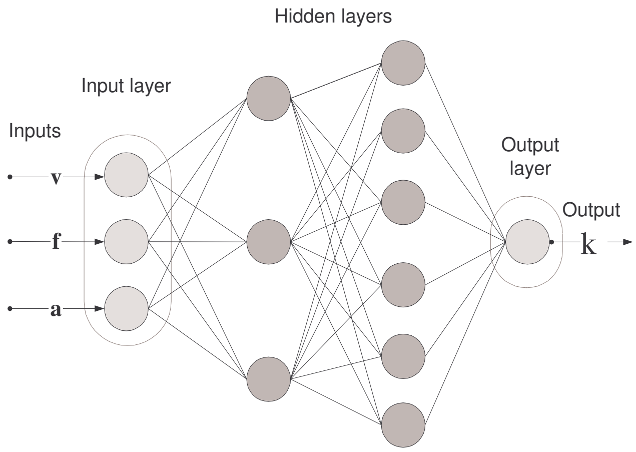

Figure 1. Representation of two-layer feed forward neural network for optimization of cutting conditions

4. SEQUENCE OF STEPS OF OPTIMIZATION OF CUTTING PARAMETERS

- Entering of input data; set-up time, tool change time, tool idle time, tool cost, labour cost, overheads, permissible range of cutting conditions, efficiency, F_{max} and $P_{max.}$
- Calculation of other values ($P, F, C_n, T, R_a, t_m, k$).
- Preparation of data for training and testing of ANN. Uniting of cutting conditions and other calculated values into a data matrix. Breakdown of the data matrix into the input and output vector. Distribution of the input / output vector into the two sets for training and testing.
- Use of ANN. The purpose of the neural network is to predict the manufacturer´s value function *k* in case of randomly selected cutting conditions.

- procedure of training of ANN by using the training set,
- testing of trained ANN.

- **Optimization process**; The cutting conditions where the function *k* has the maximum are the optimum cutting conditions. Since the function *k* is expressed with ANN, it means that the **extreme of the neural network is searched for**. The area in which the extreme is searched for is defined with limitation equations.
- Calculation of the other variables in case of optimum cutting conditions ($P, F, C_n, T, R_a, t_m, k$).
- Graphic representation of results and optimization statistic.

5. DISCUSSION OF RESULTS

Table 1 shows the similar results obtained by the OPTIS and ANN approach [4].

Table 1
Results obtained by OPTIS and ANN

Basis	v (m/min)	f (mm/rev)	a (mm)	Tm (min)	K (EUR)
OPTIS	86,837	1,860	3,01	0,459051	0,3114
ANN	86,8549	1,8622	3,1	0,4938	0,3233

For the experiment the feed forward and radial basis neural networks were used. The feed forward neural networks give more accurate results, but they require more time for training and testing. The programme containing this network is slow. Therefore the radial basis neural network was chosen for application. Those neural networks require more neurons than the standard feed forward neural networks with the Back Propagation (BPN) Learning Rule, but conceiving of radial basis neural networks lasts only a part of time necessary for training of the feed forward network.

Advantages of developed algorithm:

- simple complementing of the model by new input parameters without significant modifying the existing model structure,
- automatic searching for the non-linear connection between the inputs and outputs,

Disadvantages:

- experience is necessary for conceiving of the network,
- repeatability of training is not assured.

6. CONCLUSION

The newly developed hybrid empirical-neural approach is an original contribution to science. The OPTIS programme selects the optimum cutting conditions from the data bases of different tool makers, where the nonlinear function of the machining cost has the lowest value and which satisfy all nonlinear limitation inequations of the metal removal process.

A neural network module to multiple-objective optimization of cutting parameters is also tested. The procedure should be used for the fast approximate determination of optimum cutting conditions on the machine, when there is not enough time for deep analysis. Although global preference modelling via supervised learning may be computationally intensive, the proposed approach is more advantageous than interactive approaches, specially for job-shop production systems, where products mix is diverse and dynamic.

REFERENCES

1. B. Mursec, F. Cus and J. Balic: Organization of tool supply and determination of cutting conditions, J. Mater. Process. Technol., Vol. 100, No. 1/3, (2002).
2. F. Cus, B. Mursec, J. Balic: Computer Integrated Manufacturing, 1 (1999) 98.
3. W. Ma, Z. Lei, Y. Rong: Int. J. of Advanced Manufacturing Technology,14 (1998) 21.
4. F. Cus, J. Kopac: Metall, 52 10/11 (1998) 602.