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Turning Parameters Optimization using Particle Swarm Optimization

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Abstract

Manufacturing technologies are currently defined as on basics of adoptability, autonomous production, and level of automatization. As we modernize the manufacturing lines, subsequently we are required to update and integrate most modern technologies in order to keep the business competitive. In such way, we can assure cheaper products, shorter manufacturing times, lowering of the production costs. Due to the dynamic processes and increase of the machining parameters optimizing the information which is essential for production got significantly harder. For solving such problems, we have to turn our choice onto the intelligent methods, such as Particle swarm optimization or similar type of intelligent optimization. In this paper we present a proposal, how to successfully gain optimal cutting parameters – cutting speed, feedrate and cutting depth for certain requirements such as cutting force, surface finish – roughness and cutting tool life.

Keywords: Turning; CAD/CAM; CNC; Manufacturing; Machining; Artificial intelligence; Particle swarm optimization; Regression analysis

1. Introduction

Using modern advanced manufacturing technologies, we can accomplish shorter manufacturing times, higher capabilities, and reduction of the manufacturing costs. This leads to either final product price reduction or gaining

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higher profits. So we tend to choose solutions which make our production lines more efficient, cost effective, and most of all accurate. In past, the parameters for machining were easily obtainable in order to achieve proper surface quality, however this required certain time and expert, who has years of valuable experience in machining, the rest of data can be obtained from machining handbooks.

However, new machining procedures have more variables, essential of those did not change, however equations can be easily upgraded in order to get them up-to-date. Following article presents proposal concept for usage of the intelligent methods in order to successfully model and optimize CNC based manufacturing processes. It can be easily adoptable, with slight modifications, for basically all standard cutting procedures. In this way we can maximize the efficiency in the manufacturing process. This can be stated in form of following segments:

- increased accuracy,
- increased productivity,
- improved quality,
- machining of complex parts,
- costs optimization and reduction,
- repeatability
- cheaper end products
- more profit

In this paper we present a particle swarm optimization algorithm implementation in order to achieve optimal machining parameters for purposes of turning.

2. Background

Problematic of the present day industry consists of mainly ever highly demanding market for better and cheaper products; however this is achievable only through production cost reduction. In this paper we present usage of the intelligent programming with Particle Swarm Optimization, in order to get proper machining parameters, so we can minimize the need for the expert, thus his expertise are used in other part of the production process.

In past, several researches have been made in this or similar direction. It is of the essence to properly present the issue behind the research with proper theory review. Concept is, to take analytical approach of solving the machining parameters and convert them into intelligent approach. For this, we have to take into aspect all essential cutting equations, which have been developed over years since machining of materials begun. A good starting point is the literature of Cus F., and Abele E., Fröhlich B., regarding high speed cutting and special material removal technologies [11, 23]. It is also vital to take into aspect theory of intelligent CNC machining processes and machining technology, presented by Balic J. [1, 2]. I order to properly understand Particle Swarm Optimization we also have to consider theory of various Particle Swarm Optimization approaches, described by Chan F. T. S., Tiwari M. K. [9]. First attempts in order to achieve successful implementation of intelligent methods into machining processes have been done quite some time ago by Billatos S. B., Tseng P. C. [5]. Later Liang M. presented integration if certain parameters in order to achieve higher flexibility [18]. Here has to be mentioned also Kyoung Y. M., Cho K. K., Jun C.S. Optimal tool selection for machining, however they only presented option for pocket machining operations [16]. There were also attempts to maximizing tool life by Bhushan R. K. [4], and Choudhury S. K., Appa R. I. V. K. [10], Krain H. R., Sharman A. R. C., Ridgway K. [15]. Here has to be implemented tool condition monitoring by Byrne G., Dornfeld D., Inasaki I., Ketteler G., König W., Teti R. [8]. For our purposes we also have to include surface roughness predictions, which were researched by Brezocnik M., Kovacic M., Ficko M. [7], El-Mounayri H., Dugla Z., Haiyan D. [13], and as well implementation of neural networks by Senveter J., Klancnik S., Balic J., Cus F. [20], essential steps on this field were done by Zuperl U., Cus F. [21]. For essential optimization using particle swarm optimization we have to check to work of Bharathi Raja S., Baskar N. [3]. Also researches have been done using genetic algorithms by Cus F., Balic J. [12], which was further developed by Brezocnik M., Jurkovic Z., Sekulic M. R. [6]. Here is in order to introduce an evolutionary approach of programming of CNC machines done by Kovacic M., Brezocnik M., Pahole I., Balic J., Kecelj B. [14], which was also presented by Quiza S. R., Rivas S. M., Alfonso B. E., however these researches have been for turning [19]. For the milling parameters we can review the article by Ammar A. A., Bouaziz Z., Zghal A.,[24]. Lee B. Y., Tarng Y. S. Presented cutting parameter selections for multistage maximization turning processes which were first steps into further optimization processes. At this point we can mention research done by Cus F., Veza I., Paulic M., Irgolic T. [22], which is advanced regulation of NC milling for optimization purposes.

3. Testing parameters

Research is prepared for CNC-turning method, so for this purpose certain parameters, which are the most common utilized, have been chosen. Essential, for proper machining, with the minimization of production costs, these parameters have to be considered essentials. As for input parameters, cutting or also known as surface speed v_c has been stated in m/min, feederate f in mm/rev, and cutting depth a_p, which is given in mm. As these parameters have been included as input, the particle swarm algorithm requires for its optimizing purposes corresponding outputs, on their basis, we can acquire optimal or near optimal equations, that can be used for optimal machining processes.

Output parameters have been chosen by distinct parameters which are essential by turning. Main cutting force F_C is given in N, surface roughness R_a in μm and maximal tool life T in min. Utilizing these parameters, including distinct optimizing polynoms we can achieve by regression analysis optimization through particle swarm optimization approach. For research purposes, 20 single tests have been made, for both rough and fine machining. For each individual test new cutting insert has been used, since tool life has also been measured. Tests have been conducted by Jurkovic Z. for the purpose of genetic programming optimization algorithm [6].

3.1. Results measuring

Results overview is prepared using following measuring instruments and tools:

- For cutting forces, measuring unit consisted of: dynamometer Kistler 9257A, which has measuring area in three axes $F_{x,y,z}$= 5 kN, which sent measured signal to computer, utilizing LabVIEW™ software graphic analysis of the measured forces could be seen, and written into database.
- For surface roughness R_a, Mitutoyo roughness measuring unit SJ – 201P has been used, with reference values 2.5 mm.
- For tool usage checking, Carl Zeiss microscope brand has been used, with magnification of 30x and resolution of 0.0001 mm.

3.2. Materials, tools and CNC machine

For our experiment, CNC lathe Georg Fischer NDM-16 has been used, few basic and important machine parameters are:

- main electric motor power: P = 30 kW,
- stage I: P = 27 kW*;* T = 625 Nm at 410 min^{-1},
- stage II: P = 30 kW*;* T = 220 Nm at 1320 min^{1},
- maximal feedrate: f = 5000 mm/min,
- maximal work piece size: Ø 160 mm x 500 mm.

Tool Holder and insert:

- tool holder 0 – 3225P15,
- insert Sandvik Coromant DNMG 150608 – PM4025
  Manufactured with CVD technology, middle layer Al_2O_3, top layer TiN covered.

Manufacturer recommended cutting conditions are:

v_c = 265–405 m/min,
f = 0.15–0.50 mm/rev,
a_p = 0.5–6 mm.

Work piece material is carbonized steel, with Standard markings C45E (EN 10083/1996.). Material was hot rolled into 6 m long cylinder with diameter of Ø100 mm, after essential forming into cylinders it was tempered. Material is later cut into cylinders with dimensions of Ø 100 x 380 mm.

Fig. 1. CNC Lathe GF NDM-16.

4. Experimental results

Two main experimental procedures have been chosen, rough turning and finish turning. Utilizing two different procedures we get two distinct set of results. Each set consists of 20 individual cutting sequences in order to determine tool life for each cutter and its distinct cutting parameters. These are:

- cutting speed v_c [m/min],
- feedrate f [mm/rev],
- cutting depth a_p [mm].

Despite the fact that 20 individual cuts have been made for rough and finish turning, only first eight cuts have been implemented into PSO algorithm, the rest are serving us as a testing numbers in order to assure that the polynom, given from Particle Swarm Optimization is optimal. The values used for preparing of the polynom are shown in Tab.1 for rough turning and finish turning.

Using these numeric values, we can start preparing intelligent algorithm calculation.

Table 1. Input and output values for turning.

	Input			Output		
Nr.	V_c [m/min]	f [mm/rev]	a_p [mm]	F_c [N]	R_a [μm]	T [min]
1	300	0.3	1.5	879.224	4.3	17.6
2	400	0.3	1.5	894.327	3.88	4.73
3	300	0.5	1.5	1436.299	11.11	6.68
4	400	0.5	1.5	1408.114	11.48	1.88
5	300	0.3	3	1754.215	4.21	13.86
6	400	0.3	3	1726.937	4.5	3.8
7	300	0.5	3	2896.122	14.29	4.1
8	400	0.5	3	2860.663	13.71	1.16
9	400	0.1	0.4	128.893	0.77	32.66
10	500	0.1	0.4	130.755	0.8	11.15
11	400	0.2	0.4	201.899	1.7	25.89
12	500	0.2	0.4	202.2	1.67	7.45
13	400	0.1	1.2	337.859	1.11	28.43
14	500	0.1	1.2	330.745	1.19	9.23
15	400	0.2	1.2	492.945	2.14	20.74
16	500	0.2	1.2	550.848	1.77	5.61

5. Particle swarm optimization

Although using intelligent methods are not particularly new to optimizing machining parameters, we wanted to create our own algorithm in order to satisfy our needs for properly to execute future experiments, since each algorithm is based on slightly different approach, and not every variant is suitable for the same purpose. Many of these optimizing algorithms, seen on Fig. 2, are base essentially solely to determine minimums and maximums of certain mathematical functions, however, in order to achieve optimal coefficients for our mathematical model for machining, we have to introduce teach-in basis for our algorithm. Since there are parameters for two distinct operations, this calls for two different sets of optimizing polynoms. We are unable to determine one single polynom for both rough and finishing procedures, since the required inputs and outputs are clearly substantially different.

According to Fig. 2, teach-in base has been added to phase one for generating particles in order to make the standard algorithm appropriate for our needs. For the purpose of reaching optimum, basic preliminal polynom has to be chosen, or created randomly. In the researches till now, results with following polynom were the best.

$$calculated\ value = k_1 + k_2 \cdot x_1 + k_3 \cdot x_2 + k_4 \cdot x_3 + k_5 \cdot x_1 \cdot x_2 + k_6 \cdot x_1 \cdot x_3 + k_7 \cdot x_2 \cdot x_3 + \\ + k_8 \cdot x_1 \cdot x_2 \cdot x_3 \quad (1)$$

Where calculated value stands for any of the resulting parameters:

- main cutting force,
- surface roughness,

- maximal tool life,
- $k_1 \ldots k_8$ – coefficients,
- x_1 – Cutting speed,
- x_2 – Feederate,
- x_3 – Cutting depth.

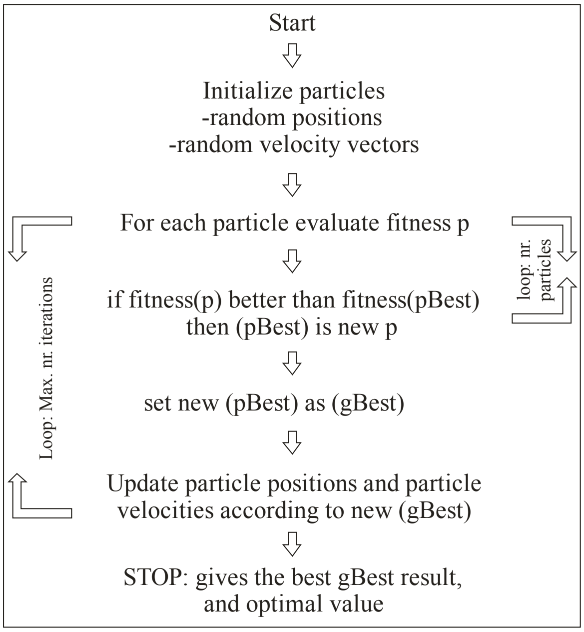

Fig. 2. Particle swarm algorithm schematics.

Results, based on this preliminary polynom, and structure of generated PSO algorithm, and input parameters, gave us following results for fine turning:

Maximal Tool life T [min], using PSO algorithm:

$$T = 141.88 - 0.25 \cdot v_c - 165 \cdot f - 10.5 \cdot a_p - 62.4 \cdot f \cdot a_p + 0.12 \cdot v_c \cdot f \cdot a_p \quad (2)$$

Maximal Tool life T [min], using analytical multiple regression analysis:

$$T = 142.025 - 0.25235 \cdot v_c - 165.9 \cdot f - 10.687 \cdot a_p + 0.257 \cdot v_c \cdot f \quad (3)$$

The results of analytical multiple regression analysis was included to give rough idea how distant or how similar results are, and are serving solely for comparison. Note, analytical approach seems to be easier to calculate with, however, per results, PSO algorithm is far superior to it. Following results are representative results for PSO algorithm for finish tuning parameters with material C45E (EN 10083/1996.) For surface roughness R_a (5) and main cutting force F_C (4), which combine with previously mentioned maximal tool life T full set of information within our PSO algorithm.

$$F_c = -169.72 + 0.4 \cdot v_c + 1697.1 \cdot f + 533.36 \cdot a_p - 3.44 \cdot v_c \cdot f - 2283.8 \cdot f \cdot a_p + 9.2 \cdot v_c \cdot f \cdot a_p \quad (4)$$

$$R_a = 0.22 + 3.51 \cdot f - 1.878 \cdot a_p + 20.61 \cdot f \cdot a_p - 0.04 \cdot v_c \cdot f \cdot a_p \quad (5)$$

6. Conclusion

The presented paper serves us for initial step into optimizing methods and it shows an elementary approach to solving machining optimization parameters. Despite its purpose for certain material, the code could get adopted for broader spectrum of parameter optimization, which means we could eliminate the factor of material in order to gain an optimization algorithm capable of optimizing parameters for different materials.

7. Future research

This particle swarm algorithm will serve us for comparison purposes for future algorithm developments, which will be based on different physical models. As a first step will be development of gravitational search algorithm, which first testing steps show excellent results in terms of optimization speed, which is roughly 60-times faster with rough initial deviation of 5 – 7 % without any basic corrections of weight factors or main polynomial correction comparing to conventional PSO.

References

[1] Balic J. *Teorija tehniskih sistemov*. Fakulteta za strojnistvo, 86-435-0467-X. Maribor, 2002.

[2] Balic J. *Inteligentni obdelovalni sistemi*. Fakulteta za strojnistvo, 86-435-0579-X. Maribor, 2004

[3] Bharathi Raja S., Baskar N. Particle swarm optimization technique for determining optimal machining parameters of different work piece materials in turning operation. *International Journal of Advanced Manufacturing Technology*, vol. 54, no. 5–8, 2011 pp. 445–463.

[4] Bhushan R. K. Optimization of cutting parameters for minimizing power consumption and maximizing tool life during machining of Al alloy SiC particle composites. *Journal of Cleaner Production*, vol. 39, 2013 pp. 242–254.

[5] Billatos S. B., Tseng P. C. Knowledge-based optimization for intelligent machining. *Journal of Manufacturing Systems* , vol. 10, no. 6, 1991, pp. 464–475.

[6] Brezocnik M., Jurkovic Z., Sekulic M. R. Modeliranje procesa obrade rezanjem primenom genetskih alogritama. *33rd Conference of Production Engeneering of Serbia with Foreign Participants* (2009).

[7] Brezocnik M., Kovacic M., Ficko M. Prediction of surface roughness with genetic programming. *Journal of Materials Processing Technolog*y 2004, vol. 157–158, pp. 28–36.

[8] Byrne G., Dornfeld D., Inasaki I., Ketteler G., König W., Teti R. Tool Condition Monitoring (TCM). The Status of Research and Industrial Application. *CIRP Annals- Manufacturing Technology* 1995, vol. 44, no. 2, pp. 541–567.

[9] Chan Felix T. S., Tiwari M. K*Swarm Intelligence: Focus on Ant and Particle Swarm Optimization*. Austria: I – Tech Education and Publishing, 978-3-902613-09-7, 2007.

[10] Choudhury S. K., Appa R. I. V. K. Optimization of cutting parameters for maximizing tool life. *International Journal of Machine Tools and Manufacture* 1999, vol. 39, no. 2, pp. 343– 353.

[11] Cus F. *High speed cutting and special material removal technologies*, Faculty of mechanical engineering Maribor, ISBN: 86-435-0639-7, Maribor, 2004.

[12] Cus F., Balic J. Optimization of cutting process by GA approach. *Robotics and Computer-Integrated Manufacturing* 2003, vol. 19, no. 1–2, pp. 113–121.

[13] El-Mounayri H., Dugla Z., Haiyan D. Prediction of surface roughness in end milling using swarm intelligence. *Swarm Intelligence Symposium, 2003. SIS '03. Proceedings of the 2003 IEEE*, 2003.

[14] Kovacic M., Brezocnik M., Pahole I., Balic J., Kecelj B. Evolutionary programming of CNC machines. *Journal of Materials Processing Technology* 2005, vol. 164–165, no. 0, pp. 1379–1387.

[15] Krain H. R., Sharman A. R. C., Ridgway K. Optimisation of tool life and productivity when end milling Inconel 718TM. *Journal of Materials Processing Technology* 2007, vol. 189, no. 1–3, pp. 153–161

[16] Kyoung Y. M., Cho K. K., Jun C. S. Optimal tool selection for pocket machining in process planning. *Computers & Industrial Engineering* 1997, vol. 33, no. 3–4, pp. 505–508

[17] Lee B. Y., Tarng Y. S. Cutting-parameter selection for maximizing production rate or minimizing production cost in multistage turning operations. *Journal of Materials Processing Technology* 2000, vol. 105, no. 1–2, pp. 61–66.

[18] Liang M. Integrating machining speed, part selection and machine loading decisions in flexible manufacturing systems. *Computers & Industrial Engineering* 1994, vol. 26, no. 3, pp. 599–608

[19] Quiza S. R., Rivas S. M., Alfonso B. E. Genetic algorithm-based multi-objective optimization of cutting parameters in turning processes. *Engineering Applications of Artificial Intelligence* 2006, vol. 19, no. 2, pp. 127–133.

[20] Senveter J., Klancnik S., Balic J., Cus F. Prediction of surfaceroughness using a feed-forward neural network. *Management and production engineering review* 2010, vol. 1, no. 2, pp. 47–55.

[21] Zuperl U., Cus F. Optimization of cutting conditions during cutting by using neural networks. *Robotics and Computer-Integrated Manufacturing* 2003, vol. 19, no. 1–2, pp. 189–199.

[22] Cus F., Veza I., Paulic M., Irgolic T. *Optimality search and advanced regulation method of NC milling*. V: Katalinic, Branko (ed). *23rd DAAAM International symposium Conference papers*, (Annals of DAAAM & Proceedings, Vol. 23, no. 1). Vienna: DAAAM International, 2012, pp. 943–946

[23] Abele E., Fröhlich B. *High speed milling of titanium alloys.* Advances in Production Engineering & Management 2008, vol. 3, no. 3, pp. 131 – 140.

[24] Ammar A. A., Bouaziz Z., Zghal A. *Modelling and simulation of the cutting forces for 2.5 D pockets machinig.* Advances in Production Engineering & Management 2009, vol. 4, no. 4, pp. 163 – 176.