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ORIGINAL ARTICLE

An approach for blank dimension design considering energy consumption

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Abstract A blank dimension is not only a premise of blank design and manufacture, but also plays a significant role to decide the machining process and the energy consumption of the machining process. The design of an appropriate blank dimension is important to ensure efficient energy usage. However, consideration of a workpiece machining process and energy consumption during the machining process in the blank dimension design phase is often neglected. To design a blank dimension scientifically and effectively, this paper proposes an optimization approach for blank dimension design, by considering energy consumption, machine cost, and process time. The three objectives are affected by three variables, cutting depth, feed rate, and cutting speed. The non-dominated sorting genetic algorithm-II (NSGA-II) algorithm was used to solve multi-objective optimization problem, and blank dimensions could be calculated from the cutting depth of minimum energy consumption and workpiece dimension. The results indicated that the proposed approach is effective in realizing energy savings due to the appropriate blank dimension design. The optimization approach not only offers some insights for designing a new blank dimension, but also provides a theoretical basis for existing blank dimension selection.

Keywords Blank dimension design · Energy saving · NSGA-II algorithm · Machining parameters optimization · Sustainable production

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Abbreviations

E	Energy consumption of machining (in kilojoules)
R	Surface roughness of workpiece (in micrometers)
p_0	The machine modules consumed power (in kilowatts)
v_c	Cutting speed (in meters per minute)
a_{sp}	Cutting depth (in millimeters)
f	Feed rate (in millimeters per revolution)
k_{Fc}	Correcting coefficient of cutting tool's parameters
x	The cutting speed affect of T
y	The feed rate affect of T
z	The cutting depth affect of T
C_{Fc}, x_{Fc}, y_{Fc}, n_{Fc}	Coefficients of cutting parameters to main cutting force
L	The cutting length of the workpiece (in millimeters)
D	Diameters of the blank (in millimeters)
d	Diameters of the workpiece (in millimeters)
n	The rotating speed of main spindle (in revolutions per minute)
a_1, a_2	Additional load loss coefficients
$k_{r'}$	Secondary cutting edge angle of cutter
r_ε	Corner radius of cutting tool
k_r	Main cutting edge angle of cutter
λ_s	Inclination angle of cutter
T	Cutting tool life (in seconds)
x	The machine cost rate
y_c	The tooling cost per cutting edge
k	Specific energy requirement in cutting operations (ws/mm^3)

y_e	The energy footprint per tool cutting edge (in kilojoules)
$\dot{v}$	Material removal rate (mm^3/s)
t_1	Machine setup time (in seconds)
t_2	Time taken for cutting (in seconds)
t_3	Tool change time (in seconds)

1 Introduction

In the twenty-first century, the blank design process is receiving increasing attention from the viewpoint of energy usage and associated environmental issues. The National Bureau of Statistics reported that 59.5 % of the total energy produced was consumed in the manufacturing industry [1]. The methods employed for reducing energy consumption in manufacturing have become a subject of intensive discussion both in the academia and industry. Manufacturing is a process which transforms material, energy, and information into goods for the satisfaction of human needs. During this process, material is removed as per requirements. Since it is inherently a process of removing material by machining, it can be wasteful both in material and energy [2].

In order to economize material and energy usage in the machining process, increasing attention is being given to perform sustainable manufacturing. The sustainable manufacturing practices concept provides a continuous improvement program structure which is focused on the improvement of risk, cost, waste, material, and energy efficiency, and environmentally friendly products and services [3]. In order to establish sustainable manufacturing, both the researchers and manufacturers carried out intensive researches [4]. The researchers focused on the sustainable assessment of the machining process [5].The manufacturers paid increased attention to make their operations and manufacturing processes highly sustainable [6].

Product design is the most decisive phase for realizing the objectives of sustainable manufacturing. A blank is designed for a machining workpiece. After the workpiece design, the next important step is blank design. Blank design is not only a premise of blank manufacture, but also a basic precondition in the decision-making of machining the workpiece. It is widely acknowledged that blank design is an important task of mechanical design and manufacturing. During the machining operation, the blank provides information about difficulties involved in the removal of materials as well as amount of material that needs to be removed. This information is the precondition of deciding the process energy consumption.

The blank dimension is an embodiment of geometry and elements of blank. Blank dimension design is a challenging issue in the design and development of products and also critical for the success and competitiveness of manufacturing operations. A number of methods for blank shape design and optimization have been previously proposed. Liu and Sowerby [7] used experimental and numerical methods based on a solution to Laplace's equation to optimize the blank shape for deep drawing prismatic cups. Park et al. [8] proposed a geometrical shape error method to determine optimal blank shape. Naceur et al. [9] used evolutionary algorithm to optimize blank shape. Vafaeesefat [10] employed an iterative finite element sheet metal mode to form simulations of the optimum blank shape. Chamekh et al. [11] applied an artificial neural network to predict the shape of the initial blank. Liu et al. [12] used a support vector regression technique to optimize the blank polygonal shape. Kitayama et al. [13] used a sequential approximate optimization approach with a radial basis function network to determine the optimal blank shape.

The blank dimension is not only a key parameter in blank design phase, but also affects the entire machining process stretching from the blank to the workpiece. Blank dimension is the sum of cutting depth and workpiece dimension. Cutting depth is one of the main machining parameters and it significantly affects energy consumption [14]. Although a relationship between the blank dimension and energy consumption cannot be directly established, it is feasible to formulate such a relationship with cutting depth.

Attempts to investigate the relationship between machining parameters and energy consumption for the purpose of energy savings have received significant attention. Such approaches lead to the development of energy-consumption models and methods for the optimization of parameters for minimizing energy usage. The reviews of research published on the optimization of parameters for energy savings are as follows: Chapman [15] suggested that energy usage in a machining process can be evaluated and reduced by concentrating on a particular process in detail. Ippolito and De [16] wrote one of the first papers to recognize the need to consider and measure energy usage in the machining process. Jain et al. [17] described the optimization of parameters for the machining processes using genetic algorithms and gave the details of formulation about optimization models, solution methodology, and optimization of results. Diaz et al. [18] analyzed the impact of workpiece material and its removal rate on energy consumption. Bi and Wang [19] analyzed the energy models based on the explicit relationships between the machining parameters and energy consumption, and chose machine tools on such basis for saving energy. Bhushan [14] demonstrated that feed is the most significant machining parameter, followed by the cutting depth and speed, for reducing power consumption and surface roughness. Mativenga and Rajemi [20] searched parameters for minimum energy consumption on the basis of tool life. Mori et al. [21] developed an acceleration control method to reduce energy consumption. Kant and Sangwan [22] provided a multi-objective predictive model for the minimization of power consumption and surface roughness in machining operation. Wang et al. [23] used non-dominated sorting genetic algorithm-II optimization machining parameters for energy saving, cost reduction, and quality improvement. Li et al. [24] carried out optimization and experimental methods optimization machining parameters for energy saving. Li et al. [25] established multi-objective empirical models and used non-dominated sorting genetic algorithm-II (NSGA-II) algorithm optimization machining parameters. Camposeco-Negrete1 et al. [26] used robust design optimization machining parameters to minimize energy consumption during the turning operation of AISI 1018 steel.

In conclusion, in recent years, researches on blank dimension optimization and machining parameters optimization for energy saving have made a marked progress. In the traditional blank design phase, blank dimension design mainly depends on blank manufacturing processing properties. After blank design and manufacture, different methods are used to optimize the energy consumption starting from blank to workpiece. An inappropriate blank dimension cannot ensure minimum energy consumption. Conserving energy is one of the main targets of sustainable manufacturing. Green design is a key technology of implementation to ensure sustainable manufacturing. The aim of blank design is for machining a workpiece. However, so far, no efforts have been made toward considering machining energy consumption as a target of blank dimension design. In the work presented in this paper, an attempt was made to choose the most appropriate blank dimension based on minimum energy consumption. The influence of the blank dimension on energy consumption was analyzed. A multi-objective optimization model was set up in which the objective energy, cost, and time were considered. These objectives are affected by three variables, namely cutting depth, feed rate, and cutting speed. NSGA-II algorithm was used to optimize machining parameters and compute energy consumption. Blank dimensions could be calculated by using the cutting depth of minimum energy consumption and workpiece dimension.

2 Impacts of the blank dimension on energy consumption

The blank dimension is typically considered as a premise of determining the process plan. The process plan is implemented to produce the features and characteristics of the workpiece. Manufacturing requirements which include the manufacturing equipment, tools, and operating conditions for each process are usually prescribed by means of process planning. The consideration of energy consumption as an additional objective in the process plan formulation may have its results to be significantly different from the one based solely on traditional objectives. Notably, both specific operations and blank dimensions impact the total energy consumption in the planning process starting from blank to workpiece manufacture.

2.1 Impacts of the blank dimension on process planning

The blank dimension is not only the basis and premise of process planning, but also a necessary condition for determining machining parameters. Different blank dimensions have different allowances, process routes and machining parameters. The process routes are determined by the manufacturing equipment, tools, operating conditions and the blank dimension.

To explain basic concepts and in the context following discussion, the component shown in Fig. 1 will be used. The dimensions mentioned in this paper are in millimeters and the surface tolerance unit is in micrometers. The workpiece, which is 300 mm in length and 50 mm in diameter, is made from a 45# carbon steel cylindrical bar. Its surface roughness requirement is 6.4 μm. Two alternative blank dimensions are available for producing the workpiece: (1) To prepare a blank having dimensions of 55 mm in diameter and 5 mm in cutting depth according to the lathe and process manuals, only one path is required to complete process [27]; (2) To prepare a blank having dimensions of 60 mm in diameter and 10 mm in cutting depth according to the lathe and process manuals,

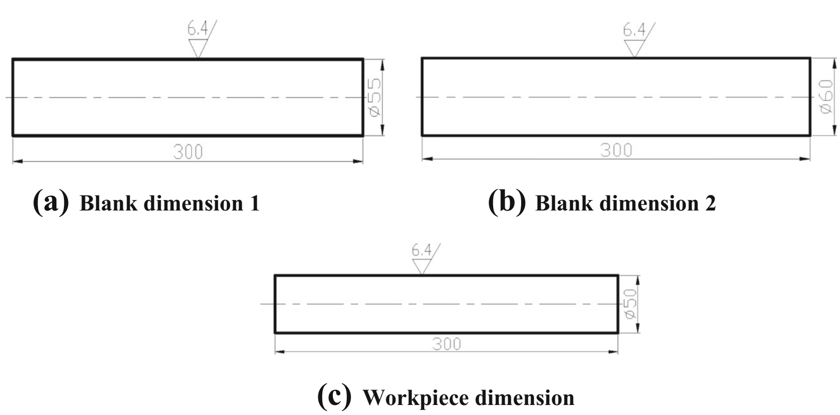

Fig. 1 Blank dimension and workpiece dimension. **a** blank dimension 1, **b** blank dimension 2, and **c** workpiece dimension

two paths are needed to complete process. The above example shows that the blank dimension can determine the process planning.

2.2 Impacts of process planning on energy consumption

Industrial process planning intends to perform the optimal resource allocation [28]. The selection of required operations that would produce the features for a given component design is a fundamental task of process planning. With increasing energy consumption and environmental degradation, manufacturers are more concerned about energy consumption especially in the process planning phase [29]. Process planning concentrates on specifying conditions that are required to produce a given component, such as the machines, operations, operation sequence, machining conditions, and tools/fixtures [30]. Machines, operation sequence, machining conditions, and tools are all parts of the process planning selected objects. Each of the above factors can affect energy consumption. Optimization of different factors for minimum energy consumption has been carried out.

Machining is a key factor deciding process planning and affecting energy consumption. There are two kinds of methods that can save machining energy consumption. One is optimization and improvement of mechanical equipment and the other is optimization machining parameters. Optimization and improvement of mechanical equipment require equipment adjustments and replacement, both of which are time and energy consuming. It also causes extra costs, which is not a favorable outcome. The optimization of machining parameters only sets up all types of models and uses arithmetic to seek the minimum energy consumption. In this paper, the optimization of machining parameters is studied.

3 Energy consumption optimization model based on the blank dimension

The impact of the blank dimension on energy consumption is important. In order to ensure minimum energy consumption, it is essential to build an energy consumption model based on the blank dimension.

3.1 Variables

For the formulation of the objective function, the three decision variables selected were cutting depth, feed rate, and cutting speed. These variables include all the machining parameters employed in the actual machining.

3.2 Objectives

Three different, mutually conflicting objective functions were optimized in this model. The first objective function is the energy consumption, which is shown by Eq. (1). It was studied by Rajemi et al. [31],

$$E = p_0 t_1 + (p_0 + k\dot{v})t_2 + p_0 t_3\left(\frac{t_2}{T}\right) + y_E\left(\frac{t_2}{T}\right) \tag{1}$$

According to Liu et al. [32], the calculation of energy consumption in the turning operation can be rearranged as Eq. (2),

$$\begin{aligned} E &= p_0 t_1 \\ &+ \left(p_0 + (1+a_1)\frac{C_{Fc} a_{sp}^{x_{Fc}} f^{y_{Fc}} v_c^{n_{Fc}} K_{Fc} v_c}{6\times 10^4} + a_2\left(\frac{C_{Fc} a_{sp}^{x_{Fc}} f^{y_{Fc}} v_c^{n_{Fc}} K_{Fc} v_c}{6\times 10^4}\right)^2\right)t_2 \\ &+ p_0 t_3\left(\frac{t_2}{T}\right) + y_E\left(\frac{t_2}{T}\right) \end{aligned} \tag{2}$$

Blank dimension is the sum of the workpiece dimension and depth of cutting. The relationship between the blank dimension and energy consumption can be written as shown by Eq. (3),

$$\begin{aligned} E &= p_0 t_1 \\ &+ \left(p_0 + (1+a_1)\frac{C_{Fc}\left(\frac{D-d}{2}\right)^{x_{Fc}} f^{y_{Fc}} v_c^{n_{Fc}} K_{Fc} v_c}{6\times 10^4} + a_2\left(\frac{C_{Fc}\left(\frac{D-d}{2}\right)^{x_{Fc}} f^{y_{Fc}} v_c^{n_{Fc}} K_{Fc} v_c}{6\times 10^4}\right)^2\right)t_2 \\ &+ p_0 t_3\left(\frac{t_2}{T}\right) + y_E\left(\frac{t_2}{T}\right) \end{aligned} \tag{3}$$

The second objective function for the machining cost is as shown by Eq. (4). It was studied by Kalpakjian and Schmid [33],

$$C = x\left(t_1 + t_2 + t_3\frac{t_2}{T}\right) + \frac{t_3}{T}y_c \tag{4}$$

The third objective function for the process time is shown by Eq. (5). It was studied by Yi et al. [34].

$$T_P = t_1 + t_2 + t_3\frac{t_2}{T} \tag{5}$$

3.3 Constraints

There were several limiting conditions for the optimization of constraints which were all taken into account. In the first place, they were the permitted values for the machining parameters, specified for the machine, tools, and processing quality limits:

$$a_{\min} \le a \le a_{\max} \tag{6}$$

$$f_{\min} \le f \le f_{\max} \tag{7}$$

$$\frac{\pi d_0 n_{\min}}{1000} \le v \le \frac{\pi d_0 n_{\max}}{1000} \tag{8}$$

The constraints related to machine features are as follows: The cutting force F must not be greater than a certain maximum value $F_{\max}$.

$$F \leq F_{\max} \tag{9}$$

The maximum allowable value for the cutting power P must be less than the motor output power.

$$P \leq \eta P_{\max} \tag{10}$$

Finally, for the finishing operations, the surface roughness obtained R must be smaller than the specified value $R_{\max}$ given by technological criteria. This condition is expressed by Eq. (11).

$$R \leq R_{\max} \tag{11}$$

4 Case studies

4.1 Background of the optimization problem

The turning operation was taken into consideration to study the effect of the blank dimension on energy consumption. The workpiece made from 45#carbon steel was 300 mm in length and 50 mm in diameter, and its surface roughness was 6.4 um. The workpiece was machined on a CNC lathe, which has a 5.5 Kw motor having an efficiency of 80 %. A maximum cutting force of 5000 N was allowed by the machine system.

According to the specifications of the CNC lathe, the allowed machining parameters for the rough turning processes were subjected to following limits:

$$a_{\min} = 0.05 \text{ mm}, \quad a_{\max} = 5 \text{ mm},$$
$$n_{\min} = 80\ r\big/\min, \ n_{\max} = 3000\ r\big/\min$$
$$f_{\min} = 0.05 \text{ mm}\big/r, \ f_{\max} = 1.12 \text{ mm}\big/r$$

The parameters of cutting tool used in optimization are shown in Table 1.

It is necessary to determine some parameters and data ahead of optimization.

Firstly, the coefficients x, y, z, C_{Fc}, K_{Fc}, x_{Fc}, y_{Fc}, and n_{Fc} should be confirmed in the optimization model. They were obtained from a mechanical engineering manual and shown in Table 2.

Table 1 Parameters of cutting tools

Parameters	Main cutting edge angle k_{γ}	Seconding cutting edge angle k_{γ}'	Inclination angle λ_s	Corner radius r_{ε}
Values	45°	20°	5°	0.8 mm

Table 2 The tool life and the cutting force coefficients

Parameters	x	y	z	C_{Fc}	K_{Fc}	x_{Fc}	y_{Fc}	n_{Fc}
Values	5	1.75	0.75	2795	1	1	0.75	−0.15

Secondly, referring to the mechanical engineering manual, the coefficients contained in the optimization model, including the tool change time t_c, the auxiliary time t_o, additional load loss coefficients a_1, additional load loss coefficients a_2, and the no-load minimum power p_{uo}, were determined. The detailed parameters are shown in Table 3.

Finally, the production and material costs were resolved. The production cost was estimated as 0.051 dollars/s, which included the direct machine tool depreciation cost, salary for the worker, and indirect management cost. The purchase price of the carbide tool was 8.33 dollars/piece and the cost of the pure emulsifier was 18.75 dollars/L.

4.2 Simulation for the optimization model

A lot of approaches were proposed to solve multi-objective optimization problems, among which NSGA-II is widely applied. Hence, NSGA-II was used to solve the problem.

In fact, population dimension and generation number are chosen according to trial as no standardized mathematical formula was available. The population dimension generally ranges from dozens to hundreds. After several trials, a population dimension of 50 was selected. The generation number generally ranges from 100 to 1000. After several trials, 100 was selected as the generation number. In addition, the crossover probability was $P_c = 1$, and the number of individuals was 100. NSGA-II algorithm was implemented in Matlab 2009 and the trade-off parameter optimization was accomplished. For the NSGA-II algorithm, the initial and final points were determined ahead of time. The assumed blank dimension interval was from 51 to 61 mm.

4.3 Simulation result

Three-dimensional view of energy consumption, machining cost and process time obtained by NSGA-II algorithm for the machining parameter optimization is similar to a parabolic surface. The typical points are distributed near the surface. The projection on energy consumption-machining cost plane

Table 3 Values of coefficients in the optimization model

Parameters	a tool change time(t_c)	the auxiliary time(t_o)	additional load loss coefficient a_1	additional load loss coefficient a_2	the no-load minimum power(p_{uo})
Values	1.5 s	0.75 s	0.227	-0.667×10^{-6}	40.6 Kw

is similar to the image of index, around which typical points are distributed. The projection on the energy consumption-process time plane is similar to the image of index, around which typical points are distributed. The projection on the machining cost-process time plane is similar to a straight line, around which these points are distributed. From the simulation, the optimal machining parameters obtained were 2.1, 0.74, and 45, and the optimal values of objective functions were 95.22, 3.73, and 9.30. The blank dimension was 54.2 mm.

5 Discussions

The present work provides an approach through optimization machining parameter to obtain minimum energy consumption, according to the cutting depth of minimum energy consumption and workpiece dimension design blank dimension. The designed blank dimension can ensure processing of minimum energy consumption. A few issues observed in this study require further discussion.

5.1 Comparison to traditional blank dimension's energy consumption

The typical optimization machining parameters and results are shown in Table 4. The energy-saving effect of the model is clearly evident. There is no doubt that the first group of parameters in Table 4 is the most energy-efficient. The energy consumption of the second and fourth scheme is 1.244 and 2.787 times that of the first scheme, respectively. The cutting depth of scheme 1 is recommended for computing the blank design dimension. According to the cutting depth and workpiece dimension, the blank dimension is 54.2 mm. This dimension is recommended as the dimension for the blank design as it can realize minimum processing energy consumption. By querying the national standard of blank dimensions, 56 and 60 mm are found as the closest design dimensions [27]. Compared to the standard blank dimension of 56 mm, the designed blank dimension energy consumption is only 80.3 % of the original; the material use is only 93.6 % of the original. Compared to the standard blank dimension of 60 mm, the designed blank dimension energy consumption is only 35.8 % of the original; the material use is only 81.6 % of the original. The blank dimension designed through this approach reduces energy consumption and saves raw material.

5.2 Comparative benefits between our approach and literature's approach

Some multi-objective methods have been reported in the optimization of machining parameters for reducing energy consumption [17, 19, 21–26], those methods and algorithms were effective for energy saving. However, those researches considering the optimization of machining parameters on the basis of the blank have been produced. In that case, it is very difficult to guarantee the minimum energy consumption due to the inappropriate blank dimension. Whether a product is sustainable is largely determined in the design phase. In this paper, the blank dimension is designed based on the cutting depth of minimum energy consumption.

5.3 Practical implications and future steps

An approach was proposed for blank dimension design and it was verified. It was useful for reducing energy consumption during machining. This study will assist academicians and practitioners in enhancing their knowledge and comprehension of blank dimensions. It will also assist the manufacturing industry in improving raw material and energy utilization. Above all, this research extends to explore the area of manufacturing especially the traditional processing region. Therefore, not only from the theoretical standpoint but also from a practical application standpoint, this research demonstrated an approach to design blank dimension that guarantees the minimum energy consumption in machining operation process. Nevertheless, in this paper, only the influence of the blank diameter dimension on energy consumption was considered. The future studies should include a comprehensive evaluation of the effect of the blank diameter and length on the workpiece, and also new methods for optimization machining parameters.

Table 4 Comparative experiments of parameter selection

Scheme	Cutting depth (mm)	Feed rate (mm/r)	Cutting speed (m/m)	Energy consumption (kj)	Machining cost ($)	Process time (s)
1	2.1	0.74	45	95.22	3.73	9.30
2	3.00	0.74	54.16	118.52	3.07	7.59
3	3.51	0.74	66.21	145.29	2.59	6.32
4	5.00	0.75	114.61	265.47	1.58	3.65

6 Conclusions

An approach of the blank dimension optimum design for minimum energy consumption during machining has been presented. Minimum energy consumption is optimized based on existing processing conditions, equipment, and process characteristics. Blank dimension design on the basis of minimum energy consumption can guarantee minimum energy consumption.

This approach, which designs blank dimensions on the basis of minimum energy consumption, is expected to be helpful to the manufacturing industry for saving energy. The design of an appropriate blank dimension is the basis in realizing a sustainable development for the manufacturing industry.

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References

1. NBS (2010) China Energy Statistical Yearbook. China Statistics Press, Beijing
2. Dahmus J, Gutowski T (2004) An Environmental Analysis of Machining. Proceedings of ASME International Mechanical Engineering Congress and R&D Exposition, pp. 13–19
3. Joseph C, Taplin R (2011) The measurement of sustainability disclosure: abundance versus occurrence. Account Forum 35(1):19–31
4. Dornfeld DA (2014) Moving toward sustainable and green manufacturing. Int J Precis Eng Manuf-Green Technol 1(1):63–66
5. Dambhare SG, Deshmukh SJ, Borade AB (2015) Machining parameter optimization in turning process for sustainable manufacturing. Int J Ind Eng 6:27–338
6. Brodsky A, Shao G, Riddick F (2014) Process analytics formalism for decision guidance in sustainable manufacturing. J Intell Manuf. doi:10.1007/s10845-014-0892-9
7. Liu F, Sowerby R (1991) The determination of optimal blank shapes when deep drawing prismatic cups. J Mater Shap Technol 9(3):153–15
8. Park SH, Yoon JH, Yang DY, Kim YH (1999) Optimum blank design in sheet metal forming by the deformation path iteration method. Int J Mech Sci 41:1217–1232
9. Naceur H, Guo YQ, Batoz JL (2004) Blank optimization in sheet metal forming using an evolutionary algorithm. J Mater Process Technol 151:183–191
10. Vafaeesefat A (2008) Optimum blank shape design in sheet metal forming by boundary projection method. Int J Mater Form Suppl 1: 189–192
11. Chamekh A, BenRhaiem S, Khaterchi H, BelHadjSalah H, Hambli R (2010) An optimization strategy based on a metamodel applied for the prediction of the initial blank shape in a deep drawing process. Int J Adv Manuf Technol 50:93–100
12. Liu Y, Chen W, Ding L, Wang X (2013) Response surface methodology based on support vector regression for polygon blank shape optimization design. Int J Adv Manuf Technol 66:1397–1405
13. Kitayama S, Saiky M, Kawamot K, Yamamichi K (2015) Multi-objective optimization of blank shape for deep drawing with variable blank holder force via sequential approximate optimization. Struct Multidiscip Optim. doi:10.1007/s00158-015-1293-1
14. Bhushan RK (2013) Optimization of cutting parameters for minimizing power consumption and maximizing tool life during machining of Al alloy SiC particle composites. J Clean Prod 39:242–254
15. Chapman PF (1974) Energy costs: a review of methods. Energ Policy 2(2):91–103
16. Ippolito R, De FA (1979) Energy savings by proper machine tool management. SME Technical Paper (Series) MM (MM79-38) SME, USA
17. Jain NK, Jain VK, Deb K (2007) Optimization of process parameters of mechanical type advanced machining processes using genetic algorithms. Int J Mach Tools Manuf 47(6):900–919
18. Diaz N, Redelsheimer E, Dornfeld D (2011) Energy consumption characterization and reduction strategies for milling machine tool use. Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Braunschweig, pp 263–267
19. Bi ZM, Wang L (2012) Optimization of machining processes from the perspective of energy consumption: a case study. J Manuf Syst 31:420–428
20. Mativenga PT, Rajemi MF (2011) Calculation of optimum cutting parameters based on minimum energy footprint. CIRP Ann Manuf Technol 60(1):149–152
21. Mori M, Fujishima M, Inamasu Y, Oda Y (2011) A study on energy efficiency improvement for machine tools. CIRP Ann Manuf Technol 60(1):145–148
22. Kant G, Sangwan KS (2014) Prediction and optimization of machining parameters for minimizing power consumption and surface roughness in machining. J Clean Prod 83:151–164
23. Wang Q, Liu F, Wang X (2014) Multi-objective optimization of machining parameters considering energy consumption. Int J Adv Manuf Technol 71(5-8):1133–1142
24. Li J-G, Lu Y, Zhao H, Li P, Yao Y-X (2014) Optimization of cutting parameters for energy saving. Int J Adv Manuf Technol 70:117–124
25. Li J, Yang X, Ren C, Chen G, Wang Y (2015) Multiobjective optimization of cutting parameters in Ti-6Al-4V milling process using nondominatedsorting genetic algorithm-II. Int J Adv Manuf Technol 76:941–953
26. Camposeco-Negrete C, Najera JDC, Miranda-Valenzuela JC (2015) Optimization of cutting parameters to minimize energy consumption during turning of AISI 1018 steel at constant material removal rate using robust design. Int J Adv Manuf Technol. doi: 10.1007/s00170-015-7679-9
27. Wang X (2007) Machining process manual. China Machine Press, Beijing
28. Tian GD, Chu JW, Liu YM, Ke H, Zhao X, Xu G (2011) Expected energy analysis for industrial process planning problem with fuzzy. Comput Chem Eng 35(12):2905–2912
29. Zhang Y, Ge Y (2015) Method for process planning optimization with energy efficiency consideration. Int J Adv Manuf Technol 77: 2197–2207
30. Yin R, Cao H, Li H, Sutherland JW (2014) A process planning method for reduced carbon emissions. Int J Comput Integr Manuf 27(12):1175–1186
31. Rajemi MF, Mativenga PT, Aramcharoen A (2010) Sustainable machining: selection of optimum turning conditions based on minimum energy considerations. J Clean Prod 18(10 –11):1059–1065
32. Liu S, Liu F, Xie J, Wang QL (2012) Energy forecasting method for CNC machine tool during its working time, Patent application no.201210131766.4, China
33. Kalpakjian S, Schmid SR (2006) Manufacturing engineering and technology: machining. Tsinghua University Press, Beijing
34. Yi Q, Li C, Tang Y, Chen X (2015) Multi-objective parameter optimization of CNC machining for low carbon manufacturing. J Clean Prod 95:256–264