Method for Synthetic Modeling of the Reconfigurable Machine Tools Using Genetic Algorithms

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ABSTRACT

This paper presents a method of synthetic modeling which can be applied by the manufacturing companies in order to rapidly evaluate the production costs, under the technical restrictions imposed by the client requests. Using the proposed approach the company can make an appropriate price quotation for its products and thus establish its profit margin. In the case of manufacturing processes, the key idea is to online model the costs occurring during the machining and consumption of time both in relation to the chips flow. After this, using the genetic algorithms technique, the optimal cutting conditions are determined as well as the minimum cost for the manufacturing task completion, under the restrictions imposed by the technical specifications and by the negotiation process. The minimum cost is considered to be a reference against which the price quotation is made in accordance with the commercial policy of the company. Using the proposed approach the company can set a price for a product and thus establish its profit margin.

KEYWORDS: costs, manufacturing, RMT, price quotation, productivity, genetic algorithms.

1. Introduction

Nowadays, the quotation process is a critical task which can determine the success of any company in the market environment. The person who elaborates a price quotation or who negotiates a contract needs to be an expert in order to correctly evaluate the cost required such as to fulfill the contract conditions. For the manufacturing companies the quotation process is more difficult because the manufacturing costs can vary in wide ranges. Also the delivery time has a great influence over the production costs. The negotiator needs to have a tool which can predict the manufacturing costs in order to establish the price in such a manner that would not be too low or to high. If the price is too low the company will work in to the disadvantage of the company, while if the price is set too high than the contract may endangered.

Some authors realized that the cost estimation is a difficult task and the construction of a mathematical model is not an easy challenge because the interrelationships between the cost and other product features. Jahna-Shahi et al. (2001) [1] investigated the fuzzy logic techniques in order to estimate de production cost and time, while others [2], [3], used artificial neural network (ANN) and others regression models [4], [5].

2. Problem Formulation

In the case of reconfigurable machine tools, which tipically are used to machine small batches, development of price commercial quatation is a frequent and difficult task because: i) the geometric features, the material and quality features for the products required by the market change frequently and widely, ii) the behaviour of machine tools are changing frequently because of the reconfiguration stages required in order to obtain the product requested by the market; iii) the time available for the development of the price quotation is very short because the negotiation is always very fast (sometimes, the price quotation is made during a conversation), iv) the commercial environment of the market and the technical environment of the workshop are very complex.

On the other hand, the development of the commercial offers is an important operation on account of the machine tool economic performance in terms of its responsiveness.

Based on the above mentioned we consider that the requirements generated by the frequency, difficulty and importance of the operation of making an offer can be satisfied if a commercial synthetic model of the reconfigurable machine tools is built.

By definition, this model describes the connection between assigning a task for the machine tool and the level of all consumption required in order to complete that task.

The person who negotiates with the client is to provide as input to the model, the product characteristics and the business conditions imposed by the client and to obtain as an output the required consumption. Then, by adding to this information, elements concerning commercial policy obtained from the management department, the person who negotiates can easily develop the associated product price quotation.

In this paper, we propose a method for the commercial synthetic modeling of the reconfigurable machine tools and prove that it can be applied practically, in the case of tasks where cutting occurs, such tasks as turning, milling, drilling and grinding where the process of cutting occurs. The resulted model will be a synthetic one because its variables have been selected selected in order to be as synthetic as possible in order to reflect the essential aspects of technical, economic and commercial processes, which occur during manufacturing of the product ordered by the customer. The synthetic form of the model is suitable not only for the activity of signing commercial contracts but also for managerial work related to the execution of such contracts.

On the other hand, values of some vriables of the synthetic model are considered as constants for analytical models are used for the development of the part-program corresponding to the machining of the required product.

3. Problem Solution

3.1. Expenditure on-machine monitoring

The proposed method consists in machine monitoring of the expenditures and the time required for fulfilling the manufacturing task followed by combining it with the manufacturing task synthetic characteristics.

The considered expenditures are the direct and indirect costs corresponding to the tool cost, the machine tool amortization, the energy consumption cost, the detached material cost, the labor cost and other costs considered to be constant.

a. Costs

The specific cost is defined as:

$$c = \frac{C_t}{V}\left[Euro / dm^3\right] \quad (1)$$

where C_t represents the sum of all production expenditures, in Euro, while V represents the volume in dm^3 for the material to be detached from the workpiece.

The labor specific cost is defined as follows:

$$c_m = \left(\tau_{a+}\tau_b + \frac{\tau_{sr}}{V_s}\right) \cdot c_\tau \quad (2)$$

where: τ_a – is the auxiliary time relative to the amount of material removed from the workpiece in minutes per dm_3,

τ_b – is the time required to machine a workpiece surface relative to the amount of material removed from the workpiece in minutes per dm^3,

τ_{sr} – is the time required to change and set the tool, after this tool is worn and is expressed in minutes,

c_τ – represents the expenditures made in order to use for a minute the working place,

V_s – the volume of material which can be detached from the workpiece until the tool has been worn out.

The time required for detaching a dm^3 of workpiece material can be expressed as:

$$\tau_b = \frac{1000}{v \cdot s \cdot t}\,[\text{min/dm}^3] \quad (3)$$

The volume of workpiece material which can be detached until the tool has been worn out can be expressed using the relation:

$$V_s = \frac{v \cdot s \cdot t \cdot T}{1000}\,[\text{dm}^3] \quad (4)$$

where T is the tool durability expressed using the Taylor relation:

$$T = \frac{C^{\frac{1}{m}}}{v^{\frac{1}{m}} \cdot s^{\frac{x}{m}} \cdot t^{\frac{y}{m}}}\,[\text{min}] \quad (5)$$

The constants *C, m, x and y* are related to the tool and workpiece materials.

The costs of the tool is expressed as:

$$C_s = \frac{C_{as} + C_{es}}{N}\,[\text{Euro}] \quad (6)$$

where: C_{as} – is the acquisition cost of the tool expressed in Euro;

C_{es} – is the operating cost of the tool expressed in Euro;

N – number of cutting edges corresponding to insert the removable tool which is used for machining.

The cost to use the tool for detaching a dm^3 of workpiece material is:

$$c_s = \frac{1000 \cdot C_s}{T \cdot v \cdot s \cdot t}\,[\text{Euro/dm}^3] \quad (7)$$

The energy consumption for detaching a dm3 of material depends on the energetic characteristics of the machining system and on the volumetric flow of chips.

$$k_w = \frac{1000 \cdot P}{v \cdot s \cdot t \cdot 60} \text{ [Kwh/dm}^3\text{]} \quad (8)$$

where: P – is the power absorbed by the spindle motor.

The cos of energy consumed for detaching a dm^3 material is:

$$c_w = k \cdot P_{kwh} \quad (9)$$

where P_{kwh} is the price of Kwh expressed in Euro.

Let’s consider that the machine tool life depends on the intensity of the cutting process in a relationship similar to Taylor relationship:

$$T_m = \frac{K_m}{v^{\alpha} \cdot s^{\beta} \cdot t^{\gamma}} \text{ [min]} \quad (10)$$

where: α, β, γ, K_m are constants specific to the machine tool.

The specific cost of depreciation of the machine tools is given by:

$$c_m = \frac{1000 \cdot P_m}{v \cdot s \cdot t \cdot T_m} = \frac{P_m}{K_m} \cdot v^{\alpha-1} \cdot s^{\beta-1} \cdot t^{\gamma-1} \quad (11)$$

where P_m – is the purchase price of the machine tool, expressed in Euro.

The cost of the detached material is c_{mat}. The constant expenditure is in relation to the amount of material removed is considered c_c.

By combining the preceding relations we get the total cost:

$$c = \left(\tau_a + \frac{1000}{v \cdot s \cdot t} + \frac{1000 \cdot \tau_{sr} \cdot v^{\frac{1}{m}-1} \cdot s^{\frac{x}{m}-1} \cdot t^{\frac{y}{m}-1}}{C^{\frac{1}{m}}} \right) c_{\tau} +$$

$$\frac{1000 \cdot C_s \cdot v^{\frac{1}{m}-1} \cdot s^{\frac{x}{m}-1} \cdot t^{\frac{y}{m}-1}}{C^{\frac{1}{m}}} + \frac{1000 \cdot P \cdot P_{kwh}}{60 \cdot v \cdot s \cdot t} +$$

$$+ \frac{1000 \cdot P_m}{K_m} \cdot v^{\alpha-1} \cdot s^{\beta-1} \cdot t^{\gamma-1} + c_{mat} + c_c \quad (12)$$

b. Productivity

The productivity is defined as the time nedeed for removing a dm^3 of material and is expressed in minutes per dm^3.

$$\tau = \tau_a + \frac{1000}{v \cdot s \cdot t} + \frac{1000 \cdot \tau_{sr} \cdot v^{\frac{1}{m}-1} \cdot s^{\frac{x}{m}-1} \cdot t^{\frac{y}{m}-1}}{C^{\frac{1}{m}}} \quad (13)$$

3.2. Proposed method

According to this method the model input variables are the characteristics of the manufacturing task, while the model output variables are the cost and the task duration. The model parameters are considered the workpiece geometry, the workpiece material, the surface quality and the delivery time (Figure 1).

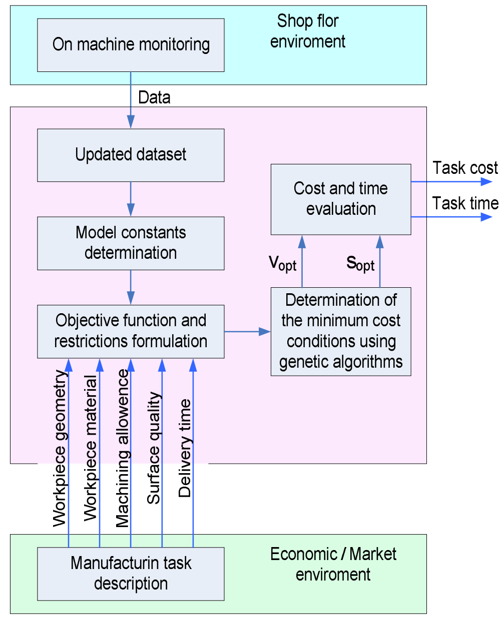

Fig. 1. *Proposed control architecture*

In particular, in the case of a machining task the model inputs are the area of the machined surface, the thickness of the removed material layer.

By monitoring the machine tools during the machining of different workpieces the values of the model constants have been determined. Once the model parameters and the constant values are determined, this will act as an objective function for an optimisation problem in this form:

$$\min \ c(v,s) \quad (14)$$

under the restrictions:

$s < s_i$ – in order to obtain the imposed surface quality;

$\tau < \tau_{min}$ – in order to comply with the time imposed by the client.

3.2. Simulation and experiments

In order to validate the proposed method, the numerical simulation were carried out. A simple turning process for a cylindrical surface was considered. The values of the model constants were determined both based on technical specifications and based on physical experiments. In practice, these simulations cosisted in determination of the cost and the time associated with turning operations.

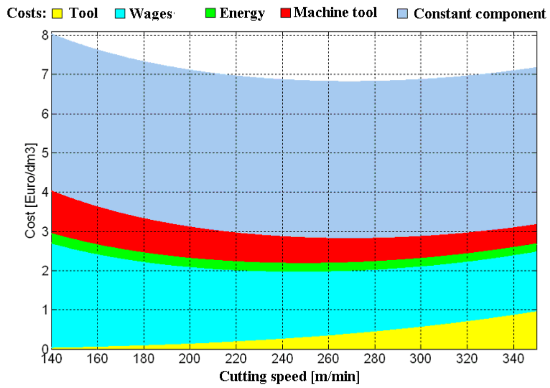

Fig. 2. *Cost components (simulation)*

In Figure 2, the specific cost variation for each cost component is presented. It is noted that for the current level of wages in Romania, the share of wages is significant. Component due tool costs are not very important because of the low tool costs

The component corresponding to the energy cost is not high and its values decrease with increasing the cutting speed. In order to compute this component, experimental data shown in Figure 3 was used. A similar behaviour is remarked for the costs reffering to the machine tool amortization. The total specific costs record a minimum amount of 6.8 Euro/dm^3 for which the cutting speed V_{opt} was of 270 m/min. The optimum value of the cutting speed was also determined using genetic algorithms and was confirmed using exhaustive numerical computation.

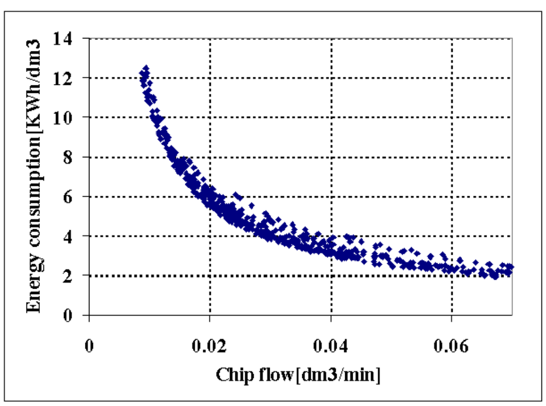

Fig. 3. *Specific energy consumption for a turning operation (experimental data)*

4. Conclusions

This research leads to the following conclusions:

- the proposed method for the synthetic modeling of the reconfigurable machine tools allows for the easy evaluation of the expenditure and time corresponding to a specific machining task;
- the only difficulty to overcome is the need for an on-line knowledge management system which can be achieved by extending the functions of the machine tool control system;
- in contrast to the current situation, the proposed method provides an assessement of the cost and time instead of fixed values of these variables;
- the optimal solution is a reference for the negotiation, because it represents a lower limit below which a price can drop. In this way the company can avoid situations in which the contracts costs can never be compensated for.

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