Proceedings of the 15th International Conference on Manufacturing Systems – ICMaS
Published by Editura Academiei Române, ISSN 1842-3183

"Politehnica" University of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania, 26–27 October, 2006

ECONOMICAL ISSUES REGARDING THE CNC TURNING

Alexandru CĂREAN, Mariana CĂREAN

Abstract: *In order to obtain competitive products and to respond quickly to the changing market demands, the companies must design more technologies in less time. This paper presents an automated method of determining the parameters describing some aspects about economical assessment of machining on CNC lathes. These parameters are: effective time of the cutting, rapid non-cutting time, machining cost, metal removal rate, cutting power and consumed energy.*

Key words: *CNC turning, CAM, economical cutting, optimization, machining cost.*

1. PROBLEM DESCRIPTION

The present market demands a big diversity of products, in small quantities. These demands can be achieved by designing more technologies. The weight of costs regarding the technological design in the total production cost increases. Therefore, the technological design departments are interested to obtain software for the automated generation of the technologies. Designing the technologies, in this case the NC programs is an important part of the manufacturing system and plays a major role in determining the general efficiency of the manufacturing.

The companies must be able to react rapidly, responding quickly to the new products offered on the market, by transforming their own products, in order to obtain competitive products.

Within an economy based on a free market, where competitive products are desired, every machining process must be evaluated from several points of view. Some of the possible criteria are from the point of view of machining time and cost, but also from the point of view of those aspects connected to the energy resources implied in the process. Such aspects are much easier to accomplish when using CNC machine tool. Nowadays, it is considered that the optimization of the NC program in order to increase the efficiency of the machining process has an important impact in the competitive manufacturing strategy [2].

2. DETERMINING THE ECONOMICAL PARAMETERS OF CNC TURNING

Within this research, the machining process on CNC lathes is obtained by using computer aided design.

The NC program is obtained by using "GENER" program that is a CAM system [3, 4, 5, 6]. It can be used not only for determining automatically the NC optimum program at turning, but also for obtaining the following results (which are the object of this paper):

- the effective time;
- rapid movements time;
- the cost of the machining;
- the metal removal rate;
- the cutting power;
- the consumed energy.

We must mention that the NC program, generated by using "GENER" program for the rough turning is optimized by taking into account the minimum path criteria.

The cutting parameters used at roughing and finishing phases are the optimum parameters obtained by taking into account the minimum machining cost criteria.

In order to determine automatically the effective time of cutting and the rapid movements time of an operation on a CNC lathe, a program has been written in Delphi 3.0. It is able to read line by line the NC program and calculates the time for each movement of the tool. This program can be run separately when the NC program is created by manual programming or can be included in "GENER" program.

The active movements of the tool when working with a cutting feed can be assigned with G01, on a longitudinal, transverse, or slope direction, or with G02/G03, on circular path. The non-cutting movements of the tool with G00 are all linear.

The relation (1) determines the effective time of a tool movement in the program line N(j):

$$\tau_{bj} = \frac{\pi \cdot l_j \cdot D_j}{1000 \cdot v \cdot s}, \tag{1}$$

where: l_j – the length of the tool path at the NC block number j [mm]; D_j – medium diameter of the path [mm].

When moving with the cutting feed G01, as shown in Fig. 1, the relation (1) becomes:

$$\tau_{bj} = \frac{\pi \cdot \sqrt{(X_j - X_{j-1})^2 + (Z_j - Z_{j-1})^2}}{1000 \cdot v \cdot s} \cdot (X_j + X_{j-1}) \tag{2}$$

where: X_j, Z_j – coordinates of the final point of the path, X_{j-1}, Z_{j-1} – coordinates of the initial point of the path.

When moving with G02 or G03, the tool path is a circle arch, whose length can be determined by using the following relation (3), accordingly to Fig. 2.

$$L_{AB} = \frac{\pi \cdot R}{90} \cdot \arcsin \frac{L_{AB}}{2 \cdot R}, \tag{3}$$

where X_{cj}, Z_{cj} – coordinates of the center or the circle arch (they are the content of I and K addresses in the NC program).

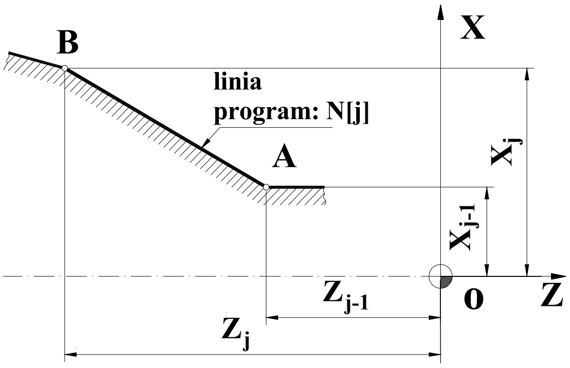

Fig. 1. Determining the length of the path for a line of the NC program assigned with G01.

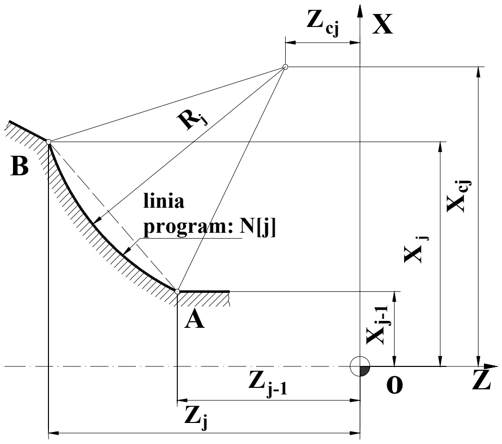

Fig. 2. Determining the length of the path for a line of the NC program assigned with G02/G03.

The final relation for calculating the effective cutting time when the tool path is a part of a circle (G02 or G03, as in Fig. 2), has the following form:

$$\tau_{bj} = \frac{\pi^2 \cdot \sqrt{(X_{cj} - X_j)^2 + (Z_{cj} - Z_j)^2}}{90000 \cdot v \cdot s} \cdot (X_j + X_{j-1}) \cdot \cdot \arcsin \sqrt{\frac{1}{2} \cdot \frac{(X_j - X_{j-1})^2 + (Z_j - Z_{j-1})^2}{(X_{cj} - X_j)^2 + (Z_{cj} - Z_j)^2}}. \tag{4}$$

A relation which is similar to (1) is used to obtain the time of a rapid non-cutting movement of the tool – G01.

$$\tau_{c-r\,j} = \frac{\sqrt{(X_j - X_{j-1})^2 + (Z_j - Z_{j-1})^2}}{v_{f-r}}, \tag{5}$$

where v_{f-r} is rapid feed.

The machining cost C_p corresponding to the machining of a workpiece can be expressed a follows:

$$C_P = C_{pe} + C_{sc} + C_{np} \tag{6}$$

where: C_{pe} – cost of the effective machining [RON/piece]; C_{sc} – cost of the tool use [RON/piece]; C_{np} – unproductive cost [RON/piece].

The cost of the effective machining C_{pe} is given by the following relation:

$$C_{pe} = C_1 \cdot \tau_b, \tag{7}$$

where: C_1 – expenses with labor and overheads [RON/min].

The cost of the tool use when machining with cutting inserts is:

$$C_{sc} = \left(\tau_s \cdot C_1 + C_{ms}\right) \cdot \frac{\tau_b}{T} \tag{8}$$

where: τ_s – time of replacing the cutting edge [min]; T – tool life [min]; C_{ms} – cost of the cutting edge [RON/edge].

The unproductive cost is given by the relation:

$$C_{np} = C_1 \cdot \tau_n, \tag{9}$$

where: τ_n – unproductive time.

The unproductive cost C_{np} depends on the implied times which generate costs and is a constant, therefore it can be left out from the optimization procedure of the cutting parameters, but it can be considered when determining the total costs.

The machining cost C_p can be determined for the whole operation (rough cutting and finishing) on the basis of the previous calculated times. It can be expressed as follows:

$$C_p = C_{\deg} + C_{fin}, \tag{10}$$

where: $C_{\deg}$ – the roughing machining cost; C_{fin} – the finishing machining cost.

The final relation for total machining cost is:

$$\begin{aligned} C_t = {} & C_1 \cdot \left(\sum_{i=1}^{n} \frac{\pi \cdot d_{id} \cdot l_{id}}{1000 \cdot v_d \cdot s_d} + \sum_{j=1}^{m} \frac{\pi \cdot d_{jf} \cdot l_{jf}}{1000 \cdot v_f \cdot s_f} \right) + \\ & + C_1 \cdot \left(\tau_{sd} \cdot \sum_{i=1}^{n} \frac{\pi \cdot d_{id} \cdot l_{id} \cdot v_d^{\frac{1}{m}-1} \cdot s_d^{\frac{y_v}{m}-1} \cdot t_d^{\frac{x_v}{m}}}{1000 \cdot C_{vd}^{\frac{1}{m}}} + \tau_{sf} \cdot \sum_{j=1}^{m} \frac{\pi \cdot d_{jf} \cdot l_{jf} \cdot v^{\frac{1}{m}-1} \cdot s_f^{\frac{y_v}{m}-1} \cdot t_f^{\frac{x_v}{m}}}{1000 \cdot C_{vf}^{\frac{1}{m}}} \right) + \\ & + C_{msd} \cdot \sum_{i=1}^{n} \frac{\pi \cdot d_{id} \cdot l_{id} \cdot v_d^{\frac{1}{m}-1} \cdot s_d^{\frac{y_v}{m}-1} \cdot t_d^{\frac{x_v}{m}}}{1000 \cdot C_{vd}^{\frac{1}{m}}} + \\ & + C_{msf} \cdot \sum_{j=1}^{m} \frac{\pi \cdot d_{jf} \cdot l_{jf} \cdot v_f^{\frac{1}{m}-1} \cdot s_f^{\frac{y_v}{m}-1} \cdot t_f^{\frac{x_v}{m}}}{1000 \cdot C_{vf}^{\frac{1}{m}}}, \end{aligned} \tag{11}$$

where: t_d, s_d, and v_d – depth of cutting, feed per revolution and cutting speed at rough; t_f, s_f, and v_f - depth of cutting, feed per revolution and cutting speed finishing turning; τ_{sd} and τ_{sf} – time of replacing the cutting edge at rough turning and finishing [min]; C_{msd} and C_{msf} – cost of the cutting edge at rough turning and finishing [RON/edge].

The metal removal rate can be determined by using the following relation [8]:

$$Q = t \cdot s \cdot v \quad [\text{cm}^3/\text{min}]. \tag{12}$$

The cutting power is calculated as follows [8]:

$$P = \frac{v \cdot s \cdot t \cdot k_{c0,4}}{60 \cdot 10^3} \quad [\text{kW}], \tag{13}$$

where: $k_{c0,4}$ – specific cutting force for chip thickness 0,4 mm.

The cutting consumed energy is obtained as follows:

$$W = P \cdot \tau_b \quad [\text{kW/h}]. \qquad (14)$$

3. RESULTS

In order to assess the six parameters described in this paper, we consider the testing piece from Fig. 3, which was machined on a SP 250 lathe with CNC H645. We can determine the economical parameters of CNC turning by using "GENER" program, at the same time with the generation of the NC program (Fig. 4).

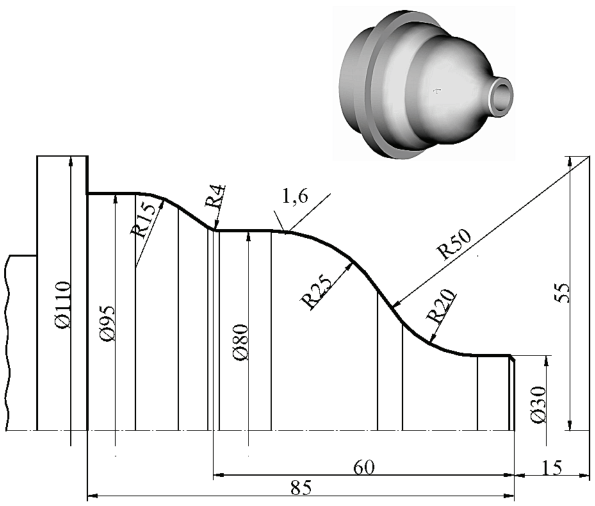

Fig. 3. Testing piece.

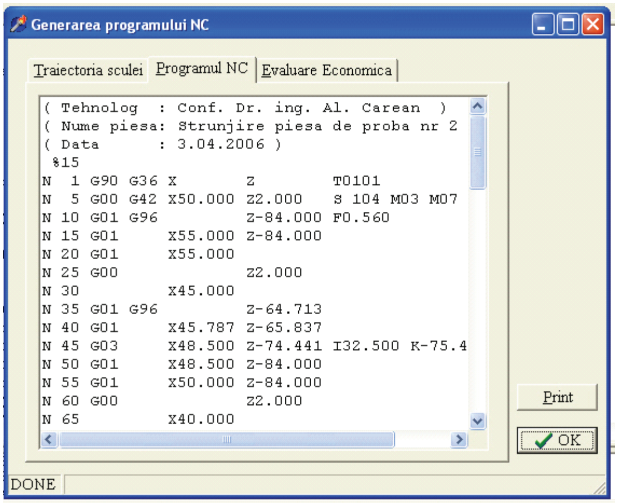

Fig. 4. NC program for a testing piece.

The economical assessment concerns 3 type of cutting inserts materials, namely uncoated cemented carbide P20, TiC – coated cemented carbides and TiN – coated cemented carbide.

The optimum cutting parameters for rough turning and for finishing have been considered for all the three cases.

The optimum cutting parameters for rough turning with the uncoated cemented carbide P20 inserts are $t_d = 5$ mm, $s_d = 0.562$ mm/rot and $v_d = 60$ m/min.

The optimum cutting parameters for rough turning with TiC – coated cemented carbide inserts are $t_d = 5$ mm, $s_d = 0.562$ mm/rot and $v_d = 104$ m/min.

The optimum cutting parameters for rough turning with TiN – coated cemented carbide inserts are $t_d = 5$ mm, $s_d = 0.562$ mm/rot and $v_d = 118$ m/min.

The optimum cutting parameters for finish turning with the uncoated cemented carbide P20 inserts are $t_f = 0.5$ mm, $s_f = 0.16$ mm/rot and $v_f = 123$ m/min.

The optimum cutting parameters for finish turning with TiC – coated cemented carbide inserts are $t_f = 0.5$ mm, $s_f = 0.16$ mm/rot and $v_f = 312$ m/min.

The optimum cutting parameters for finish turning with TiN – coated cemented carbide inserts are $t_f = 0.5$ mm, $s_f = 0.16$ mm/rot and $v_f = 376$ m/min.

Figs. 5, 6 and 7 illustrate the economical assessment (the effective time, rapid movement time, the cost of the machining, the metal removal rate, the cutting power, and the consumed energy) for the 3 type of cutting insert materials.

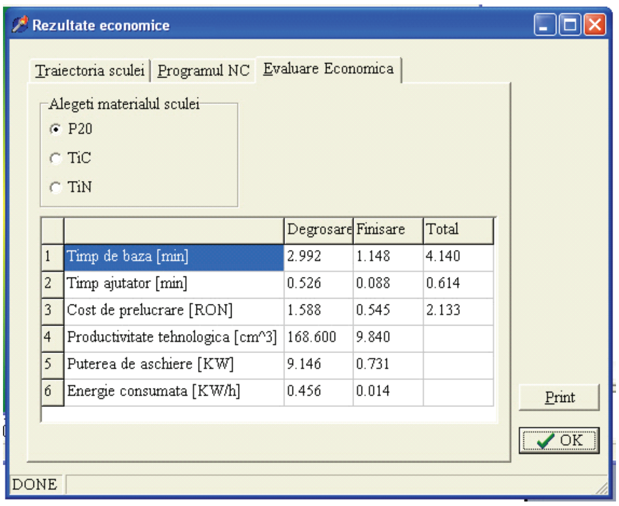

Fig. 5. The economical assessment when turning with the uncoated cemented carbide P20 inserts.

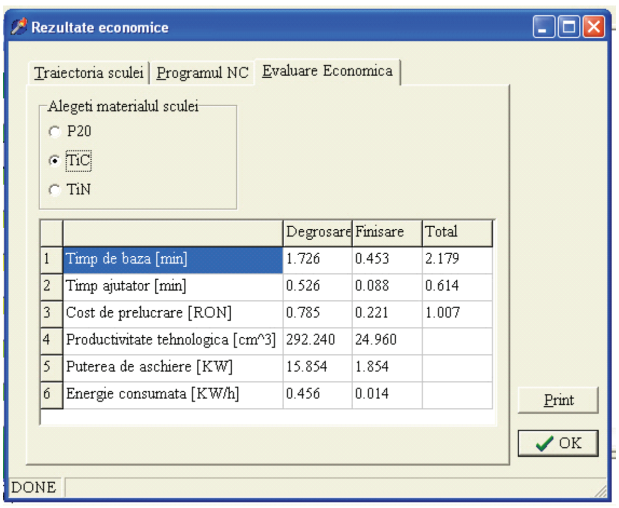

Fig. 6. The economical assessment when turning with the TiC-coated cemented carbide inserts.

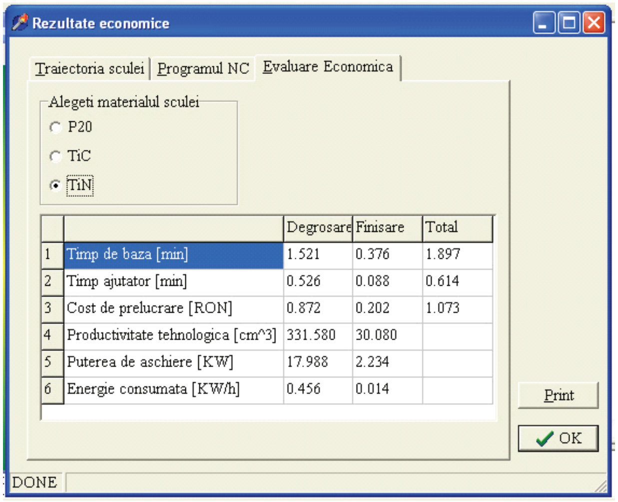

Fig. 7. The economical assessment when turning with the TiN - coated cemented carbide inserts.

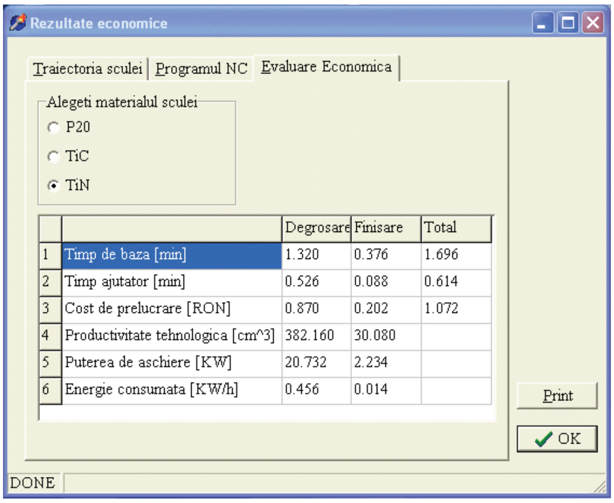

Fig. 8. The economical assessment when turning with the TiN - coated cemented carbide inserts without the power constrained.

Fig. 7 shows that the cutting power is at the limit of motor power because of the imposed constraint ($P = 8$ kW) and the optimum corresponding speed is $v = 118$ m/min. Without the power constraint, the optimum speed would have been $v = 136$ m/min, demanding a power $P = 20{,}732$ kW (Fig. 8).

Even if the price of the coated cutting inserts are bigger than those of the uncoated inserts, the machining costs with the coated cutting inserts are smaller, when using the optimum corresponding parameters.

4. CONCLUSIONS

The economical assessment of the machining processes on CNC machine-tools is very important because it creates an image about the efficiency of the machining process. Specialized software like "GENER" enables to calculate parameters as the effective time of machining, rapid movement time, the cost of the machining, the metal removal rate, the cutting power, the consumed energy, thus giving valuable information about machining efficiency.

REFERENCES

[1] Balic, J. (1999). *Contribution to Integrated Manufacturing*, DAAM Publishing Series-Manufacturing Technology, Viena.

[2] Blount, G. N. @ Rahbary, M. A. (1998). *Computer Assisted Machine Tool Part-Program Optimization*, Computer Int. Manuf. Systems, vol. 8, no. 1, pp. 41–49.

[3] Cărean, Al. (2000). *Contribuții la optimizarea proceselor de lucru în cazul prelucrărilor pe strunguri CNC*, Ph.D. Thesis, Universitatea Tehnică Cluj-Napoca.

[4] Cărean, Al. (2002). *Tehnologii de prelucrare cu CNC*, Editura Dacia, ISBN 973-35-1344-X, Cluj-Napoca.

[5] Cărean, Al., Cărean, M., Borzan, M. (2004). *Analysis of the Opportunities of Minimizing the Cutting Tool Path at CNC Machining*, Romanian Journal of Technical Sciences, Proceedings of the International Conference of Manufacturing Systems ICMaS 2004, Editura Academiei Române, ISSN 0035-4074 , pp. 563–566.

[6] Cărean, Al., Cărean, M., Borzan, M. (2005). *Studies about Determining the Tool Path at Rough Turning on CNC Lathes*, Annals of MTeM for 2005 & Proceedings of the 7th International MTeM Symposium, Cluj-Napoca, pp. 137–140.

[7] Miguel, P.A.C., Coppini, N. L. (1996). *Cost per Piece Determination in Machining Process: An Alternative Approach*, Int. J. of M. T. & Man., vol. 36, no. 8, pp. 939–946.

[8] *** (2006). *Cutting tools from Sandvik Coromant, Main catalogue*, Turning – Milling – Drilling – Boring – Toolholding, Elanders, Sweden.

Authors:

Associate Professor Dr. Eng. Alexandru CĂREAN, T. U Cluj-Napoca, B-dul Muncii, 103-105, 3400 Cluj-Napoca, Manufacturing Department,
E-mail: `alexandru.carean@tcm.utcluj.ro`

Prof. Dr. Eng. Mariana CĂREAN, T. U. Cluj-Napoca, B-dul Muncii, 103-105, 3400 Cluj-Napoca, Management and Systems Engineering Department,
E-mail: `mariana.carean@mis.utcluj.ro`