Increase Productivity and Cost Optimization in CNC Manufacturing

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Abstract. The advantage of the technological assisted design consists in easy modification of the machining technologies for obtaining machine alternation, tool changing, working parameters variation or the modification of loads to which the tools are subjected. By determining tool movement inside machining and by using tool related moving speeds needed for both positioning and manufacturing we are able to compute the required machining time for each component of the machining operation in progress. The present study describes a cost optimization model for machining operations which uses the following components: machine and its operator related cost, set-up and adjustment, unproductive costs (idle state), direct and indirect costs. By using manufacturing technologies assisted design procedures we may obtain various variants for the technological model by modifying the machining strategy, tooling, working regimes or the machine-tool that are used. Simulating those variants allows us to compare and establish the optimal manufacturing variant as well as the most productive one.

1. Introduction.
CNC mechanical machining performance requires special adapted methods for designing technologies and data management inside manufacturing industries. Finding optimum variants of machining calls for advanced knowledge in terms of working times and their costs. There are various computing mathematical relations given for the determination of the working times for simple machining if the machining related parameters are well known. But for mechanical parts which have an intricate geometry the working times are very hard to compute manually thus making their findings only possible by CAM means. Those software allow, achieve and simulate manufacturing processes in order to check the correctness of the project before its implementation.

One of the advantages of the assisted design of the machining technologies is that it allows the simulation of the working environment.

The simulation of an operation or the entire machining process consists of:
- Determination of the tool's trajectory and collision avoidance between the tool and the blank, avoidance of impacting the machine or its devices during manufacturing;
- Determination of the machining time for each operation as well as for the entire part. For machining operation's simple components there are mathematical relations which give us
exact operation times but for most of the machining the sheer number of the movements and components is way bigger and difficult to model. Using simulation procedures we can determine the total number of movements and their components which gives us exact or very close to reality working times specific values and those of auxiliary movements.

The simulation process provides important data regarding the determination of the machine's capabilities, the determination of the machining time and cost and the establishment of the optimal working variant.

Conception of the NC driven machining processes leads most of the times to different solicitations of the tools that are used inside manufacturing operations. There are differences between tools that are used for roughing as opposed to finishing or solicitation related differences appear depending on the machined surfaces geometries. Different machining times for various tools lead to different values for the expected tool life. For example, by expressing this parameter in time dependent units or in the number of the machined parts we get different estimated times for the CNC setup. But because setup times are usually higher they may influence the overall productivity of the manufacturing process as well as the machining related cost. The results obtained up till now by the authors led them to the conclusion that there is room for improvement in terms of optimization of the CNC machines adjustment times by modifying the values of the working regimes related parameters.

2. CAM model analyses and their significance in identifying the machining cost components.

The advantage of the technological assisted design consists among others in being able to easily modify the machining technology in order to obtain several machining variants which will allow the achievement of some practical requirements such as machine alternation, tool changing, working parameters variation, the modification of loads to which the tools are subjected, etc.

By adjusting the machining related parameters for different working regimes we may determine working time values as well as the auxiliary times for each tool and programmed NC machining operation which lead automatically to tool life expectancy related to the number of the machined parts. This case is especially useful when dealing with intense working regimes which use reduced working times and the related working regimes parameters also diminished in case of tools that are hardly solicited. By simulating manufacturing processes we can determine correspondent adjustment times.

One of the main advantages that make manufacturing processes simulation so necessary is tool trajectory generation which includes imposed machining movements, tool withdrawal necessary for new crossings as well as tool change. By determining tool movement inside machining and by using tool related moving speeds needed for both positioning and manufacturing we are able to compute the required machining time for each component of the machining operation in progress. After setting up the CNC we add the required times needed for starting and stopping the machine and tool change related times thus by means of simulation being able to compute the total machining time for a given part.

The above mentioned elements are obtained by means of simulation procedures provided by NX CAM software which emphasis the importance of simulation in terms of geometrical verifications and a good knowledge of the CNC's programming productivity. There have been generated CAM models for different parts using NX CAM. For each distinct part there multiple simulation sessions were carried out by shifting CNCs, tools, machining variables or the strategy regarding the removal of the working related additions [2], [6].

The simulations help at verifying the CAM machining model, its precision and quality and give us data regarding times for each machining apart as well as for the entire process.

An example for a machining model is that presented in fig. 1.

At this moment we feel that the simulation of manufacturing on machine-tool devices driven by NC must be completed with a distinct module which may allow exact machining costs preview.

Machining simulation gave us in this case complete data regarding the precision, productivity and manufacturing costs offering criteria for the optimization of the manufacturing processes on NC driven machine-tools devices.
3. Proposed algorithm for the determination of the machining cost.
The CNC machining cost depends on a multitude of elements such as CNC equipment cost, of the tools that are to be used in the process, the maneuvering and surveillance of the machining system, the quantity and cost of consumables, energy cost, etc.

The influence of cutting tools over manufacturing is a known issue in the industry. This study proposes a computational model which depends upon a newly introduced inside the manufacturing process of a cutting tool as shown in [4], [5], and [7]. This model uses the cutting time related cost as well as the one of the tool and the fine-tuning of the CNC equipment.

The analysis of spending share related to electrical energy consumption [1] uses a cost dependent computational model based on manufacturing experiments. The model is accompanied by an industry extracted particular case which estimates resulted savings and costs. The authors demonstrate that there are no electric energy consumption savings because energy related cost in CNC machining are already low but highlighting the fact that substantial savings are recorded in case of a high production volume by means of machining parameters optimization.

The present study describes a cost model for machining operations which uses the following components: machine and its operator related cost, set-up and adjustment, unproductive costs (idle state), direct and indirect cost imposed by the manufacturing process.

According to [1], [3], and [8] cost components related to energy consumption rates may be grouped as follows:

- Direct cost with the energy that has been consumed during the manufacturing process;
- Indirect cost regarding the supplementary energy consumed during the working process such as general illumination, heating, etc.;
• External cost dependent on the environment, or given by advertising and commercial presentation of the product.

The authors present cost components and their conclusion is that 38.7% are represented by direct cost, 34.7% is tool related cost and the energy related cost is low peaking a 0.45% from the overall. We thus estimate that energy cost isn't high enough to arouse any special interest or to consider it as a radical saving component inside CNC manufacturing processes [1]. Nevertheless savings can be made at the real cost level by decreasing working times. In case of a high production volume by optimizing the machining parameters we can safely assume that energy related savings and costs may become important factors.

The proposed algorithm ensures the cost computation per one part.

The total machining cost is composed from blank related cost, CNC equipment related expenses, and its operator related cost or the tools that are used (1):

$$ C = C_{\text{blank}} + C_{\text{machine}} + C_{\text{operation}} + C_{\text{tool}} $$

The cost related to the machine is represented by the electrical energy amortization one consumed during a single part manufacturing (2):

$$ C_{\text{machine}} = \frac{P_{\text{equipment aquisition}}}{t_{\text{amortization}} \times t_{\text{working time}}} \times t_{\text{program}} + P_{\text{electric energy}} \times t_{\text{program}} \times P_{\text{per \_kW}} $$

Where $P$ signifies "price" and $t$ "time".

The cost per operation is represented by the operator remuneration and machine human adjuster (3):

$$ C_{\text{operation}} = (t_{\text{program}} + f \times t_{\text{program}}) \times \frac{\text{salary}}{\text{min}} $$

Where $f$ stands for a fraction of the $t_{\text{program}}$ needed for the adjustments and the programming activities.

The last component of the cost computational algorithm (4) is represented by the tools that are used to machine the part and results as a sum of the tooling cutting heads related cost with regards of the manufacturing time for each tool, tool durability and the number of cutting edges it has.

$$ C_{\text{tool}} = C_{\text{cutting head}} \times \frac{t_{\text{tool}}}{T_{\text{economic}} \times N_{\text{no \_of \_cutting \_edges}}} $$

Where $T_{\text{economic}}$ stands for an economical tool life.

4. Different costs for various CNC machining.

The machining cost computational algorithm was successfully tested in MS Excel. It uses modules in order to determine cost components for each machining operation as well as total cost.

Computing manufacturing steps related cost has been carried out by considering NX CAM program component which resulted as shown in figure 2. For each machining operation we know the manufacturing regime related parameters, the tool code and its location on the machine and the working time.

For each machining it has been determined the cost driven by the cutting tools. By knowing the tool's price, its lifespan and the number of repositioning of the cutting component we have been able to determine the price per minute of each tool based on which we could compute the tool imposed cost per working time for each machining operation.

Based on the total time we can determine machine imposed cost as well as the ones for the operator and electrical energy consumption. The spreadsheet also depicts graphical representations of these costs in order to highlight the significance of cost components which also makes it easier to interpret the simulation results.
The cost driven by the machine-tool uses as reference the machine cost for one minute of utilization. Based on the machine's electrical power we can determine the consumed electrical energy related cost per minute. In order to simplify the computation we appreciate that the consumed electrical power equals the nominal power. In such a situation the value of the electrical energy cost is approximately 1/6th of machine cost, but realistically this ratio has a much smaller value considering either idle state or the fact that finishing requires reduced electrical power.

For the computation of the salary cost for each working minute of the operator we consider both direct and indirect salary related expenses. As results from the shown elements cost computation is being made in Euro's and RON's.

Figure 2. Obtained results using NC machining cost computational algorithm.

The cost per one minute of use of the cutting tool utilizes structural elements from a database for each tool, producer or supplier, data related to the number of cutting edges and facets, tool durability levels and price.

By knowing the tool type and the one of the blank's material we have determined values for the manufacturing regime parameters which helps defining the NX CAM working steps and thus providing machining times.

5. Conclusions.
The simulation of the manufacturing process on NC driven machine-tool equipment’s allows the visualization of the tool's trajectory, the possibility to check the correctness of the machine's programming as well as the avoidance of the cutting tool with the blank, the machine itself or its devices.

The tool movement during machining consists of rapid approaching moves, feeds and rapid withdrawals for which we have to determine the execution times. By summing them up we obtain the required times for each machining operation as well as the total machining time.

The simulation of the manufacturing process that has been approached in the current study has led to the necessity to develop a machining cost computational algorithm. It has been implemented in MS Excel and it uses the following modules in order to identify the necessary costs for the machine-tool equipment: operation, tools, energy and blank material.
For a given part for which we knew its geometry and manufacturing process structure there have been simulated variants characterized by different values for used tool life spans (15 to 45 minutes). Thus we had an increase of the working times and a decrease of cost. Identifying cost components weights such as 42% for the machine-tool, 38% tooling, 12% operation and 8% energy allowed us to propose a strategy for the optimization of cost and machining operation variants.

Analyzing data we saw that the most significant cost component is represented by the CNC machine having an almost 42% weight in the overall process. Very close come the tools used in the process with almost a 38% share. We conclude that by using expensive but performant tools we can assure the quality of manufacturing processes.

The CNC operator salary related cost is about 12% in weight which represents nearly a quarter of the CNC machine cost. That being said we can safely assume that expenses made by four operators cover the acquisition cost of a CNC machine thus explaining why companies focus on a reduced number of highly qualified operators.

The total weight for energy related cost is about 8% but in reality may have smaller shares. When increasing tooling cost we expect a significant decrease of CNC machine related cost, operation cost and energy cost.

Because of the tool lifespan of 15 to 45 minutes, manufacturing regimes are less intense which leads to the possibility of increasing machining times and decreasing productivity. By analyzing data from the diagram it results that by increasing the working time by 32.49% we may achieve an economy up to 10.33% for the manufacturing cost.

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