Energy and cost efficiency in CNC machining

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Abstract

General cost for CNC machining and the associated energy cost are set in the context of making economic and environmental improvements. This creates an incentive for manufacturing companies to investigate the energy efficiency of manufacturing processes. The paper presents a costing model, based on machining experiments. The model is accompanied with an industry based case to estimate the cost savings. The results show that substantial cost savings with respect to energy efficiency is unlikely, since energy costs in CNC machining comprises a small cost component. However significant cost savings can be achieved if the production output is increased as a consequence from higher material removal rates due to optimised machining parameters.

Keywords:
Cost efficiency, Energy efficiency, CNC machining, Green manufacturing

1 INTRODUCTION

Increasing environmental pressure from government regulations as well as raising customer awareness underlines the importance for companies to improve their environmental performance. Consequently, it is important to raise the knowledge in the industry, how environmental improvements of operations can be achieved cost efficiently so that changing customer demands are met regarding environmental demands as well as ensuring competitive prices.

It is an accepted practice that companies account the electrical energy cost to the general company over head when calculating manufacturing cost. This means that they have little knowledge about the actual cost of machining operations regarding energy consumption.

To decrease our society's environmental impact each area in the society must be targeted with appropriate measures. This of course includes the manufacturing industry. CNC machining is one of the fundamental manufacturing technologies. Its main environmental impact is attributed to electrical energy use [1], hence there is a need to understand the machining processes better with respect to energy consumption and company economics so that necessary and cost efficient measures can be taken. The manufacturing industry is in general not very energy intensive, but because of its total size it is a large energy consumer [2]. The electrical energy that is consumed by value adding activities in the manufacturing industry makes up approximately half of the consumption. The other half is required for building heating, light and fans [2].

Energy can account for 4-20% of the life cycle cost for machine tools [3]. In these cases, the operator cost is not included, which in many cases, where the automation level is low, can be the single most important cost component.

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1.1 Paper scope

The paper presents important areas for consideration regarding environmental impacts from CNC machining in relation to manufacturing cost and turnover. *What are the economical drives/motifs for making energy savings in CNC machining?* This question imposes a number of subsequent questions to be answered:

- Can energy savings directly have any real impact on machining costs and thereby prices to customer, i.e. what is the magnitude of cost savings to be made?

- Energy cost is often accounted as general company overhead. Are there good reasons for regarding the energy cost as a variable cost?

- Does future cost on labour and energy change the present situation?

1.2 Cost model description

The foundation for the paper is an extended cost model for machining operations. The traditional machine cost model often used to estimate and to calculate the cost of machining operations including the following cost components:

- Machine tool and labour cost
- Set-up cost
- Idle cost
- Direct tool cost
- Indirect tool cost – tool change cost

However, in order to understand the relation between the aforementioned costs components and the environmental impact from machining operations the model has been

extended to include cost of energy use. These non-traditional cost components are:

- Direct energy cost
- Indirect energy cost
- External cost of environment i.e. carbon dioxide emission cap and trade cost

The cost model is not described in detail here, but the constants used are presented in Table 1. The detail model can be found in Ref. [4]. Labour, energy costs and carbon dioxide emissions are based on EU 27 average. Carbon dioxide emissions are calculated by using calculation method as presented by Ref. [5]. Idle and set-up times are approximations of reasonable and often estimated times. Set-up time include NC programming, loading of tools etc.

1.3 Experimental data

An experimental machining case was used to provide the data for the cost model. A simple cylindrical part of mild carbon steel was straight turned. The total energy consumption of the machine tool and cutting tools' flank wear was measured in a lab setting. A flank wear of 0.8 was used as tool life criterion and the wear was measured after five machined parts. The then measured flank wear was linearly extrapolated in order to find the tool life and related tool costs. Machining was carried out using five different machining strategies regarding feed rate and depth of cut. This generated five different material removal rates, which dictates the number of possible produced parts per time unit, i.e. production rate. Due to the non-linear relation between certain machining parameters and required power, a lower total energy can be achieved with higher material removal rate [6, 7, 8, 9, 10]. The results that the different machining strategies resulted in are presented in Ref. [4], where a more thorough analysis and explanation of experiment are given.

Table 1: Constants used in machining cost model

Constant	Value	Unit	Source
Machine cost	5.2	[€/h]	
Operator cost	40	[€/h]	[11]
Set-up time	60	[min]	
Batch size	100	[pieces]	
Idle time	0.5	[min]	
Tool holder prices	100	[€]	
Tool holder life	400	[nr of inserts]	
Insert price	8	[€]	
Nr of insert edges	6		
Tool change time	1	[min]	
Energy cost	0.1	[€/kWh]	[12]
CES^{TM}	131	[kg CO2/GJ]	[5, 11]
Plant efficiency	34%		[5]
CO_2 cost	15	[€/tonne CO2]	[13]

2 RESULTS

The three cost components related to energy consumption, is very small in comparison to the major cost components. The energy cost is dominated by direct machining energy cost (Figure 1).

Even though the electrical energy cost is small in relation to other machining costs, on a larger scale; it confines a large expenditure for a company and consequently considerable cost savings can be made if more energy efficient machining is facilitated (see section 2.4).

■ Cm = Direct machining cost (machine tool + labor cost)
■ Ci = Idle cost
■ Cs = Set-up cost
■ Cc = Tool changing cost
■ Ct = Tool cost
■ Cde = Direct energy cost
■ CCO2 = Carbon dioxide emission (cap and trade) cost
■ Cie = Indirect energy cost

31,3%
0,9%
2,5%
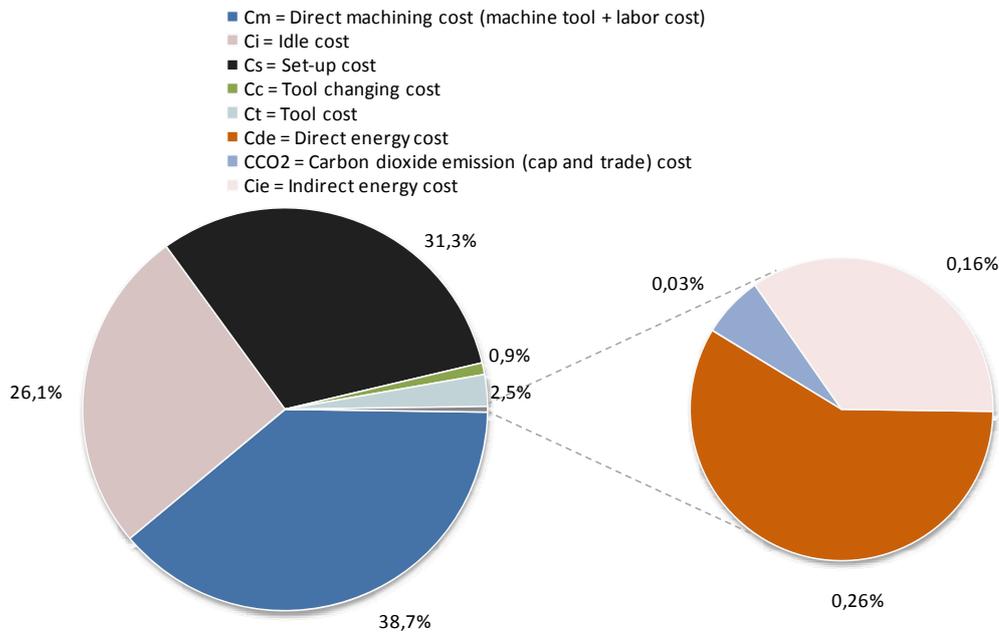26,1%
38,7%

0,03%
0,16%
0,26%

Figure 1: Proportion between cost components for one of the experimental cases. The energy related cost components are shown in the cut out pie chart.

2.1 Total annual energy cost for machining operations

Figure 2 shows the annual electrical energy cost for different machining strategies (using different combinations of feed rates and depth of cut) of one simple part. For the case with higher material removal rates, which generate higher production output, a 200% increase in production rate can be generated by an annual electrical energy consumption increase by only 19% (Case A and E in Figure 2).

Figure 2 illustrate two different options where standby consumption is either included or excluded. For the case as exemplified here with a single shift plant, the standby consumption is considerable. It roughly accounts for half the electrical energy cost. It is in this context, essential if the machines would be switched off, after working hours. However, the cost as such is rather small per machine.

Case D (Figure 2) shows the lowest machining energy cost in relation to production output, which follows a reduced specific cutting energy under the given machining parameters [4]. The total machining cost is on the contrary much higher than the most cost efficient alternatives, which comes from excessive tool wear.
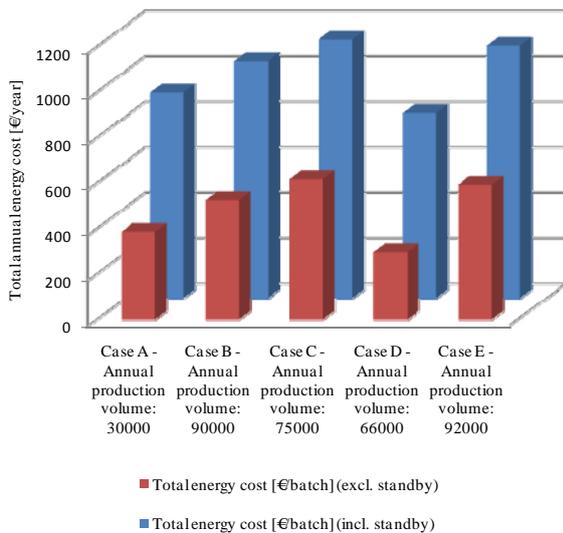

Figure 2: Annual electrical energy cost from one machine tool plotted for different machining parameters. 240 production days at 1 shift annually.

2.2 Energy cost in relation to other machining cost components

Figure 3 shows the energy cost's relative influence on the total machining cost. Depending on the automation level (or operator demand) the energy cost's relative influence varies. Naturally it answers for a larger part when the operator cost decreases, as it does when the automation level increases. The energy cost accounts for between 1-6% of the total machining cost (Figure 3)

2.3 Future forecast in labour and energy cost

Case E in Figure 2 is used for further analysis of the energy cost in relation to the total machining cost. Figure 3 presents the electrical energy cost for machining as the proportion to total machining cost for a present scenario and two future scenarios. The presented future scenarios are for year 2013 where labour costs are linearly extrapolated from historical values (1995-2005) [11], which gives an increase with 20% by 2013. The electrical energy cost is less straight forward and not easy to extrapolate from historical data, since many parameters influence the results, hence two different scenarios are presented here. First a scenario for a linear extrapolation from historical (2005-2008) electricity costs [14] is presented, which gives a electricity price increase of 40% over 5 years. The second scenario presents a more extreme forecast, where the electrical energy cost has tripled [15] (Other machining costs are kept constant, e.g. tool cost, machine cost).

The level of automation is altered for the three scenarios, where the extreme case is for complete automation during machining, thus no operator needed for supervision etc. and the case when one operator is needed at all times for machine operation.
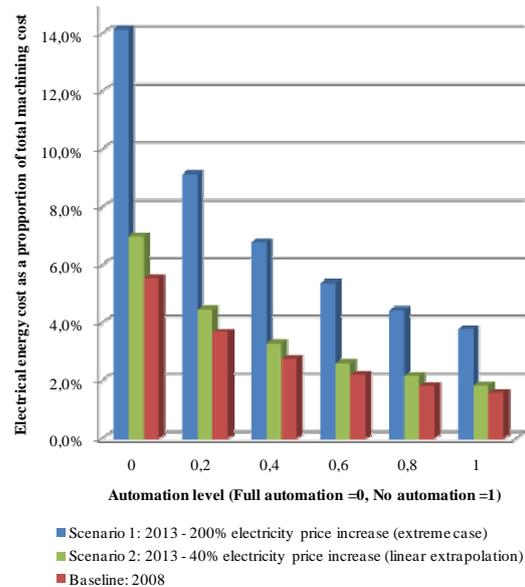

Figure 3: Future development of energy cost in relation to total machining cost (including standby energy). The energy cost's proportion of the total machining cost in a present and future scenario – where the labour cost increase is 20% and energy cost is extrapolated.

As seen in Figure 3, the level of automation has a significant influence on the proportion between the compared cost components. In the extreme case with the highest forecasted energy cost and full automation, the energy cost account for as much as 14% of the total machining cost. However, when the automation is low, the relative importance of energy cost is decreasing. Operator cost is then a dominating cost post.

In scenario 2, where linear extrapolation of electricity cost is used, show that the present situation will be kept, even though a slight increase in energy cost is noticed. The historical trend of increasing level of automation will (as seen in Figure 3) lead to a situation where the electricity cost is growing in importance relative other costs.

2.4 Industrial comparison

In order to relate the calculations made for the cost model above, which was carried out in a lab setting, an industrial example is given to show the validity of the results. A Swedish subcontractor in the general engineering field carries out heavy machining operations and has an annual electric energy consumption of 1.5 GWh. This corresponds to a total cost of 0.14 million euro. The total turnover is 5.5 million euro, hence the energy cost stand for 2% of the company's total turnover. This figure also includes the total cost of cooling, lighting and additional heating for unusually cold days. The company have 10 vertical lathes (spindle power = 60-80 kW) and 3 horizontal boring machine, run in 2 shifts. This means that the energy consumption in the company to a large extent is dedicated to machining operations. Any substantial energy savings must consequently be made in machine operations – methodological or technical. However, since the energy cost for machine operations is only 2% of the turnover, the drive for making energy savings is small. This means that companies must have other or at least complementary motifs or drives for making energy savings.

This shows that the magnitude of the calculated costs and energy consumptions are reasonable, although somewhat lower. This is certainly a consequence from the relatively small machine tool used in the lab experiments, which had a maximum power of 5.5 kW. This generated a energy share of less than 0.5% as compared to 2% for the exemplified company.

In this perspective it is essential to have knowledge about the relation between different machining parameters and their relation upon and machining time and thereby cost parameters. A green machining approach [4, 6] is one possibility, where machining parameters are optimised for increased material removal rate, since this lowers the specific cutting energy. This will have positive influence on cost and energy efficiency.

3 CONCLUSIONS

The paper has highlighted a few interesting areas of cost and energy efficiency for CNC machining:

- The energy prices of today are not high enough to pose any particular need for making radical energy savings for CNC machining. However, real cost savings can be made as a consequence from time savings. If production output can be increased due to optimised machining parameters, cost and energy savings can concurrently follow.

- Depending on the need for manual work in CNC machining, future increased costs of electricity can play an increasing role in the machining costs. The

trend towards increased automation will accordingly cause energy cost to amount to a bigger portion of the total machining cost.

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