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INFLUENCE OF THE MAINTENANCE AND ADJUSTMENT OF MACHINING CENTERS COMPONENTS IN ELECTRICAL ENERGY CONSUMPTION

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Abstract. *The electricity consumption in manufacturing line increases progressively and this consumption should be used rationally due to the scarcity of this resource and its cost. However, there are few studies about the consumption of electricity in machining center in relation with the setting and wear of its components. To quantify this influence, measurements were made at different CNC machining centers in a manufacturing line and quantified the consumption of different machines with the same technical specification, during the same period of use and the same machining process. The results show, for example, machine tools with the same machining process, consumes between 1.0 kWh and 1.2 kWh per workpiece. Machines should have the same results but there is a variation of 0.2 kWh / workpiece. This represents an increase of 20% in electricity consumption in comparison with the most economical machining center with the same machining process. The research aims to show the influence of wear of the machining centers components in the consumption of electricity.*

Keywords: *Machining, Electricity, machine centre, wear, maintenance*

1. INTRODUCTION

Nowadays, the importance of energy efficiency theme is increasing. Besides the high cost of electricity, there is a global trend of increased energy consumption and raw material. Global demands for production resources such as oil and several strategic metals (eg, platinum and indium), according to projections, will exceed supply (ANGERER, 2009; Schulz et al, 2011).

Industrial manufacturing is one of the main economic activities of our time and has required large amounts of energy resources, it needs to transform and create products using energy. This industry demand is increasing more than in other sectors. Statistics of energy consumption in Europe show that it is larger than a quarter of the total consumption of energy required. Worldwide, the industrial sector consumed about 98 exajoules (EJ) in 2008 (year of global crisis), representing 28% of total energy consumption (EUROSTAT, 2009; INTERNATIONAL ENERGY AGENCY, 2010; Renaldi et al, 2011; Schulz et al, 2011).

Machining is one of the production processes performed with computer numerical control (CNC) machine tools and powered by electricity. According to Behrendt et al., in 2010, the electricity consumption of these machine tools represented approximately 31% of the total US consumption of energy. Analyses of the energy consumption of machine tools by Gonzalez (2007) found that 56% of energy consumption is due to machining, 25% due to positioning operations, and 19% is due to energy being expended by auxiliary devices that are always on. The design of machine tools and machining processes obviously influence these levels of consumption.

In Brazil, the market for CNC machining centers is around 10,000 machines per year (MÜLLER, 2013). Whereas in-floor factory, each machine when turned on without production, have a constant demand of 4 kW and a service life of about ten years, the sum of the machines installed in the country will have a consumption of 400,000 kW. This amount represents approximately 2% of the power installation of this set in Brazil in 2013 (ANEEL, 2013) Apud (Carvalho and Gomes 2015). Electric power expended without adding value.

Filippi and Ippolito (1981) and Avram and Xirouchakis (2011) were some of the first to study energy efficiency in machines with numerical control (NC). They compared data from 10 different NC machines involved in various operations. They concluded that the installed capacity was never fully utilized because the average power was less than half of the power available; only 60% of the total time was spent on production. A review of recent literature shows efforts being made to increase energy efficiency in the machine tool industry. For example, Weinert et al. (2004) investigated reducing the cutting fluid used during the machining process. Rangarajan and Dornfeld (2004) proposed a tool path and workpiece preparation method based on energy efficiency. Mori et al. explored the monitoring of energy consumption by machine. Diaz et al. (2010) investigated the reuse of electrical energy from a spindle. Neugebauer et al. compared different drilling processes with different cutting tools and material removal rates. Suggestions to increase the energy efficiency of machining processes include turning some components of the machine off and on via NC or a programmable logic controller (PLC) (Mori et al., 2011; Dietmair, 2009; Li et al., 2011), redefining the parameters of cutting tools to reduce the machining time (Mori et al., 2011; Mativenga and Rajemi, 2011; Balogun and Mativenga, 2013), redefining the cutting strategy for the trajectory and path of the cutting tool, changing devices of low-performance machines for equipment with higher performance (Dietmair, 2009; Li et al., 2011), and setting machine parameters to reduce consumption (e.g. axis and spindle acceleration) (Dietmair, 2009). Chen et al. and Hinduja and Sandiford created models and methodologies for selection of cutting conditions in machining, based on minimizing the costs of turning and milling processes. Narita et al. described a methodology for reducing the environmental impact of a machining process. Chapman suggested that the energy used in a machining process can be reduced by studying each aspect of the process in detail. Mantivenga and Rajemi (2011) stated that optimisation should be performed to select the combination of cutting depth (ap), feed (f), and cutting speed (v) that minimises energy consumption and process restriction.

However, there is no study relating the influence of the electricity consumption of machine tools due to the wear and maintenance of its components. Thus, the aim of this study is to measure and validate the following hypotheses:

Hypothesis 1: Similar machining centers can, after a certain period of production, have different consumption of electricity.

Hypothesis 2: The maintenance of the machine tools is important for increasing energy efficiency.

2. METHOD

The electrical energy consumed by each machine is measured using measuring equipment. The measuring equipment is the RE6000 portable power analyser (EMBRASUL). at the This equipment is installed entrance of CNC machines. Figure 1.

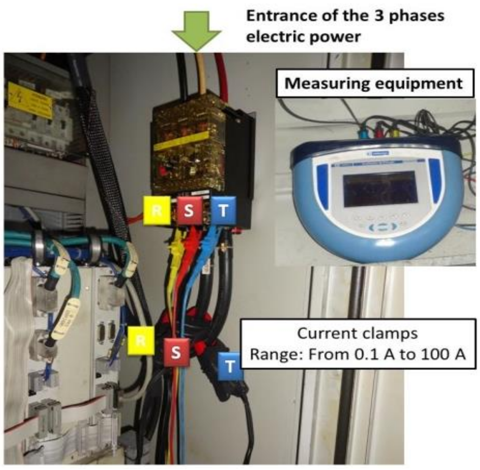

Figure 1. Measuring equipment inside machining centre.

The power analyser stores data on the active power, reactive power, and effective power measured at intervals of up to hundredths of a second. Energy metering and monitoring is essential to obtaining authentic information from each individual machine, and the sample rate should be less than 0.5 s (Balogun and Mativenga, 2013). Data are stored in a file which can be transferred to a computer via a network cable. By means of a software program within the measuring equipment and later opened in a spreadsheet, as shown in Fig. 2. This procedure is the same used in (Carvalho and Gomes, 2015a), and (Carvalho and Gomes, 2015b).

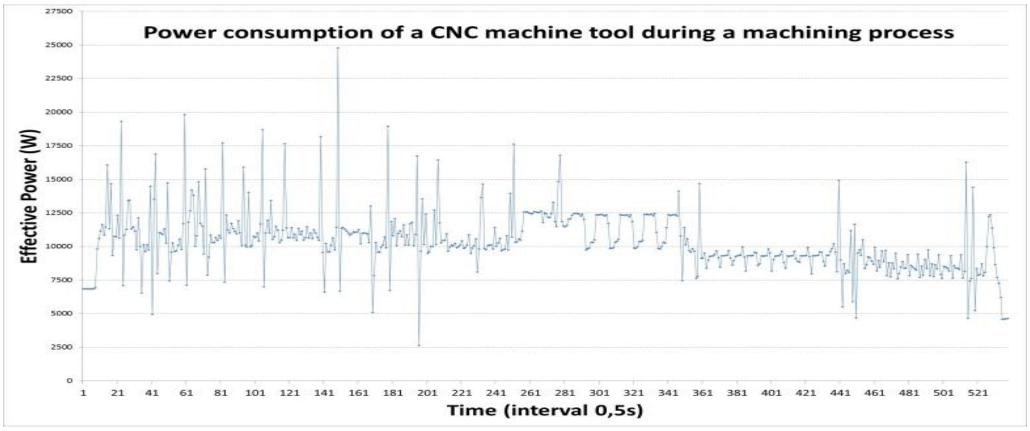

Figure 2. Electricity consumption of CNC machine tool during machining.

3. RESULTS AND DISCUSSIONS

To validate the hypothesis the research analysed the operation 130 (grinding process) in the crankshaft line, the operation 50 (milling process) and the operation 80 (drilling and reaming process) in the block cylinder line. The measurements of the three machines in the crankshaft machining line was the first study to validate the hypothesis as the maintenance influence the energy efficiency of CNC machines. These machines are CNC grinders applied for an operation of crankshaft bearings grinding. The grinders are identical. The graph obtained after the measurement of the machines is shown in figure 3. In the graph can be seen that the consumption of standby machines ranges from 3000 W to 3300 W. The monetary impact and energy impact is about 10% per year in the consumption in standby mode of the machine tool. So, there is a difference of electricity consumption among machines of up to 300W.

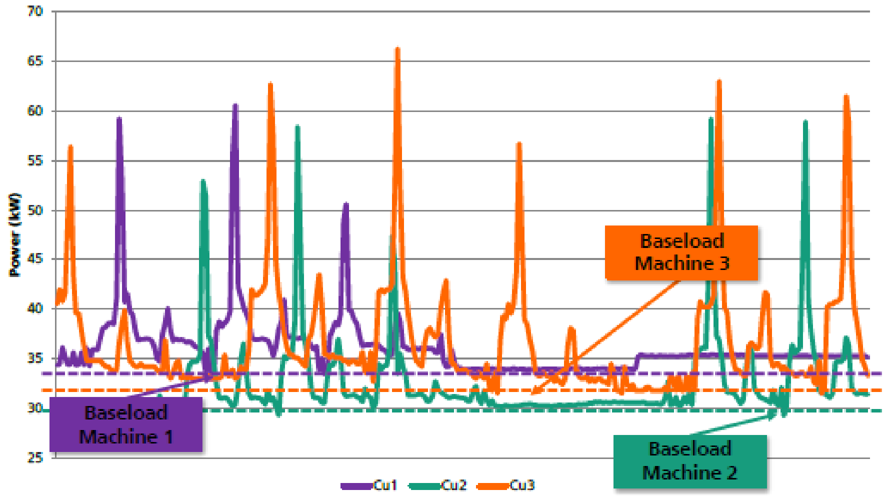

Figure 3. Base loads and processing consumption of operation OP130, crankshaft line.

The details of the measures of the three machines are showed in table 1. The base load is the consumption of the machine on standby mode and the average power is the consumption during the machine process.

Table 1: Measurement of each machine (OP130).

Operation Machine	Average Power (kW)	Base Load (kW)	Overall average power per operation (kW)
CNC Grinder 1	37.35	33.0	107.03
CNC Grinder 2	33.01	30.0	
CNC Grinder 3	36.67	32.0	

As a result, there are difference of base load consumption among the grinders with the same age and type. Moreover tools, cutting fluid and external framework are identical. This difference could happen because the differences of wear and conditions of the machine components. So, the maintenance needs to check the operation parameters of the running components and adjust sensors to a minimal effort and electrical energy consumption.

An overview of the power consumption of different machines that compose operations 130 is obtained by Figure 4. Following the same approach as previously, single grinding process was extracted. The green curves show different parts manufactured with the grinder 1 and the orange curves the same for grinder 2. Grinder 3 is not included into the diagram. Furthermore only a limited number of parts for machine 1 and machine 2 are shown to support the analysis.

The power consumption shows similar load profiles. The peak loads as well as their points in time are quiet similar. Based on this, the process, its control and also the machine tools seem to be working well and consistently. However there might be potential by exchanging single high energy intensive components by less energy consuming components since the average energy consumption is comparatively high (~ 35 kW).

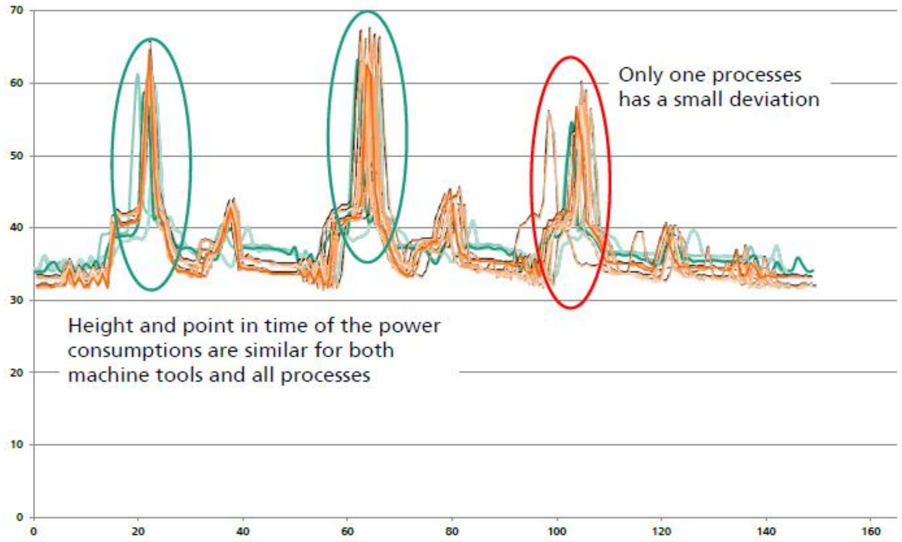

Figure 4: Power consumption of several parts machines OP130 of crankshaft line.

Other operations were analysed in the cylinder block manufacturing line. The data analysis of all measured machines was done in OP50 and OP80, two operations among the 20 that compose the entire machining line. Each operation is composed of several machining centers that done the same job. For each machine a representative power consumption profile was selected and plotted within one diagram. Figure 5 gives an overview of four processes and their load profiles.

The sequence of the displayed machine tool operations, machines 1 to 4, shows similarity. However, there are some differences concerning the height of the power consumption especially in the first phase of the process. The peak after approx. 15 s differs from 40 to 52 kW and the second significant peak after 40 s from 40 to 50 kW. The minimum power consumption of the machining centers differs slightly. The two orange curves have a lower power consumption level after approximately 100 s. This power consumption influences the whole energy consumption per part. The deviation between the investigated machine tools with the highest and the lowest energy consumption per process is up to 0.2 kWh per part. This is equal to approximately 20%. Theoretically, when reducing the energy consumption to the lowest value the cost per part could be reduced as follows:

$C_{OP50,\ 100\%\ reduction}$ = 0,20 KWh* 0.30 R$/ Kwh = 0,06 R$/ part (1)

The electrical energy cost is a hypothetic value.

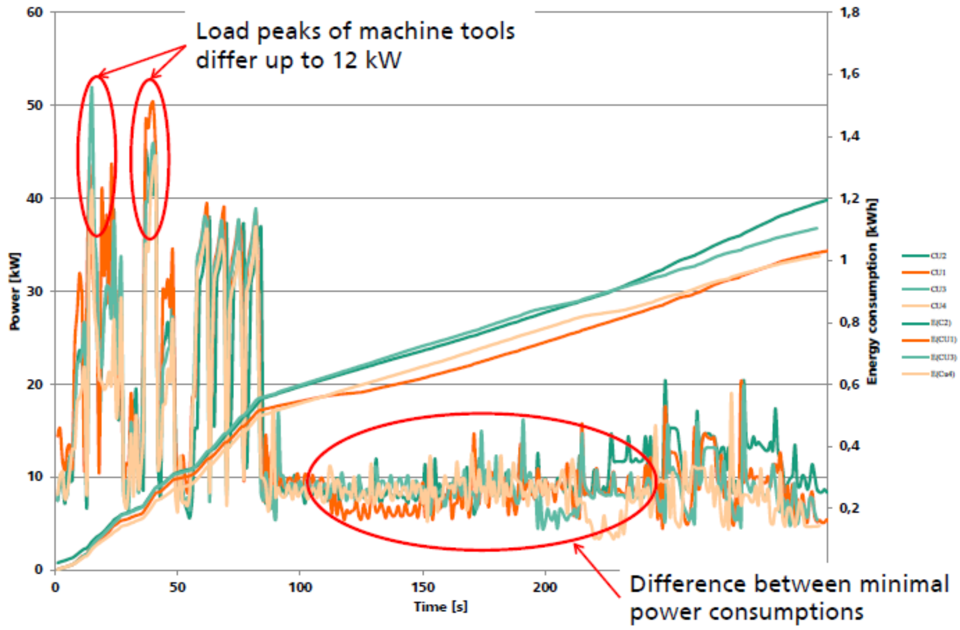

Figure 5: Measuring plot of four machine tools of operation OP50 (OP50CU1 to 4).

Assuming, that at least 50% reduction is achievable, the following costs can be reduced per part:

$C_{OP50,\ 50\%\ reduction}$ = 50%*0,20 KWh* 0,30 R$/ Kwh = 0,03 R$/ part (2)

This seems to be a small amount, however considering a daily production volume of 1450 parts and 225 days of production per year, the whole savings for energy consumptions per year can be calculated to

$C_{OP50,\ 100\%\ reduction}$ = 0,06 R$/ part*1450part/d * 225 d/a = 19.575 R$/a (3)

$C_{OP50,\ 100\%\ reduction}$ = 0,03 R$/ part*1450part/d * 225 d/a = 9.787,50 R$/a (4)

Based on the measurements and the knowledge about the differently manufactured product variants, the power consumption of single processes can be separated and illustrated within one diagram. Figure 6 gives an overview of four randomly, but typical and representative engine blocks manufactured on OP80, machine center 2 (CU2).

Besides power, energy consumption is displayed on the diagrams' second y-axis. The maximum deviation of the energy consumption of the four parts can be calculated to approx. 17% (±8.5% from the midpoint of range). However, most of this deviation is caused by a continuous difference in power consumption: the base load shifts between the four processes can be seen in Figure 6.

The levels of the orange curves, which display the cumulative power consumption over time, increase in a linear way and run higher than the level of the green curves. The peak loads of the power consumption behave quiet similar. The difference in power level might be caused by operation of peripheral components which are not directly necessary for the process, e.g. cooling of the controller.

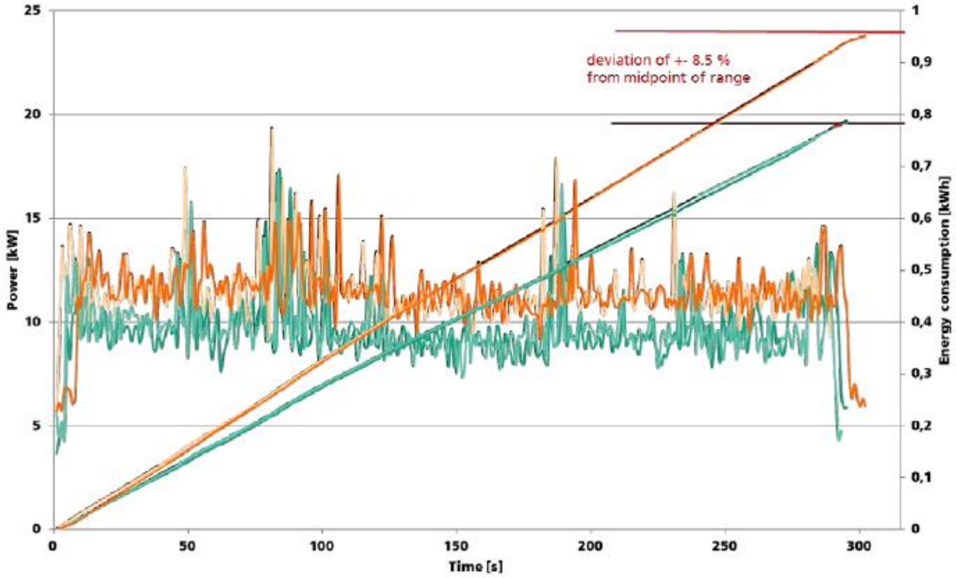

Figure 6: Measuring plot of four representative engine blocks.

For really achieving a reduction of electrical consumption, further investigations on the power consumption of each machining center component and comparison to each other as well as to the state-of-the-art are necessary.
Figure 7 and table 2 visualizes the distribution of the base load induced energy consumption in comparison with the direct processing-related consumption. In OP50 and OP80 of the cylinder block machining line with 47% respectively 53%, this figure is moderate compared to 89% of grinding process OP130 in crankshaft line. Moreover, the OP130's base load of more than 30 kW is six times higher than the averagely 5 kW in the prior OP's.

Table 2: Consumption of the OP50 and 80.

Operation code	Average Power (kW)	Base Load (kW)	Overall average power per operation (kW)
OP50 Machine 1	11.92	5.0	97.15
OP50 Machine 2	11.93	5.5	
OP50 Machine 3	12.42	6.0	
OP50 Machine 4	11.14	5.5	
OP50 Machine 5	14.09	7.0	
OP50 Machine 6	11.36	5.0	
OP80 Machine 2	8.63	4.0	61.71
OP80 Machine 3	9.02	4.5	
OP80 Machine 4	8.63	4.5	
OP80 Machine 5	8.65	4.5	
OP80 Machine 6	8.70	5.0	
OP80 Machine 7	8.31	5.0	
OP80 Machine 8	9.77	5.5	

For that, the plant should focus on reaching the operations internal benchmark ("levelling") regarding the two engine block operations OP50 and OP80. In contrast to that, in OP130 both measures should be improved due to levelling all the operational base loads as well as to reduce the base load according to improvements of the components.

Figure 7. Base load energy consumption in comparison with the direct processing-related consumption for operation 50 and 80 (Cylinder block Line) and OP130 (Crankshaft Line).

4. CONCLUSIONS

The research shows that the two hypotheses are correct:

Hypothesis 1: After a certain period of production, similar machine tools can have different consumption of electricity.

Hypothesis 2: The machines maintenance is important for increasing energy efficiency.

There are differences among similar machines in different kind of process and manufactured part and a monitoring of the machine consumption is important to save energy and money during the life of the machine tool.

Next research is to define a method to analyze which components causes the differences in the electrical energy consumption inside the machine and how to identify the component consuming electrical energy more than necessary.

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