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ENERGY ANALYSIS DURING THE TURNING PROCESS OF ABNT 1045 STEEL

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Abstract. *This work has the objective of performing an energy study on the main machining parameters found in turning ABNT 1045 steel. An energy analyzer capable of recording all the energy potentials present in the system was used. Besides, depth of cut, feed rate, the shear rate was defined originally so that the constant values of chip volume removed were satisfied. Feed rate is the parameter that most influenced the specific energy during turning, followed by the depth and cutting speed.*

Keywords: *Turning, Energetic power, feed rate.*

1. INTRODUCTION

Machining processes have the objective of transforming raw material into ready-to-use finished products, and it is through them that operations can be carried out to give form, dimensions, and finishing, with the production of the chip (MACHADO et al., 2009). Also, the machining process is characterized by high energy demand, which promotes a significant change in specific cutting energy for the same material removal rates. However, to determine the most relevant machining parameters in this work, an analysis was made on the energy demands in the turning process, thus explaining the main energetic phenomena that influencing the process.

The reduction of the energy consumption during the machining process is significant because it is directly linked to a decrease of the quantifier of materials used, improvements in the machining parameters and the surface finish of the materials. To solve the problems related to the energy consumption in machining studies being carried out, where energy consumption problems are related the measurement of the electric powers for improvement of the characteristics and sustainable machining (ALRASHDAN; BATAINEH; SHBOOL, 2014; GARG et al., 2016; ZHANG et al., 2018).

The overall process of this research is to acquire the different energy power signals in a turning process by varying the main machining parameters that influence the process, feed rate, depth of cut, and cutting speed. For this, a data collection was performed utilizing an energy analyzer of the brand EMBRASUL (model RE 4001). The analyzer gives an accuracy of 0.7% for analysis of the electrical powers with a range of 200 milliseconds which makes it possible to measure the rapid power peaks.

2. METHODOLOGY

2.1. Behavior in turning

Turning is a machining process characterized by the removal of material through the revolution of the part, so it is characterized by the obtaining of surfaces of revolution. The method for removing chips from turning is derived from a two-dimensional plane in the cutting tool. Therefore, a machining process with the system of forces makes it easier to calculate (SHAW, 2005). The decomposition of the turning power is related to the machining force and the cutting speed. The machining force (F_u) can be decomposed into two parts, the active and the passive. Of these two, the passive portion is perpendicular to the work plane, and therefore, does not generate a job. The active portion can still be further magnified and divided into shear force (F_c) and shear force (F_f) (AMORIM, 2002). The sheer power, therefore, can be found through Eq. 1

$$P_c = \frac{F_c \cdot V_c}{60 \cdot 10^3} \quad (1)$$

In Eq. 1 it is possible to observe that the cutting power is a function of the shear force and the cutting speed. For the definition of sheer force, it is necessary to understand the three primary parameters that influence it. The feed rate (f), which is the distance traveled at each turn (mm/turn), the depth of cut (a_p) which is the amount in millimeters in which the tool penetrates the workpiece, and the cutting speed (V_c) which can be defined as the peripheral speed of the workpiece, where contact with the tool occurs (m/min) (DINIZ; MARCONDE; COPPINI, 2014). From this, it is possible to determine the shear force by means of Eq. 2.

$$F_c = k_s \cdot A, \tag{2}$$

k_s is the specific cutting pressure, and A is the section area of the chip. The particular cutting pressure can be tabulated for various machining conditions, such as part material, tool geometry and conditions, lubrication system, cutting speed, chip area, and feed rate. It is possible to tabulate this coefficient, but due to the number of variables that affecting the system, one must make some corrections in the parameters. The specific cut-off pressure can also be verified experimentally for each case to be studied (CARVALHO, 2015; MACHADO et al., 2009).

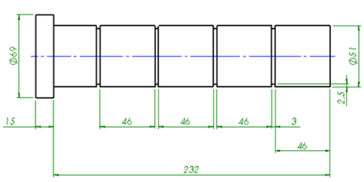
2.1. Electrical power

Electric power is the capacity that a voltage source has in converting the electrical voltage of the system with a respective current to perform some work (NILSSON; RIEDEL, 2009). For the vast majority of problems encountered in electrical circuits, the power used must be calculated by alternating the current equation. The problem happens because of these circuits present both resistive, capacitive, and inductive electronic components (CHAPMAN, 2013). All electric power is composed of a real part and an imaginary one, its three different types, apparent (S), active (P) and, reactive (Q) can be defined. In general, the power that is produced in the system is a vector representative of two other parts of the equation (BOYLESTAD, 2012; CHAPMAN, 2013).

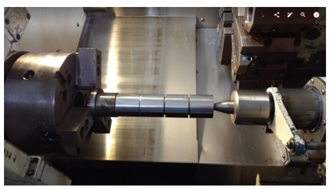
Apparent power is the total power of an electrical system. It is composed of the vector, polar or rectangular sum of the active and reactive power components simultaneously. The apparent one has the function to explore relations between the continuous and alternating currents conceptually (POLITÉCNICA, 2012). Active power is found purely in resistive electrical systems (JACQUES, 2014; NILSSON; RIEDEL, 2009). In general, the active or average power (NILSSON; RIEDEL, 2009) is responsible for the work involved in the system (ELEKTRO, 2014). The reactive power is the imaginary component of the total (apparent) power of an electric circuit that compose the resulting vector along with the active one. When dealing with voltage and current values in electrical circuits and also the average power absorbed by the system, it is not possible to infer the nature of the capacitive or inductive system (POLITÉCNICA, 2012). Unlike the active power, the reactive presents a variation of its sinusoidal equation under the abscissa axis. This characteristic is predominant due to its operating cycle that works by storing energy and then releasing it to some magnetic field, which can be both inductive and capacitive (CHAPMAN, 2013). Although reactive power can magnetize the coils of electrical equipment, such as electric induction motors, it does not perform work on the system (ANEEL, 2012; ELEKTRO, 2014).

2.2 Used Materials

The Galaxy 20 CNC was chosen to perform all experiments. The power analyzer was coupled to the power cables of the Galaxy 20 CNC lathe with the Fanuc command so that all power measurement was done integrally. The machine has a maximum rotation of 4500 rpm, with a larger plate diameter of 228 mm and a length of 400 mm. The specimen was an ABNT 1045 steel turned a shaft, with a nominal diameter of 51 mm in fixation area, a region with a larger diameter, to improve its effectiveness. As shown in Figure 1a, four channels 3 mm long with a depth of 2.5 mm were realized in the radius, to perform four experiments per piece. Besides, two parts of the same material were used to guarantee eight tests (cuts) involved with a cut length per experiment of 46 millimeters. The fixation of the workpiece can be seen in figure 1b and was performed through nuts and counterpoint, to reduce as much as possible any unwanted vibrations to the process during the experiment.



(a)



(b)

Figure1. Dimensions and fixation of the workpiece.

For the turning, a cutting tool of the Sandvik Coromant company, model CNMG 120408-MM 2025 was used. With the substrate of Hard Metal of type M and class 2025, with CVD process cover of Ti (C, N) + Al2O3 + Tin, indicated for the machining of stainless steels and medium roughing, with intervals recommended by the manufacturer of a depth of cut (ap) between 0.5 and 5.7 millimeters. Besides, it was the use of a cutting edge for each test, preventing the maximum wear of the tool during the experiment.

2.3. Experimental procedure

The experiments were carried out from a factorial design. For this, three factors, the advance, cutting speed and depth of cut were assigned, and two levels of variation with the same amplitude between them of approximately 50% of their initial value. The advances selected were 0.2 and 0.3 mm / lap; depth of cut of 1.0 and 1.5 mm; for the cutting speed, tree spindle rotations of 1203 and 1804 rpm (183 and 275 m / min respectively) were chosen. From the pre-established conditions, a matrix was created with eight tests. This information can be found in Table 1.

Table 1. Performed tests

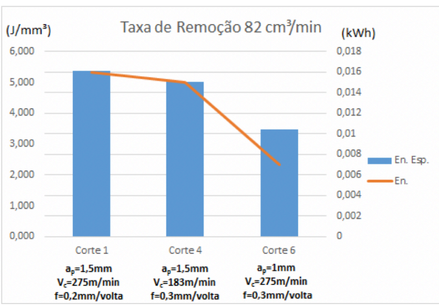
	a_p (mm)	n (rpm)	f (mm/rev)
Cut 1	1,5	1804	0,2
Cut 2	1,5	1804	0,3
Cut 3	1,5	1203	0,2
Cut 4	1,5	1203	0,3
Cut 5	1,0	1804	0,2
Cut 6	1,0	1804	0,3
Cut 7	1,0	1203	0,2
Cut 8	1,0	1203	0,3

After the acquisition of the power and energy data consumed by the machine during machining, the data was processed, separated and analyzed statistically to make the appropriate comparisons and to find out which of the machining parameters factors (feed, cutting speed and depth of cutting) more affects the specific cutting power.

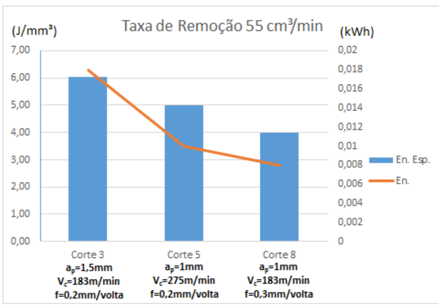
3. RESULTS

The calculation of the specific cutting energy in the machining process was made from the total power of the system. For this, the potential of the constant parts of the machine (rotating spindle, electronic components in general and motors), and the energy acquired in the cutting process was added.

For the first analysis, the removal rate was kept constant, Figure 2a and 2b show the first results. In this result, it is possible to observe that the specific energy did not remain constant during the process despite the same material removal rate. As the particular energy values varied from the feed change, sheer depth, and shear rate, this work relied on these three parameters to analyze the process. When comparing cut 1 and four simultaneously in figure 5a, it was possible to observe that the increase of the advance and the reduction of the cutting speed, caused the specific energy to decrease approximately 7%. Besides, when comparing cut 1 to cut 6, where there was a 50% reduction in the depth of cut and a 50% increase in feed, and the specific energy reduced by approximately 54%. In a similar way to the analysis of cuts 1, 4 and 6, sections 3, 5 and 8 showed very similar characteristics, where the first parameter that influenced the decrease of the specific energy was the depth of cut. In Figure 2b, in sections 5 and 8, the depth of cut was kept constant, and the cut-off and feed rate parameters were changed. In this case, the increase of the cutting speed and the reduction of the advance represented 25% more in the specific energy. When cut 3 is compared to 8, it can be observed that there was an increase of 52% in the specific cutting power with increasing cut depth. Therefore, in this preliminary analysis, the depth of cut is a parameter that has much influence in the process.



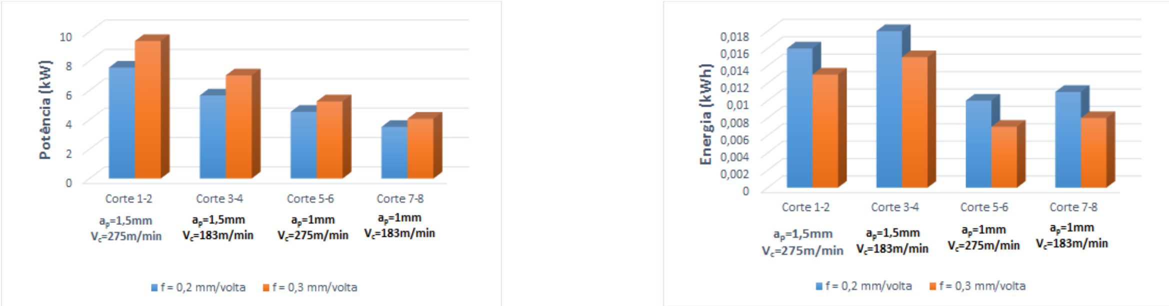
(a)



(b)

Figure 2. Comparison between of material removal rate.

The increase of feed by 50% caused a decrease in electrical power and energy consumption. The increase was because an increased feed causes a reduction of the specific cutting pressure in the machining process and also reduces cutting time. So as energy is the product of power over time, the further advance decrease the energy consumption of the machining. Figures 3a and 3b show the feed increased.



(a) (b)

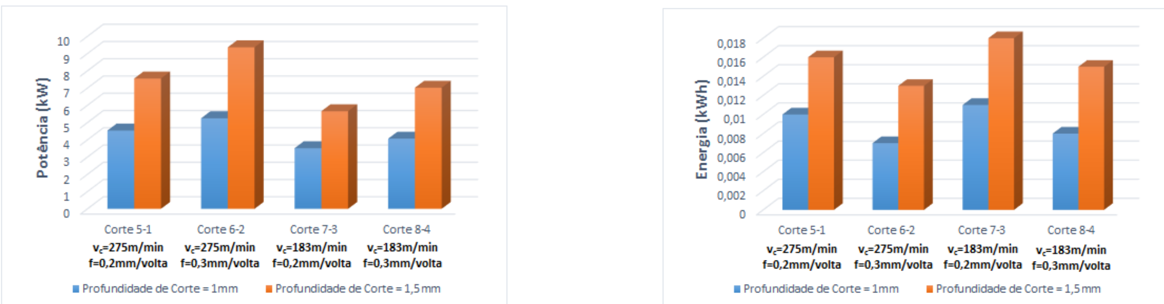
Figure 3. Variation of the feed and the influence of parameter.

Already the increase of the cutting speed of 50% caused the energy consumed by the system to be diminished by the process the reduction of the time of machining. As speed does not affect the specific shear pressure, the decrease rate of the energy consumed in the processes with a variation of the speed was smaller than in the processes of variation of the feed. The decrease rate was related to the feed, and consequently, the specific pressure influences much more energy consumption than the cutting speed itself. Figures 4a and 4b show the variation of the cutting speed and the influence of its parameters.

(a) (b)

Figure 4. Variation of the cutting speed and the influence of parameter.

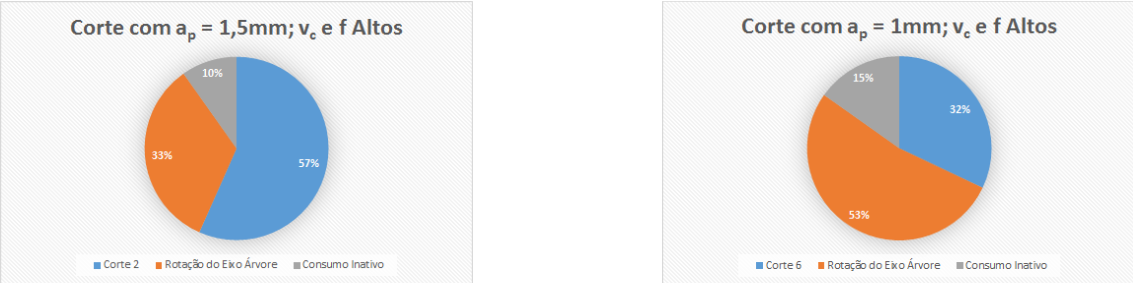
However, the 50% increase in the parameters of the machining depth did not present similar characteristics to the other processes already mentioned. As the increased cutting depth does not reduce cutting time, the average power of the running machine remains high, causing the energy consumed by the system to rise simultaneously. Figures 5a and 5b show the relationship between the depths of cut with the power and energy consumed respectively.



(a) (b)

Figure 5. Relationship between the depths of cut with the power and energy

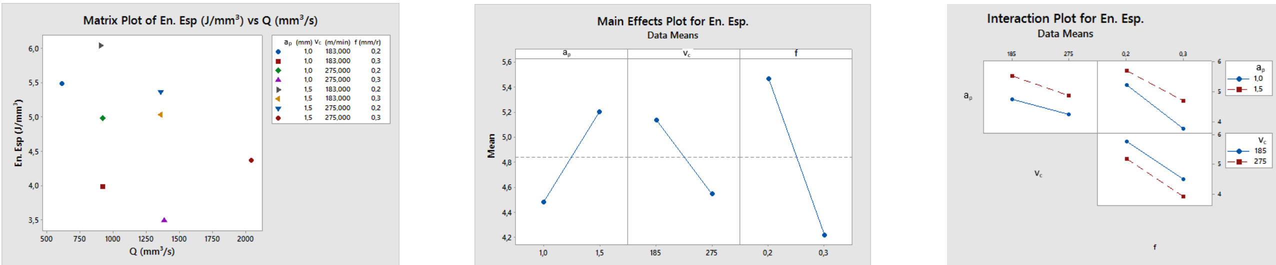
As already seen, one of the main parameters that influence the energy consumption in the system is the depth of cut. Therefore, the two cuttings with the highest values of cutting speed and feed (cuts 2 and 6) were selected. In the case where the process presents the lowest specific energy (cut 2), the cutting power increased in the same proportion of the depth's increase, and the cutting energy consumed was higher than the others (Figure 6a). In the process with a smaller depth of cut (cut 6), a cutting power cut of approximately 44% was observed (Figure 6b), making the cutting energy also more modest than that of cut 2.



(a) (b)

Figure 6. Cutting with a_p = 1.5mm (a), a_p = 1mm (b), and highest v_c and f.

Despite these results, factorial statistical analysis - ANOVA - were performed to compare the influence of each machining parameter on the process. It was possible to observe for the higher values of the depth of cut, the higher the specific energies for the same rates of material removal, figure 7a. In Figure 7b, the advance was the parameter showing the most significant influence on the particular energy results. This fact may be related to the substantial impact of the progress on the specific cutting pressure. Moreover, Figure 7c shows the combination, of depth and feed, had the highest correlation.



(a) (b) (c)

Figure 7. ANOVA, factorial statistical analysis

4. CONCLUSIONS

From the analysis of the results, it was possible to verify the variation of the machining parameters interfered actively in the specific cutting energy for the same material removal rate. Besides, the influence of the advance was the parameter that most suffered impact among the others in the specific energy. The depth of cut was what most influenced the energy consumed. The constant aspects depend on each machine and its state of conservation; therefore, one must survey the electrical power of each element of the set to estimate the efficiency of the process. Finally, the results of the parameters analyzed simultaneously, to predict the interference in the process, did not present any significant effect in the results.

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ANÁLISE DE ENERGIA DURANTE O PROCESSO DE TORNEAMENTO DO AÇO ABNT 1045

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Resumo. *Este trabalho tem como objetivo realizar um estudo energético sobre os principais parâmetros de usinagem encontrados no torneamento do aço ABNT 1045. Foi utilizado um analisador de energia capaz de registrar todos as potências energéticas presente no sistema. Além disso, profundidade de corte, velocidade de avanço, taxa de cisalhamento foram definidos previamente para que os valores de volume de cavacos removidos fossem constantes. O avanço foi o parâmetro que mais influenciou a energia específica durante o torneamento, seguido pela profundidade e velocidade de corte.*

Palavras-chave: *Torneamento; Potência energética, Avanço.*