Determining the energy demand towards sustainable machining of AISI 316L stainless steel

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Abstract. Minimizing the energy demand of machining operations has become mainly in the manufacturing field; encouraged by the significantly increase in the energy cost and the environmental effects due to high levels of energy demand. The energy consumed to cutting operation in turning process was divided into two sections, i.e. the energy used to setup machine and the energy consumed to cutting process. The total energy demand of machining process can be estimated with prediction equations based on material removal rate (MRR) and cutting force. This paper aims to promote an approach to predict and calculated the total energy demand of cutting operation performing the sustainable in turning process. The results presented that the estimated of energy demand values are almost similar to the actual values about 7.3 percent than the actual energy demand.

1 Introduction

Consumption of natural resources and pollution resulting from the life of technical products has become a global environmental problem and has resulted in increased political pressure and stronger regulation applied to producers and users of those products [1]. The existence of sustainable development activities in production has been adopted in a cost-effective route industry to improve economic, environmental, and social performance.

Sustainable production as a problem solving in dealing issues of higher energy demand and costs, including applicable in the fields of engineering, such as the machining process [2]. In the sustainable production, reduction of energy consumption becomes an important consideration in addressing the issue of energy [3, 4].

In production processes, improving sustainability performance and saving money can be performed by minimizing energy demand. The production process highly requires the energy, and production is also integrated with machinery. Thus, the reduction of energy demand to generate parts can be contributed by reducing energy demand in machinery.

A prerequisite in targeting energy reduction in a machining process is the capability to determine the total energy used during machining. This identification of energy usage in a machining process can be done by studying a particular machining process in detail [5]. Previous works on identifying the machining process and deriving the calculation for total energy demand were reported by Rajemi et al. [4] and He et al. [6], to name some. The first stated that total energy during machining is the sum of the energy consumed by the machine during setup processing, during cutting process, during tool change, and to produce a cutting tool and normalized per cutting edge. The last observed that total energy was from constant energy demand (corresponding to idle condition) and from variable energy consumption (related to cutting power). In this paper, the first approach is used. The machining process studied is turning of hardened steel under dry condition (no cutting fluid). The cutting tool used is carbide insert, which means the machining process is in extreme range of its capability [7]. The energy calculated is total energy consumed in machining the hardened steel starting from the beginning of cutting process (when the tool is still fresh) until the cutting tool reaches its tool life.

In this paper, the energy demand of turning process is investigated by using three methods. The experimental was performed on the turning of AISI 316L austenitic stainless steel.

2 Determining Energy Demand

The energy demand in turning process can be obtained using the measuring the power meter includes voltage, current, power and energy demand. Furthermore, the total of energy demand (E) can be formulated using a modified equation [4], as following equation:

$$E = E_1 + E_2 + E_3 + E_4 \quad (1)$$

The energy consumed during the setup processing as E_1, during the cutting operation as E_2, for changing a tool as E_3, and for resulting cutting tools as E_4. In this paper, the energy used to cutting process for calculation of

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energy consumption, namely E_C. Thus, equation (1) can be modified as below:

$$E_C = E_1 + E_2 \quad (2)$$

E_1 is the energy that is used to setup operation and can be formulated from the amount of power demand during timing setup, as shown in the equation:

$$E_1 = P_0 \cdot t_1 \quad (3)$$

whereP_0, namely idle power, is the power required for devices to support the machine, such as the computer and fans, motor, coolant pump etc. The power required by a machine tool using a three-phase motor, P_o, is formulated as follow [8]:

$$P_0 = V \cdot I \cdot \sqrt{3} \cdot Cos\ \phi \quad (4)$$

where$V$, is the voltage, I is the current [A], and $Cos\ \phi$ is the power factor (0.8 – 1.0). The value of V and I can be obtained from the machining data that shown in the control panel of CNC lathe machine, t_1 is the time needed to setup the machine [s].

E_2 is the energy demand during cutting process and can be formulated by the power engine module for removing material, as developed by [9] in equation below.

$$E_2 = (P_0 + k \cdot \dot{v})\ t_2 \quad (5)$$

where $(P_0 + k \cdot \dot{v})$ can defined as the electrical power required (P) for machining [9] with following equation below:

$$P = P_0 + k \cdot \dot{v} \quad (6)$$

where, P is the power [W] consumed by machining process, $P_0$is the power [W] consumed by all machine modules for a machine operating without loading, k is the specific energy requirement [Ws/mm^3] in cutting operations (Table 1), and$\dot{v}$ is the material removal rate (MRR), in [mm^3/s] which can be calculated as follows:

$$\dot{v} = V_C \cdot f \cdot a_p \quad (7)$$

where$f$ is the rate of feeds (mm/rev) and V_c is the cutting speed (m/min), and a_p isthe depth of cut (mm).

Table 1. Energy specific for Cutting (k).

Material	k value [Ws/mm^3]
Aluminum alloy	0.4 – 1.0
Cast iron	1.1 – 5.4
Copper iron	1.4 – 3.2
High-temperature alloy	3.2 – 8.0
Magnesium alloy	0.3 – 0.6
Nickel alloy	4.8 – 6.7
Refractory alloy	3 – 9
Stainless steel	2 – 5
Steels	2 – 9
Titanium alloy	2 – 5

Value of $(k \cdot \dot{v})$ can be summarized as the cutting power. Thus, the above equation for the total power consumption in cutting process (P_t) was assumed as follow:

$$P = P_0 + P_C \quad (8)$$

where $P_c$is the cutting power which is the product of cutting force and cutting speed [10, 11] :

$$P_C = F_C \cdot V_C \quad (9)$$

whereV_c was cutting speed (m/min), and F_c was cutting force that supplies the energy needed for the cutting operation. Thus, the cutting process have an equation as follow:

$$P = P_0 + (F_C \cdot V_C) \quad (10)$$

As described in equation 1, the energy requirement for the machining process can be summarized based on the cutting force and the cutting power (measured by using power meter) with following equation:

$$E_2 = (P_0 + F_C \cdot V_C)\ t_2 \quad (11)$$

$$E_2 = (P_0 + P_C)\ t_2 \quad (12)$$

Based on theequation 2, theenergy consumed for cutting process can be calculated by equation below:

$$E_C = P_0\ t_1 + (P_0 + Pc)\ t_2 \quad (13)$$

$$E_C = P_0\ t_1 + (P_0 + k \cdot \dot{v})\ t_2 \quad (14)$$

$$E_C = P_0\ t_1 + (P_0 + Fc \cdot Vc)\ t_2 \quad (15)$$

3 Experimental Setup

In this paper, the turning process was performed using the ALPHA 1350S 2-axis CNC lathe machine (100 - 6000 rpm of spindle speed ranges and 8.3 kW of horse power and) under without cooling conditions using uncoated carbide tool (Mitsubishi's UTi20T) with featured 0.8 mm nose radius and designated as TCLNR 2020K12. The cutting parameters were selected after the recommendations given by the tool's manufacturer. The criteria of tool life were adjusting at 0.2 mm of maximum flank wear width or until the tool was severely damage.

The workpiece material used in the turning process was AISI 316L austenitic stainless steel, with a diameter of 150 mm and length of 300 mm. The composition of AISI 316L was detailed in Tables 2.

Table 2. Composition of AISI 316L.

Composition	Min	Max
C	-	0.03
Mn	-	2.00
Si	-	0.75
P	-	0.05
S	-	0.03
Cr	16	18.00
Mo	2	3.00
Ni	10	14.00
N	-	0.10

The experimental setup was developed using nine experiments as shown in Table 3. It was conducted to repetition for each parameter.

Table 3. Cutting parameters.

Levels	Low	Centre	High
Cutting speed (m/min)	90	150	210
Feed (mm/rev)	0.10	0.16	0.22
Depth of cut (mm)	0.4		
Coolant	No Fluid		

4 Results and discussion

The energy demand was calculated by using Equation 13 to 15. The calculation results for energy demand based on experimental, cutting force and material removal rate (MRR) are shown in Figures 1, 2 and 3 for feeds of 0.10, 0.16 and 0.22 mm/rev respectively.

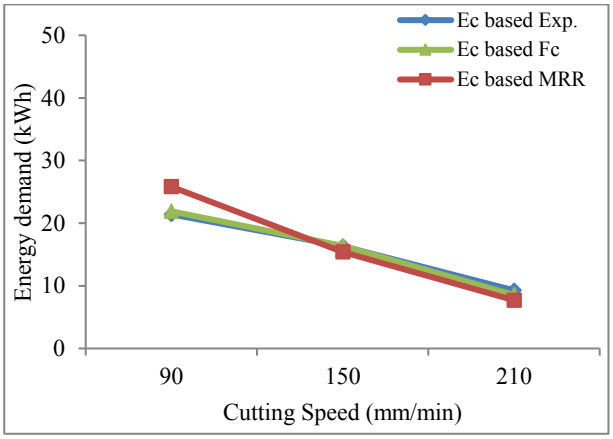

Fig. 1. Plotting energy demand for 0.10 mm/rev of feed in different of cutting speeds.

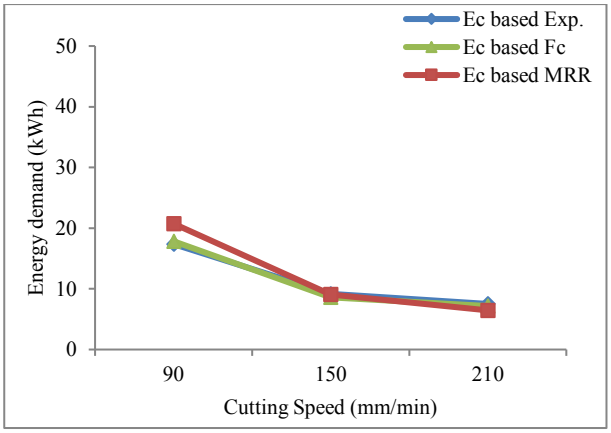

Fig. 2. Plotting energy demand for 0.16 mm/rev of feed in different of cutting speeds

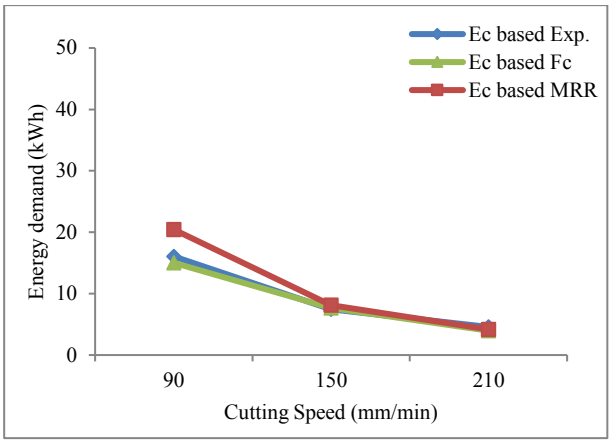

Fig. 1. Plotting energy demand for 0.22 mm/rev of feed in different of cutting speeds

Figures 1, 2 and 3 illustrate further comparison between the actual based on experiments and the estimated energy demand based on cutting force and material removal rate. All estimated energy demand values of the cutting operations are almost similar to the actual values, and the estimated value of the total energy demand is average difference of 7.3 percent than the actual one. In machining processes especially CNC machining, the energy demand that required was dominantly influenced by cutting parameters i.e. speed of cutting, feed rate and depth of cut. The cutting speed was more significant for the energy demand than feed rate. It found that the increasing cutting speed will be increase the energy demand.

These results were confirmed by Velchev et al [12], their study presented that the increasing cutting speed decreases the energy demand when turning of steel 17G2SAF using insert grade GC4235. Nur et al. [13,14] also investigate the turning of AISI 316L stainless steel using coated carbide, they concluded that the equations prediction developed for machining output can be useful in determining the optimum cutting parameters. Another study was conducted by Nur et al. for turning of aluminum alloys [15-17] and carbon steel [18-19]. The research result stated that the energy demand was influenced by cutting speed. Increasing the cutting speed will decrease energy demand, because the cutting process was faster.

5 Conclusions

In this paper, the turning of AISI 316L stainless steel using an uncoated cemented carbide was studied and concluded as following results:

- The energy demand was significantly affected by the cutting speed as compared with feeds.
- Increasing the cutting speed can be decrease the energy demand for particular machining, it is due to shorter the cutting time during the machining process.
- Determining the energy demand in the machining process can be performed with the three approaches, namely: direct measurement in the experiments, calculations using data cutting force and MRR.

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