LINKAGE OF POWER CONSUMPTION TO DESIGN FEATURE ON TURNING PROCESS

ZAHARI TAHA, HANI KURNIATI, HIDEKI AOYAMA, RAJA ARIFFIN GHAZILLA, JULIROSE GONZALES, NOVITA SAKUNDARINI
Centre for Product Design and Manufacture
University of Malaya
Faculty of Engineering, University of Malaya 50603 Kuala Lumpur
MALAYSIA
kurnia_lelana@yahoo.com  http://umisisweb.um.edu.my

Abstract: - Manufacturing process are not considered in detail in (Life-Cycle Assessment) LCA. Recently, the environmental impact of machining in LCA is determined from the rough volume material removed or weight ratio of construction material only. In this study, LCA in machining process can be related to energy and design feature by a linkage called Life-Cycle Design (LCD). Specific Energy Consumption (SEC) from various combination of machining parameter can be used to evaluate machining process in detail from design stage. Present study is an experimental study to get SEC from various combination of machining parameter. The focus of the experiment is turning process, with a combination of spindle speed, and feed rate setting. This data is useful in analysis of environmental impact in machining process at the design stage.

Key-words: machining, turning process, SEC, power, design, LCA,

1 Introduction

Currently, the environment has become a focus in every aspect of life in this ‘increasingly ageing world’. Throughout the years, innovations and inventions by human have taken a lot of unrenewable resources, left a huge amount of carbon foot-print, and created many hazardous substances that endanger human life and ecosystem. Thus, many communities are now trying to quantify or evaluate the environmental impact of a product, from the cradle to grave, from the initial raw material until the end-of-life of the product. It is commonly known as Life-Cycle-Assessment (LCA). Life Cycle Assessment is a process of evaluating the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and released to the environment; and to identify and evaluate opportunities to effect environmental improvements [1].

Life-Cycle Design (LCD) takes into account the design in the life-cycle knowledge. LCD is a tool to minimize the environmental impact of the manufacturing process from the early stages of design [2]. However, existing environmental impact assessment tool in manufacturing process are still estimated by analyzing the weight ratio of material’s construction. In fact, weight ratio is not really sufficient to account for environmental impact during process. Cutting process covers more areas that are potential to be optimized than only weight of material machined. The change in environmental impact during machining process as a result of changes of design is a linkage to develop in this study.

2 Literature Review

Power consumption of machine tool behavior has been presented by Kordonowy [3]. There are two sections of power consumption in machine tools. First, is power consumed by peripheral devices, such as spindle, servo-motor, and linear motor. This is constant over time the machine turned on and considered as fix power consumed during idle time. Power for cutting process is only consumed during cutting process. In manual machine, constant power consumed by peripheral devices takes smaller percentage of power consumption (29.8 %) than power for cutting process (70.2 %). While for automated milling machine, constant power consumption takes higher percentage (49.8 %), and the rest is for variable power (50.2 %).

Since there is different behavior between those two types of machine, the strategy to reduce power consumption for each machine tends to be different. Strategy on power consumption reduction has been highlighted by some researchers. First strategy is energy reduction by reducing fixed power from peripheral equipment, such as spindle, servo-motor, and linear motors [4,5]. This condition will reduce power consumption constantly during idle time. However, this
power consumption reduction is not related to machining condition. This method is more applicable for automated machine which has higher percentage of fixed power.

‘Cutting-energy saving’ is power consumption reduction that directly related to machining process. Different machining parameter gives different effect on power consumption [6, 7]. It is stated that machining parameter which effecting power consumption during turning process are cutting speed, feed rate, and depth of cut [7]. The higher parameter used, the higher power consumed. This last option is suitable for manual machine tool where the variable power for cutting process takes higher percentage than constant power for peripheral devices. Hence, focusing on this method is expected to give significant impact on power reduction.

Some studies on power prediction model development have been conducted. Kadrigama [6] established model for power prediction for milling 618 stainless steel using Response Surface Methodology. The model relates machining parameters such as, cutting speed, feed rate, axial depth, and radial depth with power as the response. Radhakrishnan and Nandan, [8], had developed an empirical relationship between cutting force (related to power) and the cutting parameter, such as speed, feed rate, and depth of cut in milling machine. The analysis was using regression model to filter abnormal data then continued by neural network to develop the final model. This study showed that conventional regression analysis can supply a more accurate data for force prediction in neural network.

However, still few studies that build a link between feature and environmental impact due to machining process. Shoji Nawata [2] develop a Life Cycle Design that link the LCI data to the feature in CAD/CAM data. The data of power consumption and coolant consumption are calculated from the removal volume and machining time. (Figure 1) This study compares machining process using conventional lubrication to Minimum Quantity of Lubrication (MQL).

Present study will link the LCI data of power consumption from machining process to the design feature. The change of cutting condition and dimension results in different power consumption. This data can be added to LCI data for a more accurate environmental impact assessment.

3 Concept of Study

At the design stage, a designer will come up with the dimensions of a part, material used, and surface roughness limit (Figure 2). These specifications will determine the machining recommendations. This can be obtained from a machinery handbook [9] or machining recommendation from manufacturer [10].

![Fig. 1. Linkage of LCI data to CAD/CAM data [2]](image)

Calculation of spindle speed is conducted in metric unit, using

\[ N = \frac{1000V}{\pi D} \]  

(1)

Where \( N \) is Spindle speed; rpm, \( V \) is Cutting speed; m/min, and \( D \) is the outside diameter of work piece mm).

The time of machining is calculated by

\[ T = \frac{L}{f \cdot N} \]  

(2)

Power consumption measurement is conducted from the electricity main source. So, the measured power is the accumulated of electricity power including ‘fixed power’ and ‘cutting power’. The accumulated electricity power is measured to get the overall electricity power taken by the machine tool during machining process, include the power which are distributed and wasted. Hence the data only refer to a specific machine.

<table>
<thead>
<tr>
<th>Table 1. Machining recommendations from material manufacturer [10].</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting data parameters</td>
</tr>
<tr>
<td>Cutting speed (V in m/min)</td>
</tr>
<tr>
<td>100 - 150</td>
</tr>
<tr>
<td>Feed rate (f, in mm/rev)</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
</tr>
</tbody>
</table>

Data of power resulted from machining parameter combinations are used to calculate Specific Energy Consumption (SEC) of electricity power in KWh/mm³. It is the total of energy consumed over the volume of material removed during specific machining time.
The changes of dimension change the machining time as equation 2 and automatically change the energy consumption. Therefore, the change in energy consumption as the result of the change in design aspect (dimension) can be seen clearly.

\[
SEC (\text{KWh/mm}) = \frac{\text{Power Consumption (KWh)}}{\text{volume of material removed (mm) }^3}
\]  

(3)

Figure 2. Concept of Study

4 Experimental Set-up

Power consumption in this study refers to the power consumed during turning process. The instrument used is a power meter, PROVA 6830 Power Analyzer which is equipped with three clamp on ammeter 100 amp (for three ‘3 phase’ wires), and three voltmeter mounted at the machine’s fuse box (Figure 3). Data of power consumed is recorded during machining in some combination of machining parameter, while the duration is kept the same (10 sec). Then, the power is converted into the SEC

The experiment is conducted on a manual Colchester 600 Lathe machine for turning operation. The material used is AISI D2. It is a Hot Work Chromium type that is commonly used as a punch and dies/insert in Blanking application [10]. The range of stock size in this study is 35 mm to 60 mm in diameter. The experiment is conducted by varying the cutting parameter in rough turning and fine turning. Machining activity is limited to dry cutting. This limitation has been made since this study is focused on the effect of design on the power consumption. A study by Campatelli [7] showed that power consumption of dry cutting and MQL seems to be comparable. However, the difference is on the tool life used in the two methods.

Environmental impact is calculated based on the baseline emission factor for Peninsular Malaysia given by 0.614 t CO2/ MWh (0.0614 kg/KWh) [11].

5 Result and Discussion

When the machine is running without load, the higher spindle speed will result in higher power consumption. But interestingly, when loaded, the power consumption is dependent on the set of parameter. Higher cutting speed, feed rate, and depth of cut result in a higher power consumption. (Figure 4 and 5). While in reverse, the specific energy consumption will reduce.

Figure 3. Instrumentation setup of power meter a. Clamp-on Ammeter, b. Voltmeter

It is because the higher machining parameter is able to machine a higher amount of material. Hence, it can be seen from the graph that a higher depth of cut, cutting speed, and feed rate, consumes smaller SEC (Figure 5). This result is supported by the study of Campatelli on an environmental study for a turning process of AISI 1040 steel as shown in Figure 6.

Figure 4. Power plot in cutting speed 100 m/min. Show that as the feed rate and depth cut increase, power is increase

Figure 5. Power plot in feed rate 0.2 mm/rev. Show that as the cutting speed and depth cut increase, power is increase
6 Case Study

The collected data can be used to determine power consumption for a specific design. As an example, a machining combination is used for a turning process in 2 designs of shaft (Figure 10).

Both designs have their own machining parameter combination, but on the same volume of material removed. Design 1 has the initial diameter 55 mm, machining length is 200 mm, with cutting speed 200 m/min, feed rate 0.05 mm, and depth of cut 0.5 mm. It is considered as fine turning. Second design is rough turning, and the scenario is explained in Table 2. The power is obtained from experimental study. SEC and CO₂ emission can be calculated.

From the result (Table 3), it can be seen that Design 2 which has a bigger cut but shorter cutting length, results in a lower environmental impact than the design 1 which has a smaller cut but longer cutting length. Even Design 1 used higher power (1810 Watt) than Design 2 (4092 Watt), but it needs a longer machining time than Design 2. This result reveals that by varying the depth of cut, feed rate, cutting speed, and dimension of a part (in this case length), different power is resulted. It is also shown that the reduction of power consumption can be achieved by reducing machining time as short as possible. Hence, machining parameters which are responsible for a shorter time will result in a lower power consumption as well as CO₂ emission.
Table 3. Result of case study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (mm)</td>
<td>55</td>
<td>53</td>
</tr>
<tr>
<td>Machining Length (mm)</td>
<td>200</td>
<td>43.17</td>
</tr>
<tr>
<td>Volume of material removed (mm³)</td>
<td>17113</td>
<td>17113.67</td>
</tr>
<tr>
<td>Cutting speed (m/min)</td>
<td>200</td>
<td>150</td>
</tr>
<tr>
<td>Feed rate (mm/rev)</td>
<td>0.05</td>
<td>0.4</td>
</tr>
<tr>
<td>Depth cut (mm)</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Power (watt)</td>
<td>1810</td>
<td>4092</td>
</tr>
<tr>
<td>Time (min)</td>
<td>3.454</td>
<td>0.119739</td>
</tr>
<tr>
<td>Power consumption (KWh)</td>
<td>0.1041957</td>
<td>0.008166</td>
</tr>
<tr>
<td>SEC (KWh/mm³)</td>
<td>6.089E-06</td>
<td>4.77E-07</td>
</tr>
<tr>
<td>CO₂ emission (gram)</td>
<td>6.3976139</td>
<td>0.501405</td>
</tr>
</tbody>
</table>

7 Conclusion

The results show that every machining parameter has impact to power consumed in machining process. Combinations of machining parameters need to be optimized in order to get minimum power consumption. However, machining time is the most influencing factor in power consumption.

The relationship between design, material, and machining parameter should be established to get a more practical system to detect environmental impact early in the design process. In this study data that can be used to calculate the change of power consumption as the dimension changes has been obtained. More data from several combinations of parameters and materials are still needed to have a complete database for specific material and machines type. In future work, a model can be built for environmental impact prediction of machining process at the design stage.

References:


