Establishing the Energy Profile for Geometric Variations of a Planar Surface

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Abstract

The focus of this paper is to establish energy requirements for controlling different geometric variations of a planar surface. Two test parts with 6 different planar surfaces are machined on a Prolight CNC machine. The energy consumed is gathered through Kistler piezoelectric force dynamometer, a voltage amplifier and data acquisition system. The point cloud data of the machined surface, obtained through a 3D scanner (NextEngine) is used to compute flatness zones, using MinMax algorithm. The resulting tolerance zone values and energy data observed in the machining process are then used to establish the energy profile of geometric tolerances for flatness.

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1. Introduction

Energy is critical for sustaining all living beings on the earth. Energy from the sun is used in all activities within the animal kingdom. Humans also utilize various other forms of energy (hydro, nuclear, fossil fuels, etc) besides solar energy. Due to increase in human activities, specifically manufacturing, in the past century, energy from limited resources has been depleting at a fast pace. This has led to increase awareness of energy efficiency and different notions of lean and sustainable manufacturing.

In order to increase energy efficiency in manufacturing, it is critical to understand the impacts of energy reduction on the quality of products manufactured. The geometric quality of a product is measured through evaluation/inspection of the product with regards to its conformance to the specified Geometric Dimensioning and Tolerancing (GD&T).

GD&T is the technique for specifying dimensional tolerancing and geometric tolerancing as per the ASME Y14.5 [1] and ISO1101 [2] standards. GD&T includes geometric tolerances of form, orientation, location, runout and profile.

Data has been published in many manufacturing processes handbooks [3] that relate manufacturing processes to surface finish and dimensional accuracy. Although dimensional accuracy and surface finish are some of the attributes of geometric quality of a product, other such attributes (form, orientation, profile, etc.) have not been studied extensively with respect to the manufacturing processes.

In order to develop the relation between the geometric tolerances and manufacturing processes, this paper presents an initial study on machining processes, specifically milling operation. This paper is specifically focused on the study of the relation between the energy consumed in milling of a planar surface and the resulting flatness (type of form tolerance) of the surface. The next section presents related research activities. Section 3 presents the methodology followed by experimental setup in section 4. Section 5 presents preliminary results followed by future tasks related to this study.
2. Literature Review

Many researchers have studied the use of energy in manufacturing processes. Gutowski’s research group developed energy profile and environmental impacts profile of different manufacturing processes [4-7]. They did not relate the energy and/or environmental profile to geometric quality of the products. Other researchers have investigated the relation between tool wear and power consumption [8,9]. Although, tool wear can be directly attributed to product quality, other machining parameters and vibrations [10] also contribute towards product quality. Other authors have attempted to simulate geometric deviations from a manufacturing point of view [11].

Jeswiet [12] generalized the computation of CO₂ factors from electricity requirements for product related CO2 emissions. However, the author did not consider the variability of manufacturing processes. Munoz & Sheng [13] found an analytical approach to determine the environmental impact of machining; Sheng et al. [14] investigated an environmental-based systems planning for machining. However, the research focused on energy consumption only in the process of material removal. Chen et al. [15] created a life cycle energy-consuming model to estimate the energy consumption during the entire product life cycle.

The literature review shows three different groups of researchers, first group is of the researchers who are interested in environmental impacts of manufacturing as a whole. Second group is of the researchers who are pursuing better quality (mostly surface finish) by optimizing and monitoring machining conditions. The third group is of the researchers that are utilizing machining parameters and related uncertainties to better utilize tolerance analysis for design and manufacturing. None of the groups concentrate on investigating energy profile or environmental impacts for achieving a particular geometric tolerance.

3. Methodology

For studying the relation between energy usage in milling operation and the resulting flatness of a planar surface, the following method is utilized in this study. First a stock of rectangular block of aluminum 6061 is obtained. The dimensions of the stock are 2.0 inches by 2.0 inches by 1.5 inches. This stock will be milled in a ProLight CNC machine with a flat end, 3 flute, 0.375 inch diameter carbide milling tool. In order to reduce the variability arising from different tool paths, as a first step, a single straight tool path is chosen. The width of cut will be selected as either 0.1875 or 0.375 inches. The spindle speed is selected as 1000rpm as the first step.

The stock will be machined at a feed rate of 6 inches per minute and to three different depths of cut, viz., 0.02 inches, 0.06 inches and 0.1 inches.

Fig 1 shows the part (with width of cut 0.1875 inches) to be manufactured on the ProLight CNC milling machine. The part is symmetrical on the left and the right side. There are two planes at the end of width 0.1875 inches at a depth of cut of 0.1 inches. Similarly, the next two planes at the end are of width 0.1875 inches at a depth of cut of 0.06 inches. At the last two pairs of planes are at a depth of cut of 0.01 inches. All the planes will be cut with climb milling. The cutting tool is visually inspected for any wear, so as to reduce the effects of wear on the flatness of the surface.

Energy profile of flatness can be developed by measuring the energy consumed while machining a particular material with a particular set of machining parameters and plotting the energy against the flatness of the machined surface. Energy consumed by the spindle is measured through P3 energy meter. The energy consumed by the stepper motors for feed rate is measured using 3 component Kistler piezoelectric transducer (model no. 9257A) coupled with a dual mode voltage amplifier (model no. 5004) and data acquisition through measurement and computing (model USB 1608FS) system. The flatness of the milled surface is measured from the point cloud (of the milled surface) gathered through the NextEngine 3D optical scanner.

By varying the milling parameters, such as depth of cut, width of cut, type of cut, feed rate etc., different energy consumption and different amount of flatness can be observed on the milled surface. If sufficiently large number of surfaces is studied, the relation between flatness and energy consumption for the specific tool and the machine can be obtained. It should be feasible to extend the results to other tools and machined materials.

4. Experimental Setup

The experimental setup is shown in Fig 2. The stock part is loaded onto the piezoelectric transducer that is fixed on the Prolight milling table (Fig 2 (a)). As the part...
is machined to the required specification, the forces acting on the part form the cutting tool are measured, as voltages, by the 3 component piezoelectric transducer. The measured voltage is first amplified in a voltage amplifier, Fig 2(b), and then transferred to a computer through a data acquisition system (Fig 2(c)).

On the other hand, as soon as the part is machined, it is removed from the piezoelectric transducer and affixed on the NextEngine 3D scanner table (Fig 2(d)). The part is scanned at the highest resolution for the scanner. The point cloud data is trimmed so as ignore any points on the periphery of the machined surface to be scanned. This trimming is necessary to disregard any sharp corners that might be deburred while further processing the part. The trimmed point cloud data is then obtained as a text file. This text file is then fed into a MinMax flatness tolerance evaluation algorithm. This MinMax flatness evaluation is based on a convex hull derived through Qhull [16]. The convex hull is then used to compute the minimum of the maximum distances between a plane and a point on the convex hull. The minimum distance this obtained is the flatness for the machined plane.

5. Results

Two parts shown in Fig 1 are machined on the Prolight milling machine. The force versus time plot for depth of cut 0.1 inch, is shown in Fig 3. As is quite evident, the force is only present in one direction. This force is in the direction of tool motion. There are some fluctuations in all the 3 components of the force as the tool is rotating. The time to cut is approximately (2.375*60/6 = ) 23.75 seconds, as is also evident from

Fig 3. Force measured through kistler 3 component force platform at depth of cut 0.1 inches, 1000 rpm, width of cut at 0.1875 inches and type of cut climb.

Fig 4. Flatness observed in several samples of machined surface with different depth and width of cut and milling type.

Fig 3. The data in Fig 3 is used to compute the energy consumed in milling. Data similar to Fig 3 is obtained for all depths of cut.
As discussed in section 4, the parts are then scanned. The flatness values are obtained for each surface. Fig 4 shows the flatness values obtained for the machined surfaces with respect to the depth of cut, width of cut and type of cut. The first observation from Fig 4, is that as the depth of cut increases, generally speaking, the flatness tolerance obtained on the surface also increases. Furthermore, at the depth of cut of 0.06 inches and 0.1 inches, climb milling gives better flatness than up milling. At the depth of cut of 0.02 inches contrastingly, this is not the case. At 0.02 inches contrasting result is obtained for the low sample size used in this study. More samples are needed to validate the results obtained.

Table 1 shows the energy values for different depth of cuts while climb milling a 0.1875 width of planar surface. As the depth of cut increases, energy also increases, almost linearly (Fig 5.) The flatness values are not consistently increasing or decreasing. This might be due to several factors (a) inconsistent scanning of the machined surface, (b) human errors in trimming too much or too little of the machined surface or (c) many of the random errors attributed to machining. In order to eliminate these errors, a consistent plan of scanning the surfaces at different inclinations and orientation coupled with an automated trimming is required. For reducing the effect of random errors, a sample size of at least 10 machined surface is needed.

Table 1: Comparison of energy consumption based on different depths of cut for aluminum 6061 on a proligh lathe with spindle speed as 1000rpm and feed rate 6 inch per minute.

<table>
<thead>
<tr>
<th>Climb Milling depth of cut</th>
<th>Width of cut</th>
<th>Stepper Energy (W-s)</th>
<th>Flatness (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.1875</td>
<td>152.3</td>
<td>0.0191</td>
</tr>
<tr>
<td>0.06</td>
<td>0.1875</td>
<td>102.1</td>
<td>0.0140</td>
</tr>
<tr>
<td>0.02</td>
<td>0.1875</td>
<td>30.92</td>
<td>0.0158</td>
</tr>
</tbody>
</table>

6. Conclusions

The paper presents an experimental methodology to investigate energy profile for machining a planar surface with different machining parameters and the flatness tolerance obtained on the machined surface. Preliminary observations suggest that if other machining parameters remain constant, flatness of a machined planar surface is proportional to the depth of cut used in machining the surface. At depths of greater than 0.02 inches, climb milling seemed to generate tighter flatness than up milling. Although an energy profile for flatness may not be concluded in this limited study, due to small sample size, but this research lays the foundation for future studies with larger sample size.

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References


