A GREEN PROCESS PLANNING SYSTEM

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Abstract

The worldwide demand for energy has increased manifold in the last two decades. For example, manufacturing industry alone consumes one third of the world’s energy. Innovating new methods of reducing energy consumption is an important issue drawing global attention. In this work, a green process planning methodology is developed for machining prismatic parts where the alternative process plans can be evaluated to ascertain their green quality. An expert system is used for developing the process planning module. Given the information about different features present in a part, machining operations, machine tools, cutting tools and material properties as input, the expert system automatically gives alternative process plans for machining the component. The system is capable of evaluating the green quality of the alternative process plans in the green criteria evaluation module regarding specific energy consumption, machining time, use of green material and material consumption. The performance of the green process planning system is validated on a variety of prismatic parts and agreeable results are obtained.

Keywords: Green process planning, prismatic part, expert system, specific energy, MRR

1 Introduction

The growing demand for energy involving all spheres of human civilization is an important issue in need of immediate attention. Manufacturing industry involves various energy exhaustive processes and it consumes a large share of the global energy requirement. It is high time manufacturers explore means to reduce energy consumption in all spheres of manufacturing. Moreover, environmental consideration is an important issue in the present manufacturing scenario. In the emerging trend of green manufacturing, manufacturing processes should be eco-friendly, sustainable and energy consumption should be less. In view of it, objective of green process planning is to improve the green quality of process plans by using various measures. It has become an essential and fast developing research area in manufacturing. Process planning for green manufacturing emphasizes on reducing energy and resource consumption, avoid wastage, reduce noise and harmful environmental effects during manufacturing without sacrificing on productivity, quality, and efficiency. It is a supportive method for traditional process planning that makes manufacturing methods more energy efficient and eco-friendly. The present work involves developing a green process planning strategy by reducing energy and resource consumption during machining. Process planning has been an active research area in the last three decades and it is widely investigated by various researchers. Some important review articles on process planning are found in ElMaraghy (1993), Eversheim and Schneewind (1993), Leung (1996), Yip-Hoi (2002), and Xuet al. (2007). However, there was less awareness regarding energy consumption and environmental effects while developing process plans for machining. Literature review reveals that there was some awareness for green manufacturing in the last decade. Of late, there have been several efforts to develop process plans for green manufacturing. An early effort for green process planning is found in Sheng and Srinivasan (1995) where the authors selected the optimum processing path by striking a balance between environmental effect, production rate and quality. Analytical hierarchy process (AHP) was used to assess the green attribute of the process plan considering energy, recycling, toxicity, and cost. Adaptability of process plans to changing manufacturing environment is an important issue. The primary focus of Krishnan and Sheng (2000) and Jiang et al. (2008) is on developing flexible process planning support systems for green manufacturing which are adaptive to different web-based designs. They can be used by distributed manufacturers through the Internet. These process planning support systems are developed on the basis of web and capable of distributed processing and storage of the data. Two similar attempts to develop process planning support system for green manufacturing (GMPPSS) to evaluate the green attributes of process planning are found in Yan et al. (2007) and Jadav and...
Objective of these systems is to optimize raw material consumption, secondary material consumption, energy consumption and environmental impacts of manufacturing processes. Energy saving, recycling, reuse, and reducing waste, resource consumption and harmful environmental effects during machining have been the priority of several research efforts (Dahmus and Gutowski, 2004; Fei et al., 2005; Kuo et al., 2006; Park et al., 2009; Diaz et al., 2011).

It is observed from the literature review that importance is shifted from traditional process planning system to environmentally friendly process planning system in green manufacturing environment. Green process planning technique is a key approach to improve the environmental friendliness of the manufacturing processes. Exploring for the innovative ways of green process planning can give a new direction to the research on environmentally friendly manufacturing. In the present work, a green process planning methodology is developed for machining prismatic parts where the alternative process plans can be evaluated and the optimum process plan can be selected based on specific energy consumption, machining time, green material and material consumption.

2 Proposed Methodology

2.1 Process Planning Expert System

The overall architecture of the proposed green process planning system is shown in Figure 1. It has been implemented using the expert system shell CLIPS, an acronym for CLanguage Integrated Production System that is based on the forward chaining strategy (Giarratano and Riley, 1998). CLIPS facilitates modeling of human knowledge and expertise to develop intelligent software. The preliminary work for the development of the process planning expert system is based on the work presented in reference Hazarika et al. (2011). The proposed green process planning system mainly consists of two parts: process planning expert system section which gives alternative process plans to machine a component and green criteria evaluation section where alternative process plans are evaluated to ascertain their green quality. The details of each module of the green process planning system are discussed in the following subsections.

2.2 Green Criteria Evaluation

In most of the process planning efforts found in the literature, there is no evaluation tool for assessing the green attribute of the developed process plans. In this work, a methodology is developed for evaluating the green quality of the alternative process plans in the green criteria evaluation module regarding specific energy consumption, machining time, use of green material and material consumption. Working of each module of green criteria evaluation is discussed hereunder.

2.2.1 Cutting Energy Calculation Module

For comparing the cutting energy for different machining sequence and changing material removal rate (MRR), the concept of specific energy, i.e., energy consumed per unit volume of material removed is used. If the energy consumed per unit volume of material removed can be decreased, the end goal of reducing energy while manufacturing a component can be achieved.
Cutting energy for different machining sequences

There can be a number of alternative machining sequences to machine a component. Total cutting energy demand for different machining sequences will vary. This module calculates the total cutting energy needed in machining a component following different machining sequences and the least energy sequence is selected. The cutting energy required for machining a component is given by (Stephenson and Agapiou, 2005):

\[ E = u_s \times V \]  

(1)

where, \( E \) is cutting energy in Joule, \( V \) is volume of material removed in mm³ and \( u_s \) is the specific energy in J/mm³. Now total cutting energy \( E \) for machining a component can be obtained from Eq. 2 where \( E_1 \) to \( E_n \) are the cutting energy needed for individual machining operations like milling, drilling, etc. to complete the part.

\[ E = E_1 + E_2 + E_3 + \ldots + E_n \]  

(2)

Alternative machining sequences are obtained from the alternative process plans. After calculating the cutting energy for alternative machining sequences, this module will compare the cutting energy demand of different sequences and select the sequence that requires the minimum energy. For example, in Figure 2, it is evident that Machining sequence S2 will consume more cutting energy than S1 as the depth of the drilled hole is more.

\[ \text{Figure 2 (a) Machining sequence S1 (b) Machining sequence S2} \]

Reducing specific energy by increasing MRR

It is an established fact that MRR plays a dominant role in cutting energy demand during machining (Dahmus and Gutowski, 2004; Diaz et al., 2011). Higher value of MRR decreases specific energy. MRR is given by (Stephenson and Agapiou, 2005):

\[ \text{MRR} = f_r b d \]  

(3)

where \( f_r \) is feed rate, \( b \) is width of cut and \( d \) is depth of cut. MRR can be increased by increasing feedrate or width/depth of cut. However, higher feed rate is preferred to larger depth/width of cut as higher feed reduces specific cutting force more significantly (Neugebauer et al., 2012). The feedrate of the lowest energy machining sequence is obtained from the process plan and it is increased in steps to increase the MRR. The corresponding values of decreasing specific energy are calculated. The optimum MRR at which specific energy is the minimum is selected.

2.2.2 Machining Time Calculation Module

Increasing MRR (as discussed above) will decrease the time required for machining, thus saving on resource consumption. The main objective of this module is to reduce machining time by considering the optimum MRR. As the time required for machining decreases with increasing MRR (by increasing feedrate here), both resource consumption and specific energy requirement will be less. For example, the time required for milling operation \( t_m \) is given by (Stephenson and Agapiou, 2005):

\[ t_m = \frac{l + l_e}{f_r} \]  

(4)

where \( l_e \) and \( l \) are the approach length and total length to be milled. Similarly machining time for other machining operations like drilling, chamfering, reaming, etc. can be calculated in this module. The total machining time for a component is equal to the sum of machining times for all the machining operations to complete the component. The decrease in machining time for increasing MRR (by increasing feedrate) is noted. Striking a balance between the range of process parameters for the available machine tool, machining requirements, viz. surface finish, tolerance, work piece material, cutting tool, an optimum MRR can be selected for reducing machining time.

2.2.3 Use of Green Material

Due to increasing environmental concern all over the world, use of green material is encouraged in manufacturing. A material can be called green if it consumes less energy for machining, has good machinability, less effect on the environment, and can be recycled and reused. Different materials have different specific energy values. If two materials A and B have similar mechanical properties and the specific energy of B is lower than that of A, then using material B will result in less energy consumption. The main purpose of this module is to suggest the material with the lowest specific energy among the materials having similar mechanical properties. For example, specific energy of AISI 1040 steel is 1.8 J/mm³ and that of AISI 1020 steel is 1.5 J/mm³. Both the steels have similar
mechanical properties. To cut a step of size 50x25x30 mm³ and drill a hole of 20 mm diameter and 20 mm depth from the block of size 50x50x50 mm³ as shown in Figure 2, use of AISI 1040 steel consumes 78.80 kJ (from Eq. 1). However, use of AISI 1020 steel consumes less energy of 65.67 kJ.

2.2.4 Raw Material Consumption Module

Resource efficiency regarding raw material consumption and secondary material (e.g. coolant) consumption is important in green manufacturing. Reducing resource consumption and avoiding waste is the motto in green manufacturing. The density of a material is its mass per unit volume and greater the density, heavier is the material and material consumption is more. Therefore, using lower density material, raw material consumption can be reduced. Raw material consumption module will compare the density of various materials having similar mechanical properties and select the material which has lower density so that the material consumption is less.

Conventional wet machining process involves use of cutting fluids. In dry machining, no cutting fluid is used but appropriate cutting tools and process parameters are used. High pressure air can be used to remove the wastes. For green manufacturing, the present trend is to use near-dry and dry machining. In near-dry machining, the cutting fluid is a fine mist of the mixture of air and small amount of cutting fluid. Dry machining is preferred which eliminates the cost of purchase, storage, use, and safe disposal of the cutting fluids.

2.3 User Interface

The user interface is that part of the CLIPS that provides the mechanism by which the user interacts with the system. It provides a communication interface to the user. The information on the various attributes of the features and the machining operations of a component, information on machine tools and cutting tools, process parameters, properties of the workpiece material are to be given as input by the user. The user interface allows the user to create and edit the database and knowledge-base files using a text editor, save the text files, load the saved files into CLIPS environment, and execute the expert system program. Output of the final results and decisions are also communicated to the user through this interface.

3 Illustrative Example

An example part shown in Figure 3 is presented here to demonstrate the application of the proposed green process planning methodology. The raw stock is a prismatic block of dimensions 50x50x50 mm³ and the part contains five machining features.

Table 1 shows the features to be machined, their dimensions, corresponding machining operations, and the cutting tools selected for machining the example part.

<table>
<thead>
<tr>
<th>Features</th>
<th>Dimension (mm)</th>
<th>Machining operations</th>
<th>Cutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through hole 1</td>
<td>Ø5x10</td>
<td>101 Drilling</td>
<td>Drill, 5 mm dia, 118° point angle, 30° helix angle</td>
</tr>
<tr>
<td>Through hole 2</td>
<td>Ø5x10</td>
<td>102 Drilling</td>
<td>Do</td>
</tr>
<tr>
<td>Step 3</td>
<td>50x40x20</td>
<td>201 Milling</td>
<td>End mill, 10 mm diameter</td>
</tr>
<tr>
<td>Slot 4</td>
<td>20x20x50</td>
<td>301 Milling</td>
<td>End mill, 10 mm diameter</td>
</tr>
<tr>
<td>Chamfer 5</td>
<td>45°x10x50</td>
<td>401 Chamfering</td>
<td>Chamfer mill, 10 mm diameter</td>
</tr>
</tbody>
</table>

Following the methodology given in Hazarika et al. (2011), the alternative process plans are generated by executing the expert system. Table 2 shows the six alternative process plans for the example part. They contain the setups, sequence of machining operations within a setup, and primary datum for each setup. Machine tool suggested is vertical machining center (MC) equipped with rotary index table and simultaneously controlled three Cartesian axes X, Y, and Z where all the five features can be machined in a single setup. Setup-1. Spindle speed and cutting velocity for milling operations are 400 rpm and 12.56 m/min respectively and that for drilling are 800 rpm and 12.50 m/min respectively. Feed rate for both milling and drilling are 90 mm/min. Each alternative process plan is evaluated in the green criteria evaluation module for assessing their green quality following the procedure described in Section 2.2.
Table 2: Alternative process plans for the example part

<table>
<thead>
<tr>
<th>Process plans</th>
<th>Setups</th>
<th>Sequence of machining operations</th>
<th>Primary datum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan-1</td>
<td>Setup-1</td>
<td>101 Drilling 102 Drilling 201 Milling 301 Milling 401 Chamfer</td>
<td>Bottom face</td>
</tr>
<tr>
<td>Plan-2</td>
<td>Setup-1</td>
<td>201 Milling 301 Milling 101 Drilling 102 Drilling 401 Chamfer</td>
<td>Bottom face</td>
</tr>
<tr>
<td>Plan-3</td>
<td>Setup-1</td>
<td>301 Milling 201 Milling 101 Drilling 102 Drilling 401 Chamfer</td>
<td>Bottom face</td>
</tr>
<tr>
<td>Plan-4</td>
<td>Setup-1</td>
<td>201 Milling 101 Drilling 102 Drilling 301 Milling 401 Chamfer</td>
<td>Bottom face</td>
</tr>
<tr>
<td>Plan-5</td>
<td>Setup-1</td>
<td>101 Drilling 102 Drilling 301 Milling 201 Milling 401 Chamfer</td>
<td>Bottom face</td>
</tr>
<tr>
<td>Plan-6</td>
<td>Setup-1</td>
<td>301 Milling 101 Drilling 102 Drilling 201 Milling 401 Chamfer</td>
<td>Bottom face</td>
</tr>
</tbody>
</table>

Working material database contains different materials with their properties. From working material database, it is found that AISI 1040 steel and AISI 1020 steel have similar mechanical properties of hardness 149, density 7.845 gm/cc, Poisson’s ratio 0.27–0.30, elastic modulus 190–210GPa, tensile strength 518.80MPa, and yield strength 294.80 MPa (Source: www.efunda.com/materials/alloys/carbonsteel). However, specific energy of AISI 1040 steel is 1.8 J/mm³ and that of AISI 1020 steel is 1.5 J/mm³. Green material module suggests AISI 1020 steel as the working material for the example part. It has comparatively lower value of specific energy and density, and good mechanical and machinability properties. Using Eq. 1 and Eq. 2, cutting energy is calculated (considering AISI 1020 steel as work piece material) for all the six alternative machining sequences given in Table 2. It is found that machining sequences in Plan-2, Plan-3, and Plan-6 consume the least energy of 96.10 kJ compared to 105.52 kJ for Plan-1 and Plan-5 and 100.82 kJ for Plan-4. Any of the three sequences in Plan-2, Plan-3, and Plan-6 can be selected for machining the part. To study the effect of increasing MRR on specific energy and machining time, suggested feed rate of 90 mm/min is increased in steps. MRR is increased with each increase in feed rate. Total machining time for the example part is calculated as discussed in Section 2.2.2 for each increase in feed rate/MRR. Figure 4 and 5 shows the decrease in specific energy and machining time respectively with increasing MRR.

In Figure 4, specific energy decreases rapidly until a MRR of 14000 mm³/min (approx) is reached. For MRR lower than that, a slight increase in MRR causes a sharp drop in the specific energy. For MRR greater than 17000 mm³/min (approx), the gain from increasing MRR is minimal since the specific energy begins approaching a steady-state value and show only a minor decrease in energy consumption. Similar trend of decreasing machining time with increasing MRR is seen in Figure 5. Therefore, the green criteria evaluation module suggests increasing the feed rate maximum up to 300 mm/min to achieve fruitful gain in specific energy and machining time. Finally, the green process planning system suggests AISI 1020 steel for the
example part, any of the process plans given in Plan-2, Plan-3, and Plan-6 with the selected machine tool, cutting tools and given cutting conditions.

4 Conclusions
A green process planning methodology is developed for machining prismatic parts. An expert system is used for developing the process planning module. Green criteria evaluation section contains different modules where the alternative process plans are evaluated and the optimum green process plan is selected based on specific energy consumption, machining time, use of green material and material consumption. The system is capable of suggesting an optimal MRR for reducing specific energy and machining time in addition to suggesting green material which are reusable, recyclable, and absorb less energy. The working of the system is explained with an example part. The performance of the green process planning system is validated on a variety of prismatic parts and agreeable results are obtained. The optimum MRR has to be decided judiciously considering all related factors, viz: appropriate machine tool, cutting tool, range of process parameters, machining requirements, and work piece material.

References