Erratum to: Toolpath strategies and management to optimize energy consumption on 3-axis CNC milling machine

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The third paragraph on the 1 Introduction section should be replaced as follows:

Milling is one of the process of removing material which occurs because of the contact between the cutting tool that rotates on the spindle with the workpiece gripped on the machine table. In the digital era, there are many automated machines that are increasingly facilitating the production process, including milling machines. Many large industries have switched to CNC (Computer Numerical Control), but not a few manufacturers are still utilizing manual milling machines for production activities. Although it still operating on the same basic principles, modern CNC milling machines are significantly different from older milling machines. CNC machining plays an important role in current mass manufacturing because of its ability to achieve high accuracy and precision as well as its ability to accept computer commands for motion control [5].

The fourth paragraph on the 1 Introduction section should be replaced as follows:

Despite of its higher productivity and accuracy, the use phase of a CNC milling machine tool causes CO_2 emissions varying from 60% to 90% [6]. Hence, in order to achieve a sustainable state, reduction of the environmental impact and overall energy consumption on a CNC milling machine may be obtained by further research focused on reducing operational time. Improving energy efficiency in CNC milling machine requires the knowledge about the energy consumption as a function of the machine tool and the cutting process itself [3]. He et al. [7-8] reported that machine tools efficiency is less than 30% and proposed that since machine tool can be controlled through NC codes, therefore it is possible to estimate the energy consumption using the related NC codes that controls the movement of the machine tools. For a NC machine tool, the energy consuming component generally consist of spindle, axis feed, servos system, tool change system and other auxiliary equipment such as coolant pump, fans, light, computers, air pump, lubricating pumps etc. [2].

The last paragraph on the 1 Introduction section should be replaced as follows:

The aim of this research is to evaluate and compare the energy consumption required for the spindle motor, x-axis, y-axis, and z-axis feed motor on a 3-axis milling machine by using the correlation between the NC codes generated from the different types of cutting toolpath, since a part may be manufactured by various methods with each method having different machining time and energy per component. The NC codes were generated from Siemens NX CAM software. Energy consumption on the spindle motor and each axis feed motor is then processed using a Graphical User Interface, by computing the energy consumption as a summation of the energy on all the lines of the NC code. Previously, other researchers have developed energy model and energy prediction software to analytically estimate the power consumption and the processing time [9]. This research was used to develop an NC code-based software to predict the lowest energy consumption in machining a certain workpiece.

The number of references on the 2 Proposed energy model section should be replaced as follows:

According to Pavanaskar and McMain's work about energy consumption analysis for CNC-milling toolpaths, a generalized representation of most existing models can be made in the form of:

$$E = \mathbf{\Sigma} PowerState_i \, . \, time_i \qquad (1)$$

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where E is the total energy, and *PowerStatei* is the power state the machine at and *timei* is the corresponding time intervals when the action takes place [10].

While according to He et al.'s work on analysis and estimation of energy consumption for numerical control machining, the energy total has been expanded to:

$$E_{\text{total}} = E_{\text{spindle}} + E_{\text{feed}} + E_{\text{tool}} + E_{\text{cool}} + E_{\text{fix}} \quad (2)$$

where E_{total} is the total energy consumption of NC machining, E_{spindle}, E_{feed}, E_{tool}, E_{cool}, and E_{fix} are the energy consumption of spindle, axis feed, tool change system, coolant pump, and the fixed energy consumption, respectively [8].

In this study, energy consumption of tool change system, coolant pump, and the fixed energy consumption components i.e. servos systems and fan motors are ignored. The energy estimations to machine parts are only based on energy consumption of spindle and axis feed.

The title of the section 2.1. Modelling energy estimation of spindle should be replaced as follows:

2.1 Modelling energy estimation of spindle

The first paragraph, first sentence of the section 2.1 Modelling energy estimation of spindle should be replaced as follows:

According to He et al [8], energy estimation of spindle can be divided into two sections, loaded and unloaded.

The first paragraph, third sentence of the section 2.2 Modelling energy estimation of axis feed should be replaced as follows:

The energy modelling of axis feed in reference [8] is calculated as:

The first paragraph on the 3.4 Output section should be replaced as follows:

The Graphic User Interface (GUI), inspired by Edem and Mativenga's work [9], as seen in Fig. 3, is developed to assist the estimation of the energy consumption. User's input is required to calculate and estimate the energy consumption, e.g. motor axis X, Y, and Z power, spindle power, etc. These motor powers are given based on EMCO VMC 200 machine specifications. The detailed machine specs can be seen in Table 2.

The first paragraph on the 4.1 Total energy consumption on prismatic parts section should be replaced as follows:

It can be seen that in the experiment with prismatic parts I, II, and III, the toolpath strategy that has the least total energy consumption is zig zag. The total energy consumption savings in the cutting process by zigzag toolpath compared to the other two toolpath strategies for the three prismatic components are 15.48%, 20.64% and 18.73%, respectively.

One of the sentences on second paragraph, third sentence of 4.1 Total energy consumption on prismatic parts section should be replaced as follows:

Lifting and repositioning of the cutting tool from the middle of the cut area to the edge, cause a higher cycle time and energy requirements.

One of the sentences on first paragraph, first sentence of 4.2 Total energy consumption on sculptured part section should be replaced as follows:

While for sculptured part, the best toolpath strategy that has the lowest total energy consumption during the cutting process is the follow part pattern.

One of the sentences on first paragraph, sixth sentence of 4.2 Total energy consumption on sculptured part section should be replaced as follows:

While the zigzag toolpath consumes lowest energy for cutting the three prismatic parts, it consumes the second largest energy for cutting the sculptured surface part.

The Acknowledgement section should be replaced as follows:

The GUI we developed referred to the GUI of Isuamfon F. Edem and Paul T. Mativenga. This research is funded by PITTA Research Grant 2018 –Universitas Indonesia.

The Conclusion section should be replaced as follows:

This paper has estimated and predict the roughing processes energy consumption in a 3-axis milling machine using the correlation between the NC codes generated from the different types of cutting toolpath. The findings include the following:
- Zigzag toolpath strategy has the least energy consumption in machining the three prismatic parts.
- Follow Part toolpath strategy has the least energy consumption in machining the sculptured part.
- Different toolpath strategies on the cutting process of a workpiece will result in different energy consumptions in machining.
- Choosing the right toolpath strategy will have an impact on the efficiency of the milling process.
- With greater understanding on toolpath strategy, NC codes generated from CAM software with an energy consumption prediction software can be use to predict the lowest energy consumption in machining a certain workpiece.

The contents and order of the references should be replaced as follows:

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