euspen's 24th International Conference & Exhibition, Dublin, IE, June 2024
www.euspen.eu

Energy-saving tool path generation for NC machine tools by model based simulation of feed drive system

Akio Hayashi[1], Naru Kawamura[1], Yoshitaka Morimoto[1]

[1]*Kanazawa Institute of Technology*

a-hayashi@neptune.kanazawa-it.ac.jp

Abstract

Due to the problem of depletion of energy resources and the rise in energy prices in recent years, as SDGs of section 7and 9.4, and GX (green transformation) are being advocated, energy conservation has become an essential issue in various fields. Therefore, the authors focused on the power consumption required for feeding during machine tool operation and clarified that the energy consumption differs depending on the tool path. Based on the results, we thought that it would be possible to save energy by modifying the tool path when processing the same product. In this study, we regenerated an energy-saving tool path by solving a path search problem that uses energy consumption as a weight for the tool path generated by our unique tool path generation system. This paper shows that it is possible to save energy in the tool path by considering the energy required for the feed motion of the machine tool, and its effects.

Keywords: Energy consumption, NC machine tools, Tool path, Model based simulation

1. Introduction

In recent years, reducing energy consumption at production sites is an urgent issue, and efforts are being made to make NC machine tools, which are the main production equipment for machining, more energy efficient. Measurement of power consumption, miniaturization, and improvement of efficiency have been carried out, but few have focused on the tool path. The machining tool path of NC machine tools is generated by CAM software. However, these generated programs do not consider the energy consumption of the feed drive system, and cannot be said to be an energy-saving tool path.

Therefore, the authors focused on the power consumption required for feeding during machine tool operation and clarified that the energy consumption differs depending on the tool path. In this study, we develop an energy-saving tool path generation system that takes into account the power consumption in the feed drive system of machine tools. We propose a system that performs machining simulation on 3D-CAD and obtains tool position coordinates and calculates tool paths while taking energy efficiency into consideration.

Furthermore, by using the mathematical model of the machine tool's feed drive system, we simulated the power consumption in tool paths during driving of the machine tool's moving table. Finally, we verify the energy saving effect of the proposed method by estimating the energy consumption. However, this paper only examines the energy consumption due to the tool path by the feed drive axis, and does not take into account the spindle energy required for cutting.

2. Proposed energy saving tool path generation system

In this study, we used SolidWorks as the 3D-CAD software, and created a tool position coordinate acquisition system using the VBA (Visual Basic Application) engine. CAD models of machined parts and tools are placed in the assembly as shown in Figure 1. Then, the tool is moved on the CAD so that the tool end and the part shape come into contact, and the tool center coordinates at that contact point are obtained as the tool path. Rough machining is performed using scanning line machining.

Furthermore, we developed a program that generates the shortest and energy-saving tool path from the acquired tool position coordinate points. In this study, for a method for calculating the shortest and energy-saving tool path, we adopted the greedy method that minimizes the sum of the distances of a circuit that passes through the coordinate points of all points only once.

Considering that the power consumed when moving on each axis is different, we used the power consumption of each axis as a cost index, as shown in Figure 2. The system calculate for a tool path that minimizes the total cost. Equation (1) shows the cost on the X axis as C_x, the cost on the Y axis as C_y, the cost on the Z axis as C_z, and the total cost as C_min. This results in the generation of a tool path that consumes less energy. Furthermore, by using a cost index, the proposed system can be applied even if the mechanism of the machine tool used changes.

$$C_{min} = \sum_{k=1}^{n} k\, C_x + \sum_{k=1}^{n} k\, C_y + \sum_{k=1}^{n} k\, C_z \qquad (1)$$

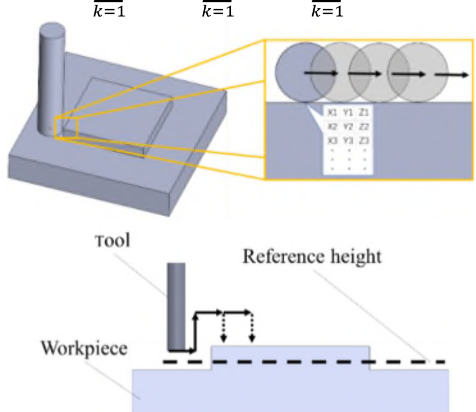


Figure 1. Schematic diagram for tool path generation on 3D-CAD

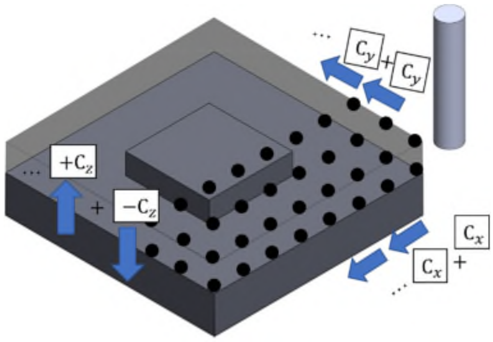


Figure 2. Schematic diagram for energy saving tool path generation

3. Evaluation of proposed method

In order to demonstrate and evaluate the energy-saving tool path generation method, tool paths were generated using a workpiece model shown in Figure 3. The tool was assumed to be a square end mill with a tool diameter of 5 mm.

Figure 4(a) shows the generated tool path when the cost values for each movement direction are set to C_x=1 and C_y=2, and Figure 4(b) shows the generated tool path when the cost values are set to C_x=2 and C_y=1.

Then, the power consumption of each axis are simurated by simulation model of the feed drive system as shown in Figure 5 [2], and calculated the energy consumption. The power consumption is simulated assuming that it is equal to the motor power, which is the multiplied of the motor torque and the angular velocity. Here, it was confirmed that the power consumption of each axis (X, Y) of the machine tool is greater for the X axis. The power consumption simulation results in tool paths are shown in Figure 6. Table 1 also shows the energy consumption.

The results for tool path (a) show that energy consumption is reduced. This is because by setting the cost values C_x=1 and C_y=2, the X-axis movement time becomes longer with low power consumption cost. From this, the effectiveness of the energy-saving route generation system was demonstrated by understanding the power consumption of the machine tool's feed axis and introducing this into the system as a cost index.

4. Conclusions

In this study, we focused on the power consumption of the feed drive system of machine tools, and developed tool path generation system that considering the energy efficiency. In addition, we performed tool path generation and simulation the energy consumption based on the model of the feed drive system, and evaluated the validity of the proposed method. The conclusions obtained in this study are shown below.

1. We proposed a tool path generation method that uses the power consumption of each axis as a cost index to generate the shortest path.

2. By the proposed tool path generation method, we achieved energy savings in the tool path based on the power consumption of each axis.

In tool path generation in this paper, only the X- and Y-axes are set as cost indicators, and the Z-axis movement is not considered. However, the power consumption of the Z-axis is extremely large, and it is known that it also varies depending on the direction of vertical movement. Taking this into account is thought to lead to further energy savings, and is the next topic of this study. In addition, the model of spindle considering cutting force will be generated. Then, the energy consumption by the cutting power can be simulated and estimated.

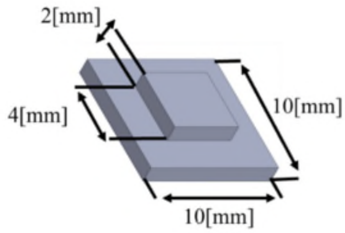
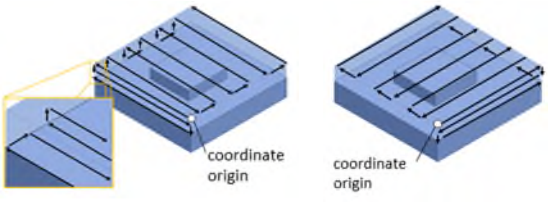


Figure 3. Workpiece model for tool path generation



(a) C_x=1, C_y=2 (b) C_x=2 and C_y=1

Figure 4. Regenerated tool paths for energy-saving

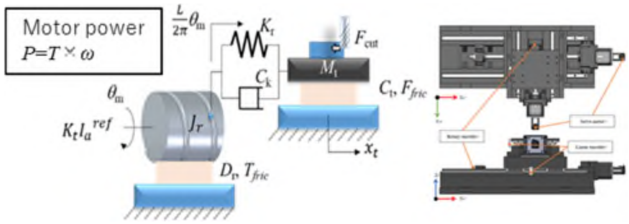
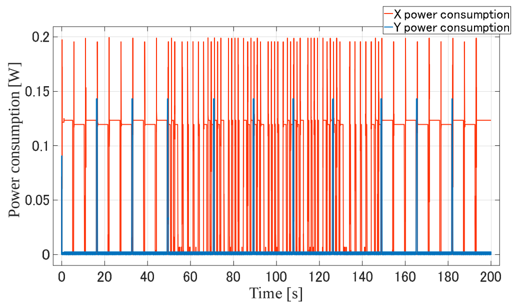
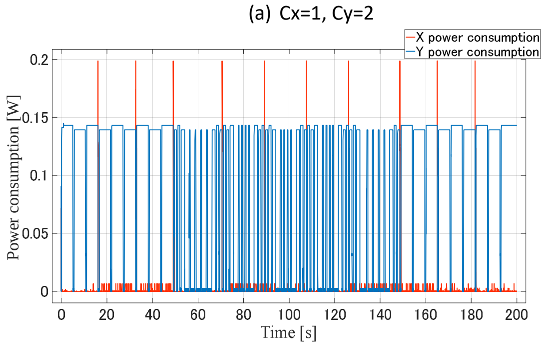


Figure 5. Two-inertia model of ball screw feed drive system [2]



(a) Cx=1, Cy=2



(b) Cx=2, Cy=1

Figure 6. Power consumption of regenarated tool path for energy saving

Table 1 Energy consumption in each axis

	X axis [J]	Y axis [J]	Total [J]
(a)	16.65	0.927	17.57
(b)	0.618	19.37	19.98

References

[1] Hayashi A, Arai F, and Morimoto Y, Simulation of Energy Consumption During Machine Tool Operations Based on NC Data, 2021 *Int. J. Automation Technol.* **15** 764

[2] Gobayashi K, Hayashi A, and Morimoto Y, Model based development of NC moving table by ball screw driving mechanism, 2023 *Proceedings of Annual Conference of the Society of Instrument and Control Engineers* 127