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Study on Optimized Machining of Duralumin using AFC

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AFC를 이용한 두랄루민의 최적화 가공에 관한 연구

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ABSTRACT

Studies on the optimizations of machining processes use two different methods. The first is feed control in real-time by spindle load in a machine tool. The second is feed scheduling in NC code control by material removal rate using a CAD/CAM system. Each approach possesses its respective merits and issues compared to the other. That is, each method can be complementary to the other. The purpose of the study is to improve the productivity of the bulkhead, an aircraft Duralumin structure. In this paper, acceleration or deceleration of cutting tool by spindle load data is achieved using adaptive feed control macro programming in a machine tool.

Key Words : Optimized Machining(최적화가공), AFC(Adaptive Feed Control, 적응이송제어), Duralumin(두랄루민), Aircraft Part(항공기 부품), Simens Controller (지멘스 컨트롤러)

1. Introduction

With industrial development, the production system is changing from large quantities with a small variety to small quantities with much variety. Consequently, smart factories using machine tools combined with information technology are appearing. The leading company in this field is Siemens in Germany. Currently, the best smart factory is the Siemens factory in Amberg, which is the leading Industry 4.0. As the performance of machine tools' controllers is improving, the precision and control of machine tools are developing. The Siemens 840Dsl controller supports various macros, which allow users to acquire information from machine tools and perform Siemens macro programming for motion and control. Furthermore, machine tools can be connected to the Internet to acquire data about the equipment status and processing in real-time. Equipment monitoring systems can be constructed using these machine tools for the efficient total management of factories. This does not require separate hardware, just an Internet cable connection (RJ45). In this study, we use Siemens macros to acquire the spindle load information of machine tools to control the machining speed and improve productivity using the adaptive feed control (AFC) feature. It is expected that this will prevent damage to cutting tools and extend the life of the spindle.

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Existing studies have mainly focused on scheduling the cutting feed rate in CAD/CAM systems.[1–6] CGTech has released commercial products, the VERICUT® Opithpath™ and Force™. These are effective software applications for analyzing MRR or the cutting force, but cannot respond to tool wear or damage.

Studies have been also conducted to control the feed rate of equipment by measuring the power consumption using an external device.[7–12] Commercialized products include one called Omative. It controlled the feed rate for machine tools by analyzing the spindle's power consumption, but the tool was often damaged when the feed rate was high due to the relatively slow reaction speed.

The cutting feed rate of the equipment designed in this study is controlled using the data of the spindle load inside the controller and the information acquired through this can be sent to the data cloud in real-time through the Internet. Furthermore, this information can be compared with existing cutting data. Big data can be used in factory monitoring systems and smart factories.

The optimization method to be developed in this study aims to shorten the machining time and prevent tool damage by controlling the feed rate. One important research subject is whether machine tools can automatically decelerate when a tool is overloaded. Existing studies suggested the method of receiving the power consumption of the spindle and returning it to the machine tool after external numerical processing. However, this method both uses expensive devices and is expected to show low responsiveness. The macro program created in this study does not generate cost because it does not require separate devices. Since this method uses Siemens macros to acquire and process spindle load data inside the controller, it provides the fastest response speed. According to official data from Siemens, the response speed is 16 μs.

The objective of this preliminary study is to improve the productivity of the bulkhead product of Boeing 787 as shown in Fig. 1. For the bulkhead component of a large aircraft, the required raw material weighs approximately 1 t (1,052 kg, 2,387 x 2,133.6 x 76.2 mm), but the completed product weighs only 47 kg. Thus, rough machining time takes a large part of the total machining time. Rough machining usually consists of repeated slot and shoulder machining. The bulkhead machining consists of more slot machining than shoulder machining; however, the tool is often damaged during slot machining and the overall feed rate is generally programmed based on slot machining. If the feed rate during slot machining can be reduced, the overall feed rate in the NC program can be increased and the productivity can be improved.

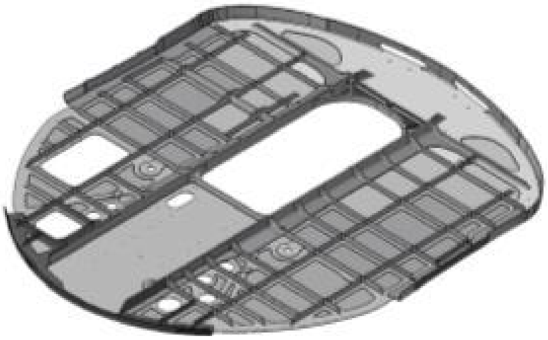

Fig. 1 Bulkhead, an aircraft structure of B737

2. AFC

The AFC method measures the cutting load (input) of the spindle, removes the hysteresis, calculates the error by comparison with the setpoint, and determines the output through proportional–integral–differential (PID) control. Then, it determines the cutting feed rate by filtering the output by the maximum/minimum ratio of the existing and set feed rates. The hysteresis parameter is removed from the external noise and the proportional control parameter performs the control action in proportion to the size of the error value. The integration control parameter suppresses the steady-state error and the differentiation control parameter increases

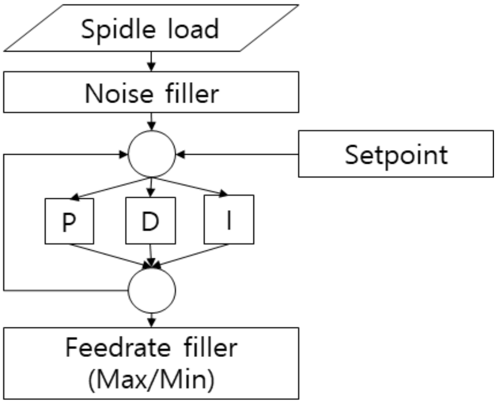

Fig. 2 Flowchart of adaptive feed control

the stability to prevent over-shooting due to rapid changes in the output.

The parameters of the AFC macro program were defined as follows:

AFC_LOAD (REAL_TARGET, REAL_PGAIN, REAL_IGAIN, REAL_DGAIN, REAL_HYST, REAL_MIN, REAL_MAX)

When the tool is worn, the spindle load increases and an active machining response is possible by reducing the feed rate without program modification. Furthermore, when the tool is damaged, the spindle load is not input. Therefore, if there is no load for a certain time, the system can determine it as tool damage, generate an alarm, and stop the feed rate. As a result, collisions between the spindle and the workpiece due to damage to the tool can be prevented and the system can stop the equipment and generate an alarm when an abnormal collision occurs.

3. Experiment Plan

In this experiment, the feed rate changes when the existing cutting method and AFC are applied are measured and how much time can be saved is determined. The experiment was planned for full slot machining because the load is the largest in slot machining.

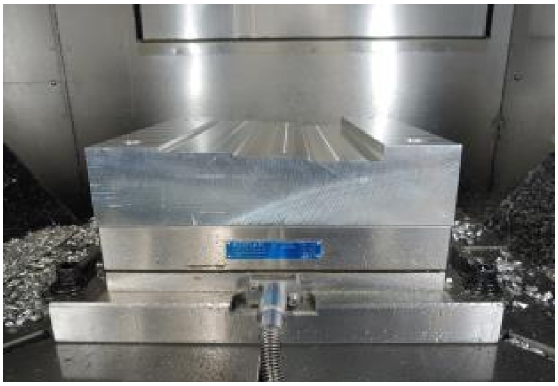

Fig. 3 Machining test specimen

3.1 Experiment Overview

As shown in Fig. 3, a height difference in the material was machined in advance to apply different spindle loads during the slot machining. To acquire the cutting load data, the input data of the AFC was checked based on the data of the controller and external data were acquired and tested.

1. The spindle load is acquired through the internal parameter, and
2. Outside, the torque and load values are measured in the X, Y, and Z directions using the tool dynamometer of Kistler (type: 9255b). Reliability can be verified by comparing these values.

3.2 Material Specifications

The bulkhead of aircraft is made of AL7000 series

Table 1 Chemical composition of Al7075 substrate (wt %)

	Al	Zn	Mg	Cu	Cr
Al7075	87.1 ~91.4	5.1 ~6.1	2.1 ~2.9	1.2 ~2.0	0.18 ~0.28
	Fe	Si	Mn	Ti	Other
	0.50 less	0.40 less	0.3 less	0.20 less	0.15 less

among the Duralumin materials. Therefore, the present study selected AL7075-T751 as raw material, which is identical to the material of a bulkhead. Table 1 outlines the ingredients of the material.

3.3 Equipment Specifications

We selected XF6300 of Hyundai WIA, which is equipped with the Siemens 840D solution line, which applies to AFC. Table 2 outlines the major specifications of the equipment. As shown in Fig. 1, the spindle has a maximum RPM of 15,000, a base RPM of 2,000, a maximum torque of 31 kW, and a firm output of 25 kW.

Table 2 Specifications of machining center

Description	Unit	XF6300
Table size	mm	630×400
Max. load capacity	kg	300
Spindle driving method		Direct
Spindle taper		HSK-A63
Spindle RPM	r/min	15,000
Spindle power	kW	31/25
Spindle torque	mm	153/123
Travel(X/Y/Z)	mm	650/600/500
Rapid feed rate(X/Y/Z)	m/min	60/60/60

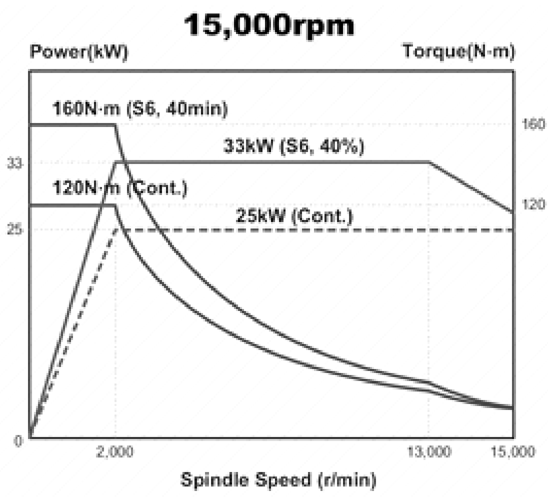

Fig. 4 Spindle output and torque diagram

Table 3 Specifications of the cutting tool

Diameter	Teeth	Helix angle	Rake angle	Teeth length	Total length
16mm	2	45deg	15deg	45mm	90mm

Fig. 5 Cutting tool and milling chuck

The spindle motor's performance is degraded by heat during machining. The NC program must be created by considering that the spindle output and torque values vary according to the RPM of the spindle.

3.4 Tool Specifications

We used AR3021610 of WIDEN for the cutting tool and the hydraulic chuck (HD20-104) of Sandvik for the milling machine chuck. When the tool length is doubled, the strain increases eightfold and the vibration and load both also increase. Therefore, though the tool length is 157 mm, the tool protrusion length was set to 53 mm. For cooling, the minimum quantity lubrication (MQL) method was used.

4. Experiment Result and Analysis

4.1 AFC Not Applied

Height differences of 12, 8, and 4 mm were machined as shown in Fig. 3. The material was processed and tested to see how the load changes in proportion to the chip removal amount.

The spindle RPM was calculated as 4,973.6 RPM (N) by substituting the tool velocity (Vc) of 250 m/min and the tool diameter of 16 mm in Eq. (1). It was rounded to the hundredth place and 5,000 RPM was selected.

$$N = \frac{1000\,Vc}{\pi D} \tag{1}$$

The cutting feed rate (F) was calculated as 1,000 mm/min by substituting the cutting quantity per blade (Fz) of 0.1 mm and two cutting blades (Z) in Eq. (2).

$$F = F_z\, Z\, N \tag{2}$$

The cutting quantity (Q) was calculated by multiplying the cutting depth (AP), cutting width (Ae), and cutting feed rate (F) as shown in Eq. (3). The cutting load (K) can be determined by the product of the resistance coefficient (k) and cutting quantity, but it can be complemented by multiplying it by the equipment efficiency for practical use.

$$\begin{aligned} K &= k\,Q \\ &= k\,Ap\,Ae\,F \end{aligned} \tag{3}$$

As shown in Fig. 6, the feed rate did not change when the AFC was not activated. Fig. 7 shows the load variations during specimen machining.

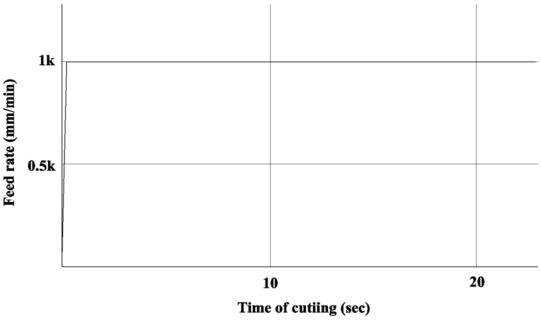

Fig. 6 Machine feed rate in deactivated AFC

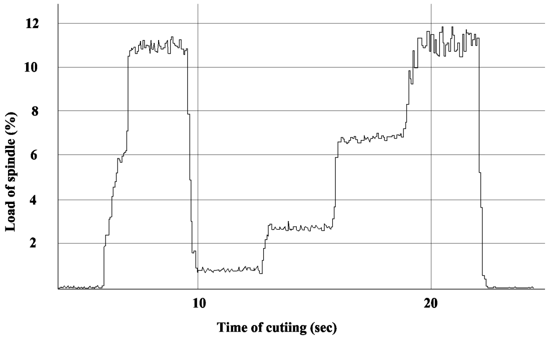

Fig. 7 Spindle load in deactivated AFC

4.2 AFC Applied

The AFC was applied as shown in Table 4 and the feed rate was changed during machining as shown in Fig. 8. Fig. 9 shows the resultant load variations. The feed rate was increased to 115% in the small load

Table 4 Parameters of an application

Parameter	Description	Value
1	Set point	8
2	Proportional	2
3	Integral	5
4	Differential	0
5	Hysteresis	1
6	Minimum feed rate	30
7	Maximum feed rate	120

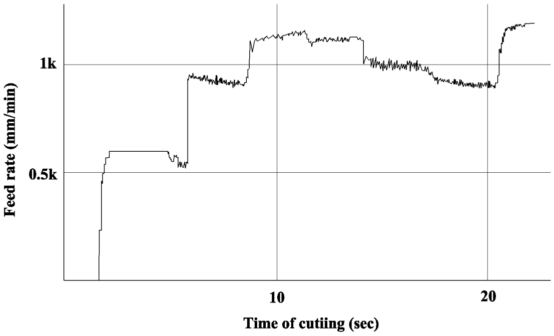

Fig. 8 Machine feed rate in activated AFC

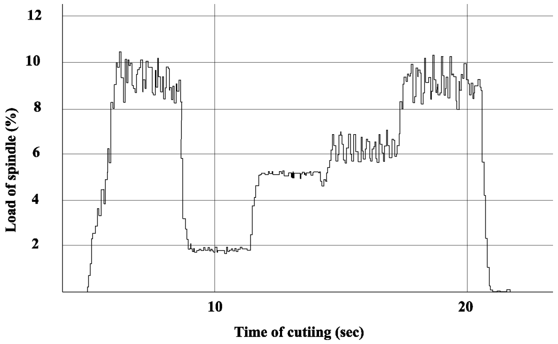

Fig. 9 Spindle load in activated AFC

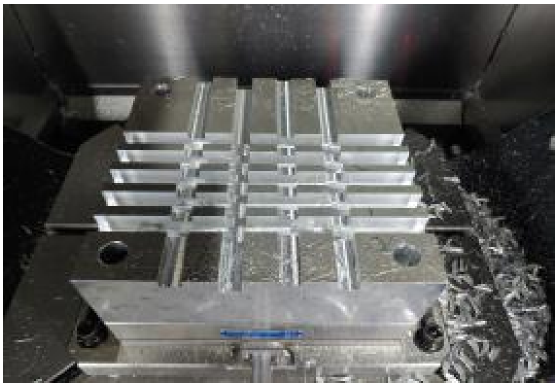

Fig. 10 Machining test specimen

section and decreased to 60% in the section under a load. Thus, the spindle load deviations were generally decreased. When the AFC was not applied, the maximum spindle load was 12%; when the AFC was applied, the maximum spindle load was decreased to approximately 12% and the minimum spindle load was increased from 1% to 2%.

5. Conclusion

In this experiment, AL7075-T751 was machined by applying AFC as shown in Fig. 10 and the following conclusions were obtained.

1. The cutting feed rate can be controlled by the target load without modifying the NC program.
2. The machining time can be reduced by increasing the feed rate in the section with a low load such as shoulder machining.
3. AFC can be applied regardless of the material shape because it is based on the spindle load.
4. Tool damage can be prevented because the feed rate is reduced even if tool wear occurs during machining.
5. The tool life can be extended because the maximum load is reduced.
6. If the tool diameter is small and the load is <1% of the spindle load, it is difficult to apply AFC due to the hysteresis filter.
7. When there is no tool load for a certain time, this can be determined as due to tool damage and the machine tool can be stopped.

In the future, we will conduct a comparative study of the process optimization method and AFC using Vericut's opti-path and force and attempt to shorten the machining time for the bulkhead by applying the advantages of each method.

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