Performance Evaluation of Microchip Removal Device Rotating by Conveyor Belt with Neodymium Permanent Magnet

Sung-Yun Choi[*], Jun-hyeong Wang[**], and Duck Hyun Wang[***,#]

[*]Graduate School, Kyungnam Univ., Manufacturing Innovation Simulation Center, [**]Korea Electrotechnology Research Institute(KERI), [***]School of Mechanical Engineering, Kyungnam Univ.

네오디뮴 영구자석을 이용한 컨베이어벨트 구동형 미세칩 포집장치의 성능 평가

최성윤*, 왕준형**, 왕덕현***,#

*경남대학교 대학원, **한국전기연구원 공정혁신시뮬레이션센터, ***경남대학교 기계공학부

ABSTRACT

Fine chips generated by machining have an impact on machine failure and quality of machined products, it is necessary to remove the chips, so the microchip collection and removal device by rotating conveyor belt with neodymium permanent magnets was developed. In this research, to solve the problem for reducing the existing microchips in the tank, a micro-chip removal device by rotating conveyor belt with neodymium permanent magnets developed. In the development of micro-chip removal device, 3D CATIA modeling was used, and the flow analysis and the electromagnetic force analysis were performed with COMSOL Multiphysics program. To evaluate the performance of the prototypes produced, design of experiments (DOE) is used to obtain the effect of neodymium conveyor movement speed on chip removal for the ANOVA analysis of recovered powders. An experiment was conducted to investigate the effect of the conveyor feed rate on the chip removal performance in detail. As a result of the experiment, it was confirmed that the slower the feeding speed of the fine chip removing device, the more efficient the chip removal.

Key Words : Micro Chip(미세칩), Permanent Magnet(영구자석), Magnetic Flux Density(자속밀도), Flow Analysis (유동해석), DOE(실험계획법)

1. Introduction

The main functions of cutting fluid in the cutting process are extraction, cooling, and lubrication of chips between the machine and the workpiece. Moreover, the selection and use of an appropriate cutting fluid can improve process productivity and stability, tool performance, and workpiece quality.[1] The microchips generated during processing are not

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Corresponding Author : dhwang@kyungnam.ac.kr
  Tel: +82-55-249-2712, Fax: +82-505-999-2160

collected by the filter on the cutting machine and, consequently, are often stuck in the workpiece part of the machine tool using the cutting fluid nozzle of the main spindle, which can fatally damage product quality.[2] Some of the processes that generate microchips include grinding, ceramic processing, graphite processing, wire cutting, and discharge processing.[3,4] Without microchip capture devices, the refinement level of the cutting fluid decreases, which can greatly affect the quality of machine tools and lead to machine malfunction.[5] In this study, device development and performance verification were conducted to improve workpiece quality and reduce the failure rate of machine tools by efficiently collecting microchips. A conveyor-belt-driven microchip collector based on neodymium permanent magnets was designed in three dimensions (3D) by using the CATIA software application. To verify the designed device, the COMSOL Multiphysics program was utilized for flow analysis in a cutting fluid tank and verification of the magnetic flux density about the permanent magnet conveyor belt drive. The device design was revised based on the analysis results, and a prototype of the device was fabricated. In addition, the chip removal rate was evaluated as a function of the conveyor belt drive speed.

2. Experimental Devices and Methods

Operation of the proposed neodymium-magnet-based microchip collector causes precipitation in the part (a) in Figure 1 because of the introduction of cutting fluid mixed with microchips. After precipitation, the cutting fluid overflows into tank (b), and the microchips are collected by a neodymium-magnet-based conveyor that moves from (d) to (c). Subsequently, the cutting fluid devoid of microchips is passed through the mesh filter (d) and into the tank (e), and the process (a)–(e) is repeated to supply clean cutting fluid to the processing equipment through a pump.

Flow analysis and verification of the electromagnetic field interpretation were conducted in the design process, and a prototype was fabricated after alleviating the predicted problems. For performance evaluation, the design of experiment method was applied to verify the performance of the permanent-magnet-based conveyor belt microchip collector by setting the transfer rate of the conveyor belt collector as a variable and the conveyor operation time and steel powder input as constants.

2.1 Prototype Design

Analytical verification was conducted during the design process to identify structural improvements and reflect them in the design. In this manner, an efficient structure was defined to improve the microchip capture performance of the device. Figure 2 shows the result of 3D modeling performed using CATIA. The cutting fluid tanks were made of transparent acrylic, a nonmagnetic material, to increase the collection of microchips and facilitate observation. The main components used in the neodymium-permanent-magnet-based conveyor belt microchip collector were an SPG drive motor (S9I40GBL), a decelerator (S9KB180BH), and a HANIL pump (PA-35). The detailed specifications of these components are summarized in Table 1.
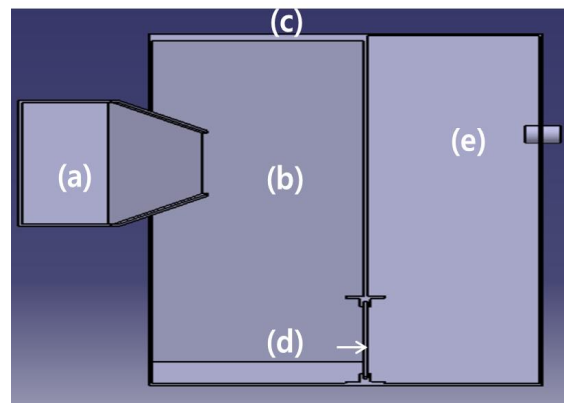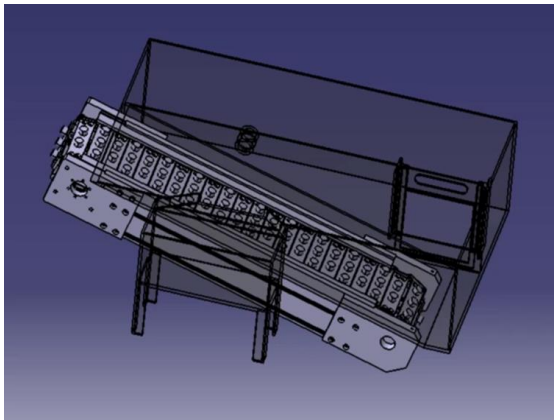

Fig. 1 Schematic diagram of coolant circulation for removing microchips

Fig. 2 3D design of coolant tank for removing micro chips with neodymium permanent magnet

**Table 1 Specifications of parts for micro chip removal device**

Part Name	Specifications	
Neodymium magnet	Magnet shape (mm)	⌀15x 10
	Flux density of work face (Gauss)	4810
Motor	Capacity (W)	40
	Revolution per minute (rpm)	1550
Motor reducer	Gear reduction ratio	1:180
Pump	Capacity (L/h)	1100
	Pump output (W)	70

2.2 Analytical Validation of Prototype

Flow analysis was conducted based on the boundary conditions specified in Table 2 by using COMSOL Multiphysics. The analysis results indicated that as the height of the chips collected by the magnet increased, the flow rate of the cutting fluid in the central part, which was characterized by the strongest magnetic field, decreased due to increased flow interference. The analysis results corresponding to the chip height of 2 mm are shown in Figure 3.

Table 2 Analysis conditions of coolant tank for flow analysis

| Division	Specifications of coolant tank		
Amount of coolant (m/s)	0.03		
Horizontal size (mm)	200		
Vertical size (mm)	200		
Total length (mm)	600		
Angle (degrees)	17°		
Height of the collected microchips (mm)	1	2	3
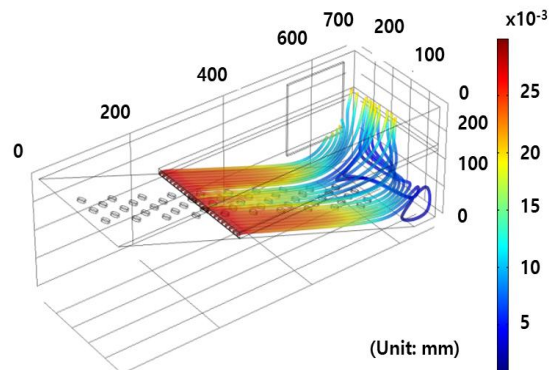
Fig. 3 Flow analysis result when the chip knob is 2mm

By incorporating the analysis results in the design, the shape of the cutting fluid tank was improved after verifying that a tank structure that centralizes the flow of cutting fluid is efficient from the viewpoint of microchip collection. The magnetic flux density of the conveyor belt microchip collector was analyzed under the boundary conditions summarized in Table 3, and the analysis results are shown in Figure 4. The results indicate that the magnetic flux density increased as the height of the collected chips increased and the movement speed of the permanent magnet conveyor microchip.

**Table 3 Conditions of the conveyor for magnetic field analysis**

| Division	Specifications of fine chip conveyor		
Array of magnets (Cross-array)	(magnet array diagram)		
Number of magnets (EA)	115		
Distance to coolant tank (mm)	1		
Height of the collected microchips (mm)	1	2	3
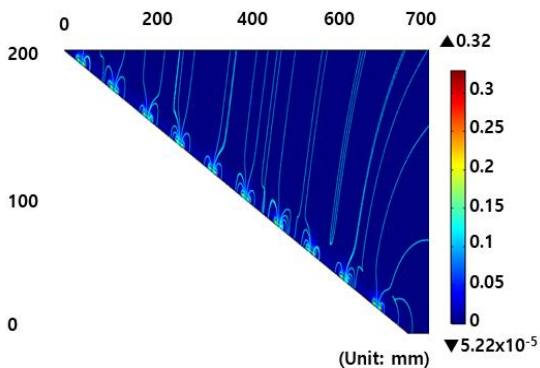
Fig. 4 Electromagnetic force analysis in neodymium magnetic conveyor

collector decreased. These results confirmed the need for motor speed control as a function of the flow rate of the cutting fluid. Speed control devices were applied to the fabricated prototype to control the speed of the permanent magnet microchip collectors in order to increase their microchip collection efficiency.

Figure 5 shows an electrical circuit diagram of the prototype, and the control panel features an emergency stop button, pump button, and separate power switch and speed control switch for the conveyor motor to enhance operational convenience and microchip collection efficiency of the device.
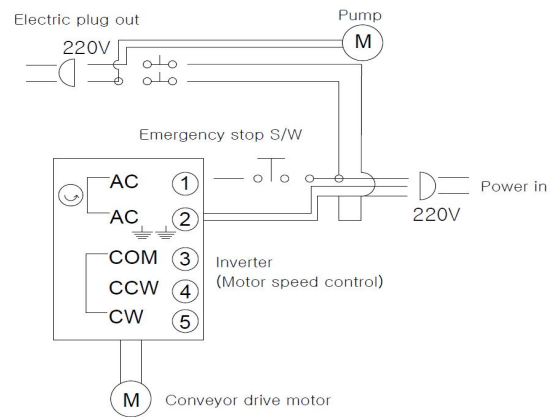
Fig. 5 Prototype of electrical circuit diagram for moving conveyor belt
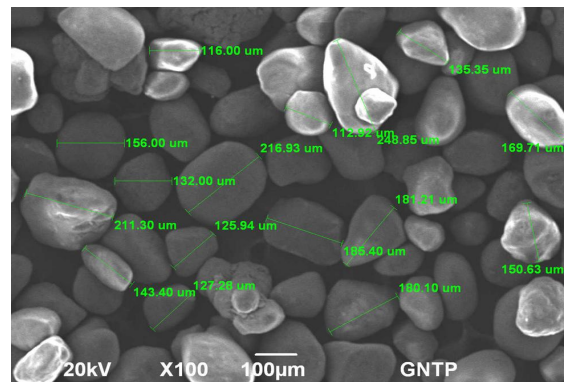
Fig. 6 Scanning electron microscopic photograph of iron powder

$\mu = E(X) = 0.016$ $\sigma = SD(X) = 0.003$ $\sigma^2 = Var(X) = 0.000009$
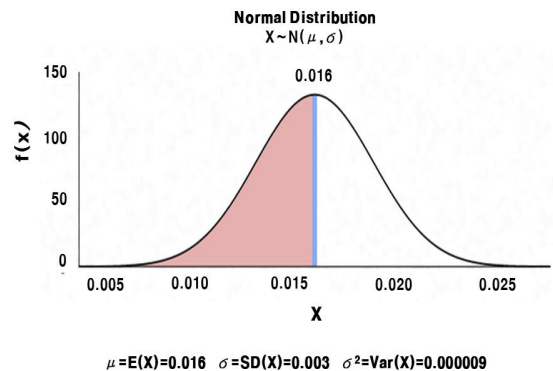
Fig. 7 Normal distribution graph of the particle size for iron powder

2.3 Particles for Performance Testing

Commercially available steel powder was purchased and used to determine the performance of the conveyor-belt-driven microchip collector equipped with neodymium permanent magnets. The average particle size of the steel powder (20 particles per gram) was 0.016 μm (Figure 6), as measured five times using a scanning electron microscope (JEOL, JSM6490) under 100 times magnification. A normal distribution plot of the measured particle size is shown in Figure 7.

2.4 Experimental Method

A fabricated prototype is shown in Figure 8 (a). The design of this prototype was optimized based on the results of flow analysis and verification of magnetic flux density. Figure 8 (b) shows a photograph of the prototype undergoing performance verification. To evaluate the microchip collection performance of the prototype as a function of the transfer velocity of the conveyor equipped with neodymium permanent magnets (1.5 m/min, 1.2 m/min, 0.9 m/min, and 0.6 m/min), other factors such as cutting oil injection, conveyor operation time, steel powder injection rate were fixed.

Three repetitions each of 12 experiments were conducted randomly to retrieve 10 g of the steel powder injected into the neodymium permanent magnet conveyor under the conditions summarized in Table 4. The recovered steel powder was naturally dried for 24 h and weighed using an electronic scale (maximum measurement capacity of 100 g and measurement resolution of 0.001 g), and the average measured weights of the powder are listed in Table 5.

To verify the performance of the prototype, the experimental results were analyzed using a statistical analysis program (Minitab). The effect of the change in the transfer velocity of the permanent magnet conveyor belt microchip collector on the amount of steel powder recovered was determined.

(a) Prototype device　　(b) Performance verification

Fig. 8　Prototype for performance verification of microchip removal device with neodymium permanent magnets

Table 4　Factors and levels of ANOVA analysis for recovered powders

	Factor	Level			
A	Conveyor rotation speed (m/min)	1.5	1.2	0.9	0.6
B	Coolant input rate (L/min)	18			
C	Operating time (sec)	120			
D	Rate of iron powder input (g)	10			

Table 5　Experimental results for recovered powders

| Experiment number	Conveyor rotation speed (m/min)	Recovered iron powder (g)	Recovery rate (%)
1	1.5	7.1482	71.5%
2	1.5	7.3302	73.3%
3	1.5	7.2872	72.9%
4	1.2	7.4272	74.3%
5	1.2	7.9572	79.6%
6	1.2	8.1922	81.9%
7	0.9	8.4602	84.6%
8	0.9	8.3602	83.6%
9	0.9	8.5002	85.0%
10	0.6	8.5842	85.8%
11	0.6	8.6682	86.7%
12	0.6	8.8772	88.8%

3. Experimental Results and Discussions

The average weights of the powder be considered statistically significant depending on the transfer velocity of the permanent magnet conveyor microchip collector because the P-value, obtained through analysis of variability, is 0.0002, as listed in Table 6, which is smaller than the significance level of 0.05.

As can be inferred from the box plot shown in Figure 9, variations in the transfer velocity of the neodymium permanent magnet conveyor do not induce a significant difference in the recovery of steel powder. In general, the closer the transfer velocity is to 0.6 m/min than to 1.5 m/min, the greater the effect of the transfer velocity, and the ability of the collector to capture steel powder increase. The lower transfer velocity increases the ability of the collector to capture steel powder by magnetism because it increases the time period for which the steel powder is exposed to the magnetism of the permanent magnets. As the amount of steel powder collected in the magnet increases, the range of magnetic forces increases, and the microchip capture efficiency of the microchip collector based on neodymium permanent magnets can increase when the conveyor is slower than faster. This is because the magnetic force of the permanent magnet, which increases the ability of the collector to collect steel powder as the exposure time increases. As the amount of steel powder collected in the magnet increases, the range over which its magnetic force acts increases. When the transfer velocity of the conveyor is slower rather than faster, the microchip collection efficiency of the microchip collection device based on neodymium permanent magnets increases. Therefore, microchip collection devices based on neodymium permanent magnets are more efficient when the transfer velocity of the conveyor is slow.

Table 6 Analysis of variance(ANOVA) analysis for recovered powders

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Conveyor rotation speed (m/min)	3	3.7647	1.25489	26.34	0.0002
Error	8	0.3811	0.04764		
Total	11	4.1458			
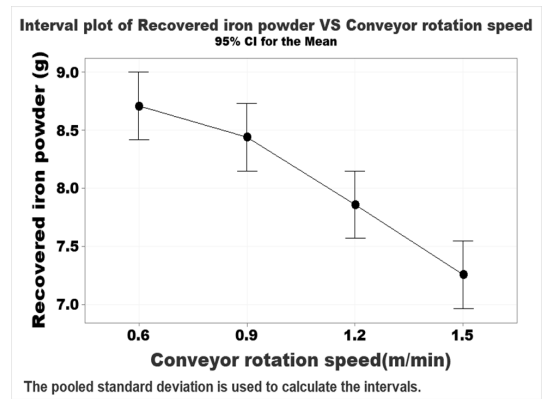
Fig. 9 Iron powder recovery plot for different conveyor speed

4. Conclusions

In this study, a microchip collection device based on neodymium permanent magnets was verified by conducting flow and electromagnetic field analyses. To verify the performance of the proposed microchip collection device, a prototype was fabricated, and an experiment was conducted with the conveyor speed as the variable.

1. In the performance verification test of the microchip-collecting conveyor, the P-value was 0.0002, and this factor majorly influenced the experiment.
2. In terms of the steel powder recovery rate, the variation in the amount of steel powder recovered remained constant even as the velocity of the neodymium permanent magnet conveyor changed.

3. The slower the transfer velocity of the conveyor, the greater was the number of factors affecting the capture of steel powder.

4. When the transfer velocity of the conveyor was slow, the collection capacity of the microchip collection device increased because the time for which the steel powder was exposed to magnetic forces increased.

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