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# Development of a Controller for Polishing Robot Attached to Machining Center and Its Performance Evaluation

***Seok Jo Go, and **Min Cheol Lee**
***Graduate School of Intelligent Mechanical Engineering, Pusan National University, Pusan 609-735, Korea**
****Division of Mechanical Engineering, Pusan National University, Pusan 609-735, Korea**
**Tel: +82-51-510-3081, Fax: +82-51-512-9835**
**Email: sjgo@hyowon.pusan.ac.kr**
**Email: mclee@hyowon.pusan.ac.kr**

**Abstract**

Cutting process has been automated due to progress of CNC and CAD/CAM, but polishing process has been only depended on experiential knowledge of expert. Polishing work for a curved surface die demands simple and repetitive operations but requires much time for its high precision. Therefore it is operated in the handiwork by skilled worker. However the workers intend to avoid gradually polishing work because of the poor environments such as dust and noise. In order to reduce the polishing time and solve the problem of shortage of skilled workers, it has been done some research for an automation of polishing.

To automate the polishing process, a 2 axes polishing robot which is attached to a 3 axes machining center has been developed by our previous research. This automatic polishing robot is able to keep the polishing tool normal on the curved surface of die. Therefore its performance of polishing is improved because of always keeping the tool normal on the surface.

In this paper, the smaller sized polishing robot is developed to improve polishing performance. And the controller for 2 axes polishing robot is developed. The controller is composed of TMS320C31 with high speed which is 40-ns instruction cycle time, RAM memory with 64K words, digital input with 64 bits, digital output with 32 bits, and D/A converter with 4 channels, which is 12 bits resolution.

To evaluate polishing performance of this developed robot, polishing experiment for shadow mask was carried out.

## 1. Introduction

In the processes of a die manufacturing, polishing is done to remove tool marks and improve the smoothness and flatness of die surfaces. Cutting process has been automated due to progress of CNC and CAD/CAM, but polishing process has been only depended on experiential knowledge of expert. When the polishing operations are done by the skilled workers, polishing takes a long time to obtain the required accuracy. It has been a major problem consuming 30 ~ 40 % of the total die manufacturing time[1,7,8,11]. However some workers intend to avoid gradually polishing work because of the poor environments such as dust and noise. To improve the productivity and solve the shortage of the skilled workers, it is required to develop an automated polishing system using manipulators[3,4,5].

Thus, in the previous study, the polishing robot with 2 degrees of freedom was developed, which has a pneumatic system and was attached to a machining center with 3 degrees of freedom. The developed automatic polishing system has 5 degrees of freedom being able to polish a curved surface die[1,6,9]. However, the polishing robot was big and heavy, it could not take a more wide workspace and then it affected badly a polishing work. Therefore, in this study, the smaller and lighter polishing robot than the previous has been designed to improve defects due to that. Also, a cheaper controller has been designed for commercializing.

Automation of polishing is expected to reduce a steps of polishing processes and improve a roughness and waviness. And the best merit of this automatic polishing system is that the polishing robot with 2 degrees of freedom is attached to the machining center with 3 degrees of freedom using generally in industry.

The developed polishing robot is controlled by

real time using DSP(digital signal processor). The controller is composed of DSK(DSP Starter Kit) included TMS320C31 with high speed and peripheral circuits. By developing the controller, the cost for commercializing is reduced and the variety in developing the system is permitted.

## 2. Architecture of the automatic polishing system

2.1 structure of polishing robot

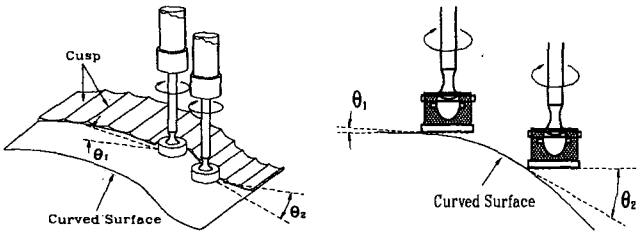
Polishing of free surface die requires basically the mechanism with more than 5 degrees of freedom. It is difficult for the mechanism with 3 degrees of freedom to polish a free surface die uniformly as shown in Fig. 1. The steeper curvature of surface is, the smaller contact surface of the polishing tool is. Because the contact surface is smaller, the polishing tool cuts deeply the polishing surface. In order to overcome this problem, the universal joint or ball joint as shown in Fig. 2 is selected. But, in this case, a polishing performance is bad because a distribution of polishing force $F_N$ is changed as a slope of free surface is changed[12]. The mechanism with 5 degrees of freedom is able to keep the polishing tool normal on the free surface as shown in Fig. 3. In this case, a polishing performance is expected to be improved because a polishing force $F_N$ is distributed uniformly as a slope of free surface is changed. It is possible for the mechanism with 5 degrees of freedom to polish a variable free surfaces. But the 5 axes articulated robot[2] is inferior to a machine tool in a stiffness and position accuracy.

To minimize these problems, the 2 axes polishing robot which is attached to a 3 axes machining center has been developed. The structure and appearance of 2 axes polishing robot is shown in Fig. 4 and Fig. 5 respectively. And the specification of polishing robot is listed in Table 1[1,9].

2.2 Architecture of the automatic polishing system

The automatic polishing system is composed of 2 axes polishing robot attached to a machining center, the real time controller for a polishing robot, and 3 axes machining center in Fig. 6.

The polishing force normal on the free surface is produced by an air cylinder and the polishing tool is rotated by an air motor. An air cylinder and an air motor are operated by an air pressure. In the case of using an air pressure, it is easily changed and maintained by an air pressure precision regulator. The velocity of air motor with a reduction gear is not changed as payload changes but maintained uniformly[1].




(a) Polishing of curved surface (b) Change of contact surface

Fig. 1 Mechanism with 3 degrees of freedom.

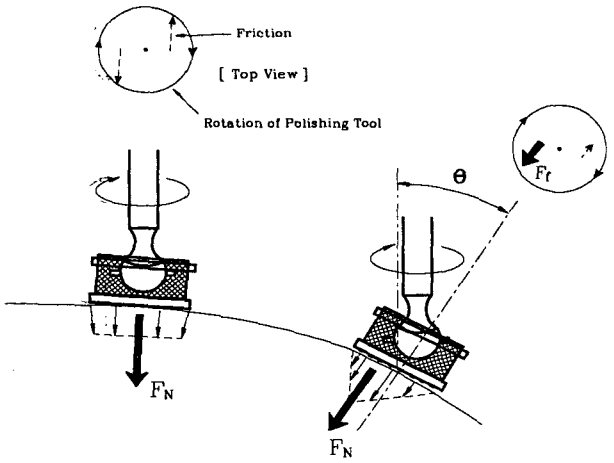
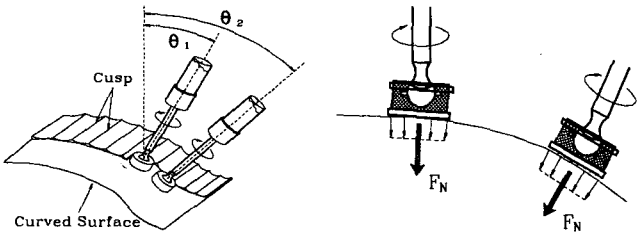



Fig. 2 Distribution of a polishing force using mechanism with universal joint.




(a) Polishing of curved surface (b) Distribution of a polishing force

Fig. 3 Mechanism with 5 degrees of freedom.

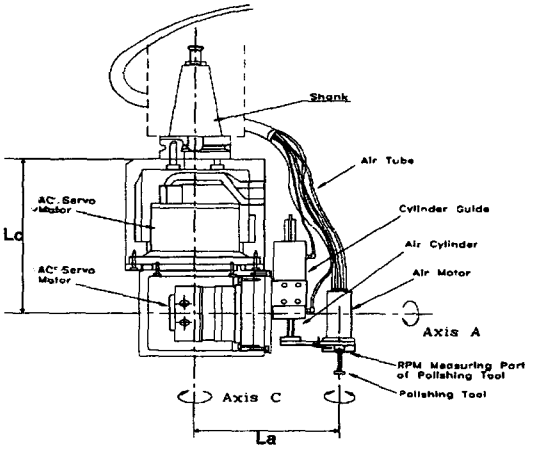



Fig 4. Structure of 2 axes polishing robot.

Fig. 5 Appearance of polishing robot.

Table 1 Specification of polishing robot.

| Item | Specification | Maker | Model Type |
|---|---|---|---|
| Machining Center | Machining Center with 3 axes | DAEWOO Heavy Ind. | ACE-V30 |
| Axis A, C | AC Servo Motor with Harmonic Drive | Harmonic Drive Systems | FHA-17A |
| Pneumatic Cylinder | Single Cylinder | FESTO | DSN-25-50-PPV |
| Polishing Force | Air Motor | FUJI | F-6SM-28R |

Polishing process of a shadow mask die is shown in Fig. 7. And a polishing sheets are shown in Fig. 8. The polishing sheet is a embossed type which sticks a diamond and CBN particles on a flexible fiber.

### 3. Design of the controller

In this study, the controller is developed to control a position of 2 axes polishing robot by real time. The block diagram of the controller is shown in Fig. 9. Appearance of the controller is shown in Fig. 10. The controller is composed of DSK(DSP Starter Kit) which includes TMS320C31 for real-time signal processing and peripheral circuits with DIO(digital input and output), D/A(digital to analog converter), A/D(analog to digital converter), and counters. DIO, A/D, D/A and timers are selected by a decoder. Host computer communicates with DSK by serial communication. The DSK has a TMS320C31 on board to allow full-verification of

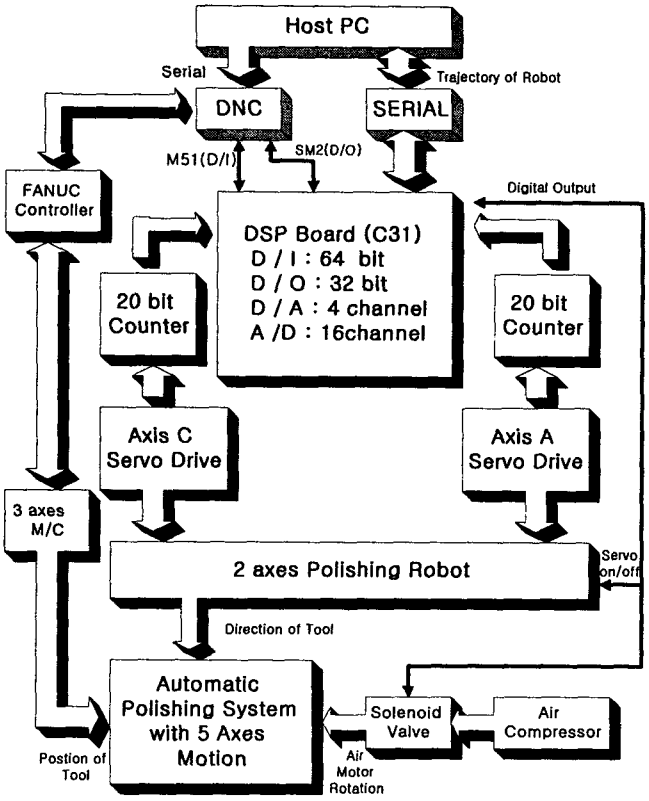



Fig. 6 Block diagram of a automatic polishing system.

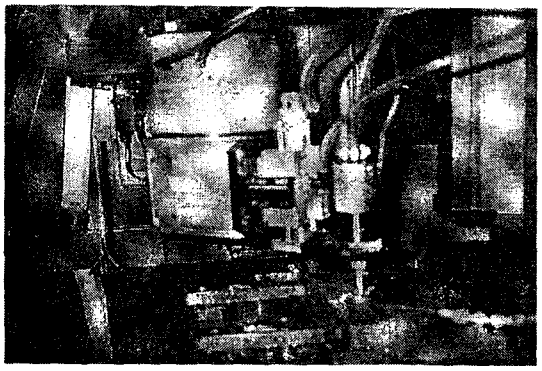


Fig. 7 Polishing process of shadow mask.

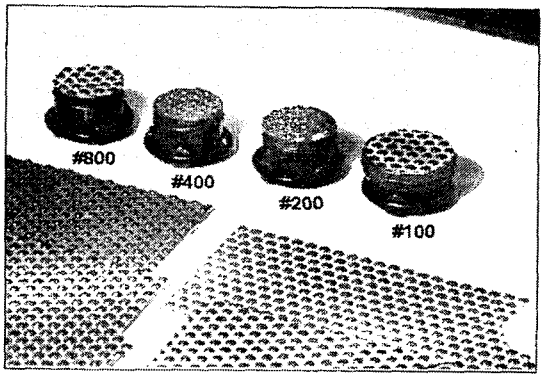



Fig. 8 Polishing sheets.

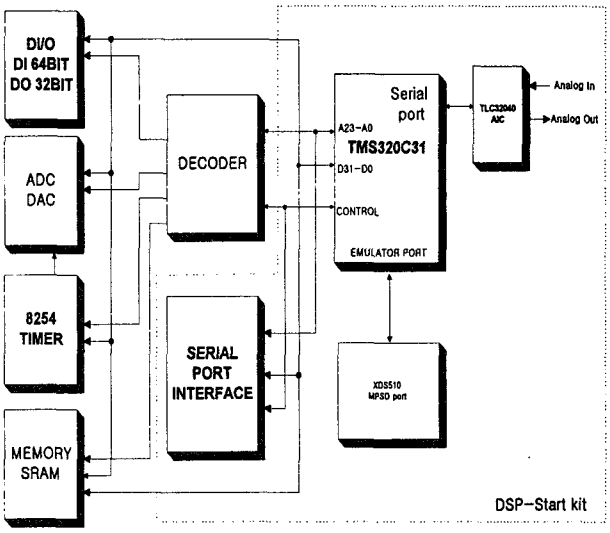



Fig. 9 Block diagram of the controller.

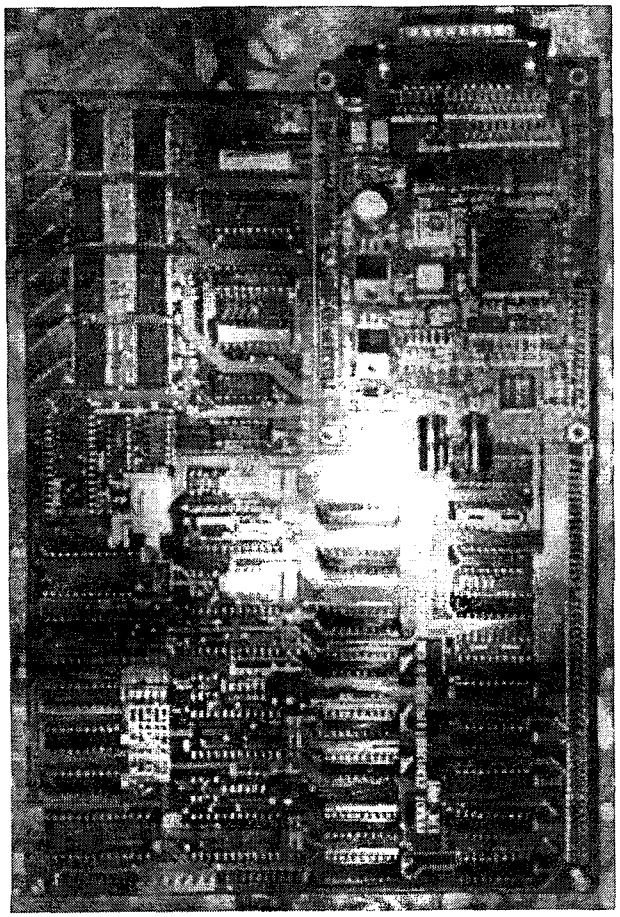


Fig. 10 Appearance of the controller.

the TMS320C3x code. The TMS320C31 is a low-cost 32-bit DSP(digital signal processor) that offers the advantages of a floating-point processor. It can perform a 40-ns instruction cycle time, 50 MFLOPS(millions floating-point operations per second) and 25 MIPS(millions instruction per second)[10]. DSK deals with a calculation of control algorithm. Also it manages digital input, output signals, and control signals. DIO port is designed with 64-bit digital input channels and 32-bit digital output channels. D/A is composed of a 4-channel converter with 12-bit precision. It converts a digital control signal calculated in DSK into a analog control signal. The analog control signal is transmitted to a servo driver to drive DC motor of polishing robot. A/D is composed of a 16-channel converter with 12-bit precision using a multiplexer. It converts a analog signal from sensors into a digital signal. Counter deals with a 20-bit count data and changes signals of a rotary encoder attached to a robot actuator into a 20-bit position data. This position data is transmitted to DSK through DI port.

| | | |
|---|---|---|
| 0h<br>FFFh | Reserved for boot loader operations | |
| 1000h<br>3FFFFFh | blank | |
| 400000h<br>41FFFFh | Boot ROM | 128K bytes |
| 420000h<br>7FFFFFh | blank | |
| 800000h<br>807FFFh | Reserved | 32K Words |
| 808000h<br>8097FFh | Peripheral bus memory-mapped registers | 6K Words |
| 809800h<br>809BFFh | RAM block 0 | 1K Words |
| 809C00h<br>809FFFh | RAM block 1<br>kernel interrupt and trap branches | 1K Words |
| 80A000h<br>81FFFFh | blank | |
| 820000h<br>82FFFFh | Zero-wait SRAM | 64K Words |
| 840000h<br>BFFFFFh | blank | |
| C00000h<br>C0000Fh | I/O | 16 Words |
| C00010h<br>DFFFFFh | blank | |
| E00000h<br>EFFFFFh | External HPI | non interlocking |
| F00000h<br>FFEFFFh | blank | |
| FFF000h<br>FFFFFFh | External HPI | interlocking |

Fig. 11 Memory Map.

Memory map of controller is shown in Fig 11.

Table 2 I/O Address(Base Address : 0xC00000h).

| | READ | WRITE |
|---|---|---|
| BASE + 0 | Digital Input | Digital Output |
| BASE + 1 | Digital Input | ADC Control |
| BASE + 2 | ADC Result | DA 0 |
| BASE + 3 | ADC Status | DA 1 |
| BASE + 4 | Reserved | DA 2 |
| BASE + 5 | Reserved | DA 3 |
| BASE + 6 | Reserved | Reserved |
| BASE + 7 | Reserved | Reserved |
| BASE + 8 | COUNTER 0 | COUNTER 0 |
| BASE + 9 | COUNTER 1 | COUNTER 1 |
| BASE + 10 | COUNTER 2 | COUNTER 2 |
| BASE + 11 | Reserved | Control |
| BASE + 12 | LCD | LCD |

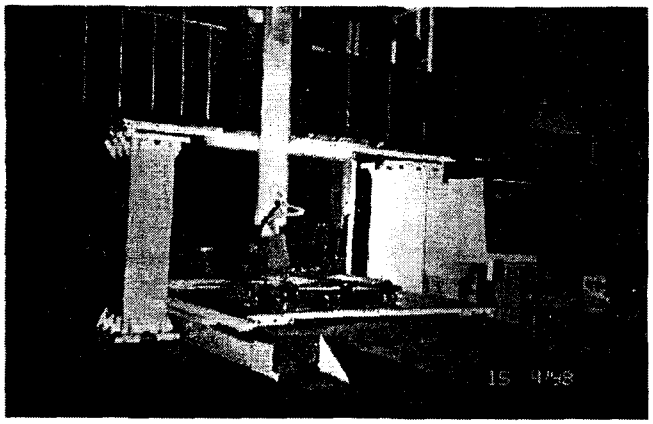


Fig. 12 The developed polishing robot system named POLYEM.

Control algorithms and result data after control are located at addresses 820000h through 82FFFFh(64K Words). I/O port is located at addresses C00000h through C0000Fh(16 Words) and Memory location C00000h is a base address of I/O port. The registers stored in these locations are listed in Table 2.

## 4. Development of POLYEM and Its performance Experiments

It is developed the automatic polishing system, named POLYEM using the polishing robot and the controller for commercializing. Appearance of POLYEM is shown in Fig. 12. The specification of POLYEM is listed in Table 3. Polishing process is shown in Fig. 13.

To evaluate polishing performance, a polishing

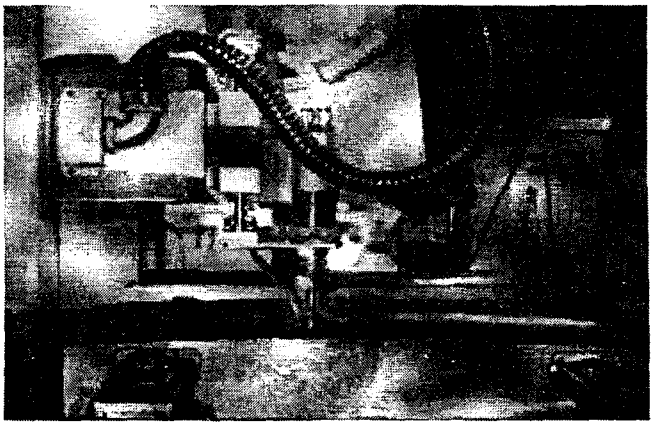


Fig. 13 Polishing of a shadow mask by POLYEM.

Table 3 Specification of POLYEM.

| POLYEM | Specification |
|---|---|
| X-axis stroke | 1800mm |
| Y-axis stroke | 2200mm |
| Z-axis stroke | 800mm |
| A-axis angle of rotation | ±95° |
| C-axis angle of rotation | ±180° |
| Working space | 1800mm×1400mm |
| Carrying capacity | 5000Kg |
| Control Units | FANUC 18M / DSP Controller |

Fig. 14 Polished surface of a shadow mask.

experiment for shadow mask die is done. Material of shadow mask die is a STD(570mm×340mm). The polishing pattern as zigzag is used. The polished surface is shown in Fig. 14. Experiments show that a polished surface of die is good such as mirror surface. More experiment should be done to prove that the automatic polishing process is more useful and effective than a manual one.

## 5. Conclusions

The automatic polishing system has been developed to automate the polishing work for the free curved surface die. This automatic polishing system is composed of 2 axes polishing robot attached to a machining center, the real time controller for a polishing robot, and 3 axes machining center. It has been designed the smaller and lighter polishing robot than the previous. Also, the cheaper controller has been designed for commercializing.

It is developed the automatic polishing system, named POLYEM using the polishing robot and the controller for commercializing. From the result of polishing experiments for shadow mask die, it is known that the surface of die such as mirror is obtained by the polishing system.

For future work, it is required more studies for better smoothness and waviness and the improvement of the controller. More work should be done to develop an expert system to determine the optimal polishing conditions from die materials and desired roughness and waviness.

## Acknowledgment

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