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# NC Program Generation Using Off-Line Teaching of Deburring Path

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## ABSTRACT

Die-casting burr to casting process is removed by post-process for assembly and quality control of product. Though robot has been widely used for deburring job before. CNC exclusive machine is currently developed for high power, high speed machining and quick tool change. Deburring tool path with complex 3D curve type is defined to make out deburring NC program. But there is no efficient method to define it currently used methods with teaching probe on machine. In this study the efficient method to make out deburring NC program is developed. 5-axis digitizing machine is used to receive data of deburring path. And the post process for NC program generation is developed in consideration of the machining conditions. The developed system is not dependent on the skill of operator and has the advantage to maintain the flexibility of job to modify NC program due to the wear of tool and aging of the die casting.

**Key Words:** Burr, Deburring, Off-Line Teaching, NC Program

## 1. Introduction

When aluminium parts are die-casting, burrs are occurred due to the gap of die-casting, assembly precision and operating pressure. These burr are removed by the next process of the assembly and finishing job for the quality improvement. Though deburring operation was mostly done by the manual process because of the uniformity of work and the consideration of environmental problems, it is done by automations currently. In order to do the automatic process of deburrring, robot and exclusive deburring machine are mainly used. The case of using robot has the advantage of the easy implement and flexibility of the systems, but it has the disadvantage of the low speed operation and small pay load. CNC is mostly used for the controller of deburring exclusive machine. This is easier to increase the cutting force and high speed operation in machining process, and to decrease the time to exchange the cutting tools by ATC. Recently many researches are accomplished for the improvement for the efficiency of deburring. These are the measurement of burr size, burr location and tool path by using machine vision system, the teaching method of the expert technique of skilled operator to the robot manipulation system and the matching method of the deburring speed with the burr height to be measured by sensors.

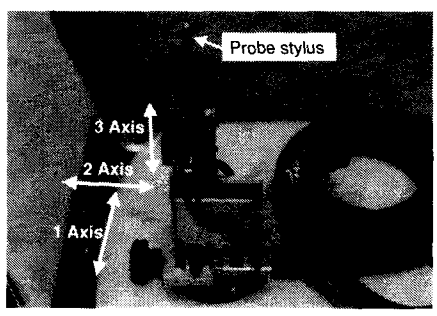


Fig. 1 Teaching Probe with 3 axes moving unit

In recently developed CNC machine, the NC programming is generally made in CNC using point data obtained by the exclusive teaching unit of CNC deburring machine. The example of the exclusive measuring probe of teaching unit is given as Fig 1. This unit addes the extra 3-axis motion to the deburring machine tool and the flexibility to the input data of the deburring tool path by reading the moving displacement externally. But, in this case, it has the non-productive factors that the machine tool can not produce the products during teaching process, that the new teaching process is done for changing the machining conditions and environments and that the teaching process is dependent on the skill of operator. To solve these problems there are the methods that it is to make the NC program by using determination of the shape of burr defined by the CAD drawing of the die casting and that it is to make the NC program in off-line by using the master of the die casting parts.

This paper is to study the deburring machine that the deburring NC program is made by off-line teaching method. To do this the developed studies are the teaching technology to input the deburring tool path in off-line and the post processing technology to make NC program by using the data obtained by the teaching unit.

## 2. Definition of Deburring and Method of NC Programming

In NC programming there are the general methods to use the manual or CAD in the case of the regular shape such as circle and rectangular and to use the CAD data in the case of the irregular shape such as free curve. But, in the case that the irregular shape is too complex to define in CAD, it is much more effective to make NC program by the pre-made mock-up and CAM using the machining point data obtained by 3D measuring system. When the burr shape of the die casting is considered in the characteristics of the cutting section it is the free curve. To remove the burr to have the characteristics the NC program is made in CNC machine. The exclusive measuring probe easily to obtain the point data of deburring path is installed because of the complexity of the definition of the deburring shape. And the NC programming method is used in NC machine with the shape information of burr obtained by it. But, in this case, the controller is dependent on the special specification and the exclusive probe to be installed on every machine is not economical. And it has the disadvantage that the teaching is dependent on the expertise of the operator. Because of these disadvantages, this study used the off-line programming method using the digitizing machine to obtain the data of deburring path. With considering the obtained data, cutting conditions and machine structure the transformation of coordinates and NC programming are accomplished in PC. To send the created NC program the applied communication is the method of DNC communication. This method has the advantage that the flexibility of job is secured by the off-line teaching and created NC

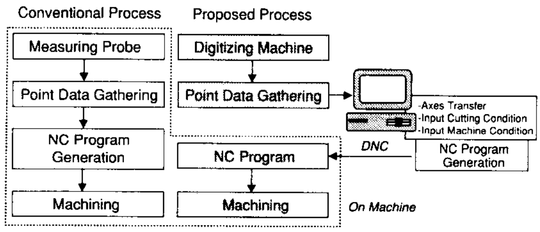


Fig. 2 NC program generation methods

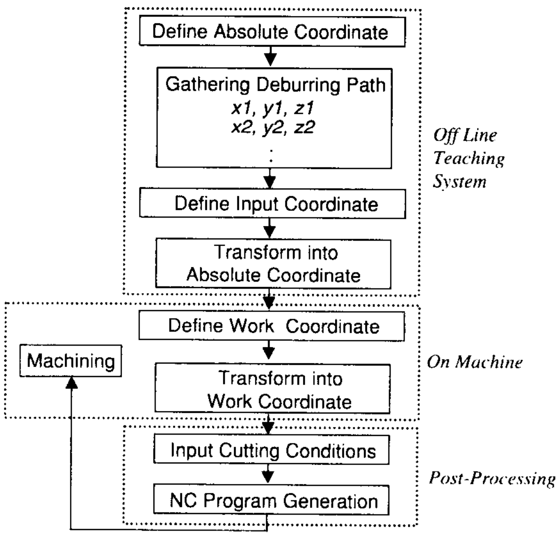


Fig. 3 Procedures of off-line teaching

program without being dependent on the CNC specification. The concept of it is given in Fig 2.

## 3. System Configuration and Job Flow

The off-line teaching and flow job of deburring are given in Fig 3. The configuration has the off-line teaching unit to obtain th e point data of deburring path, the mechanical unit to accomplish the deburring job with considering the coordinate system of the deburring machine and the post processing unit to input the cutting conditions and to create NC program.

### 3.1 Data Aquisition of Deburring Path

Two coordinates are used for collecting data of deburring tool path. One is the absolute coordinate system $CS_O$ to be used as the origin of collecting device of data and the other is the input coordinate system $CS_I$ to define the plane in arbitrary space. The digitizing machine(Micro Scribe-3D) to be used in this study has the joint structure of 5-axis and the repeatability of 0.3 mm. And it receives the measuring data through RS-232C port of PC. Fig 4 shows the picture to collect the data of deburring path of the automobile part by using digitizing machine. Fig 5 defines the used coordinate system to be used for collecting the data of deburring path. When it is to define the absolute coordinate system $CS_O$ the origin $O_O$ is defined as (0,0,0). In the coordinate system $CS_I$ ( $dp_1$, $dp_2$, $dp_3$, ...) is to express the collected position data of burr to define the deburring path and ( $P_1$, $P_2$, $P_3$) is to express the input data to define the plane in the coordinate system $CS_I$. When the input coordinate system is transformed to the absolute coordinate the point $P_1$ is arranged to be matched with the point $O_O$ and the point $P_2$ is arranged to be located in X-axis of the coordinate system $CS_O$. 3D data is collected by using the master workpiece to be well machined along the deburring path in Fig 5. The collected data is as the following.

| | | | |
|---|---|---|---|
| *dp1* | 66.15 | 124.57 | 236.76 |
| *dp2* | 70.98 | 125.20 | 236.12 |
| *dp3* | 76.49 | 125.79 | 235.45 |
| *dp4* | 83.01 | 127.46 | 235.11 |
| *dp5* | 87.55 | 128.68 | 235.07 |
| *dp6* | 92.32 | 130.68 | 234.88 |

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.

Fig 6 shows that 3D data of 222 points to be collected in off-line teaching is used for graphics.

### 3.2 Coordinate Transformation of Input Data

In order to create the NC program to be considered the deburring machine, the input coordinate system is transformed to the absolute coordinate system. The relationship of the arbitrary position points between two axes is considered as the following.

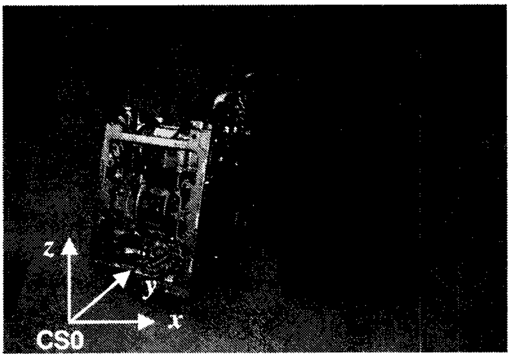



Fig. 4 Gathering of deburring path data using digitizing machine

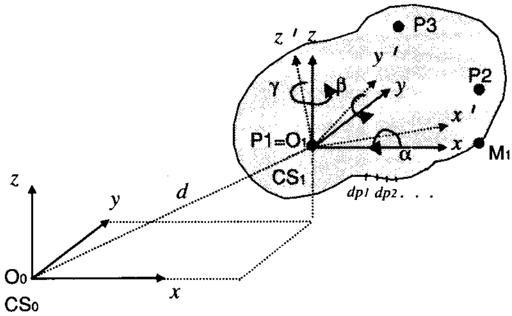



Fig. 5 Coordinate for off-line teaching

The arbitrary point $M_I$ in the input coordinate system $CS_I$ can be expressed in term of $M_O$ in the absolute coordinate system as the followings.

$$M_0 = H\,{}_0^1M_1 \qquad (1)$$

(H: Homogeneous Transformation Matrix)

Here, the point $M_I$ to be obtained can be expressed as the following equation as if each point of the path in the coordinate system $CS_O$ is expressed in term of the coordinate system $CS_I$ .

$$M_1 = (H\,{}_0^1)^{-1}M_0 \qquad (2)$$

$$H^{-1} = \begin{bmatrix} R^T & \vdots & -R^T\,\mathbf{d} \\ \cdots\cdots & \cdots & \cdots\cdots\cdots\cdots \\ 0 & \vdots & 1 \end{bmatrix} \qquad (3)$$

Here, the matrix $R$ is the matrix to have the column vector of the unit vector of each axis in the coordinate system $CS_I$. When the unit vector of each axis is expressed in ( $e_x$, $e_y$, $e_z$), the matrix $R$ is as the following.

$$R = [R_1\ R_2\ R_3] = [e_x^T\ e_y^T\ e_z^T] \qquad (4)$$

Here, $e_z = (x_z, y_z, z_z)$, $e_x = (x_x, y_x, z_x)$,
$e_y = e_z \times e_x = (x_y, y_y, z_y)$

In Fig 5 $d$ is the distance between two points in the coordinate system $CS_O$ and the point $P_I$ is defined as the origin of the coordinate system $CS_I$. Three points of $P_1$, $P_2$ and $P_3$ to define the plane in the coordinate system $CS_I$ are located in the same plane. And so the following matrix can be expressed.

$$\begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \end{bmatrix} + \begin{bmatrix} d \\ d \\ d \end{bmatrix} = [0] \qquad (5)$$

$$P \cdot Q + D = 0, \quad \therefore\ Q = -P^{-1} \cdot D \qquad (6)$$

$$P^{-1} = \frac{1}{\Delta}\begin{pmatrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \end{pmatrix} \qquad (7)$$

Here,

$$\Delta = x_1(y_2z_3 - z_2y_3) + x_2(z_1y_3 - y_1z_3) + x_3(y_1z_2 - z_1y_2) \qquad (8)$$

Therefore,

$$\begin{bmatrix} a_x \\ b_x \\ c_x \end{bmatrix} = \begin{bmatrix} y_2z_3 - z_2y_3 \\ z_2x_3 - x_2z_3 \\ x_2y_3 - y_2x_3 \end{bmatrix}, \begin{bmatrix} a_y \\ b_y \\ c_y \end{bmatrix} = \begin{bmatrix} y_3z_1 - z_3y_1 \\ z_3x_1 - x_3z_1 \\ x_3y_1 - y_3x_1 \end{bmatrix},$$

$$\begin{bmatrix} a_z \\ b_z \\ c_z \end{bmatrix} = \begin{bmatrix} y_1z_2 - z_1y_2 \\ z_1x_2 - x_1z_2 \\ x_1y_2 - y_1x_2 \end{bmatrix} \qquad (9)$$

The relationship between coefficient $(a, b, c)$ of each term in plane equation and normal vector of the plane is expressed as the following.

$$a = -(a_x+a_y+a_z) \cdot t,\ b = -(b_x+b_y+b_z) \cdot t,$$
$$c = -(c_x+c_y+c_z) \cdot t,\ t = d \qquad (10)$$

Therefore, the normal vector $e_n$ is expressed as the following.

$$e_n = (x_n, y_n, z_n) \qquad (11)$$

Here,

$$x_n = \frac{a}{\sqrt{(a^2+b^2+c^2)}},$$
$$y_n = \frac{b}{\sqrt{(a^2+b^2+c^2)}},$$
$$z_n = \frac{c}{\sqrt{(a^2+b^2+c^2)}} \qquad (12)$$

Therefore, the normal vector is the same vector of Z-axis in coordinate system.

$$e_z = e_n = (x_n, y_n, z_n) \qquad (13)$$

For the sake of convenience, it is assumed that the point $P_2$ to define the plane in the input coordinate system is arranged with the X-axis in the absolute coordinate system. Under this assumption, the unit vector $e_x$ of X-axis is obtained by the point $P_1$ and $P_2$. And the unit vector $e_y$ of the Y-axis is obtained by vector cross product. The operation of computation is the same as followings.

$$e_x = (x_x, y_x, z_x) \quad (14)$$

Here,

$$x_x = \frac{(x_2 - x_1)}{x_m}, \quad y_x = \frac{(y_2 - y_1)}{x_m}, \quad z_x = \frac{(z_2 - z_1)}{x_m} \quad (15)$$

$$x_m = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (16)$$

$$e_y = e_z \times e_x = (x_y, y_y, z_y) \quad (17)$$

Here,

$$z_y = (x_z y_z - x_z y_x)$$
$$x_y = (y_x z_z - y_z z_x), y_y = (z_z x_x - z_x x_z), \quad (18)$$

The transformation between two coordinate systems is obtained by the matrix $R$ because the unit vectors $e_x$, $e_y$, $e_z$ of each axis are obtained by the above equations. In the above equations, the input coordinate system is transformed to the absolute coordinate system if three points $P_1$, $P_2$, $P_3$ to define the input coordinate system is used. The transformation of the point data to be obtained in the input coordinate system, in section 3.1, to the point data in the absolute coordinate system is the same as the following.

P1=(47.45, 111.55, 236.60),
P2=(229.17, 327.47, 274.28),
P3=(-17.55, 327.77, 316.35)

*dp1'* 21.830 -6.489 -0.747830
*dp2'* 25.306 -9.961 -0.765154
*dp3'* 29.181 -13.977 -0.689908
*dp4'* 34.564 -18.025 -0.465339
*dp5'* 38.382 -20.750 -0.140952
*dp6'* 42.918 -23.242 -0.153992
.
.

Fig 7 shows the example that the point data to be transformed to the absolute coordinate system are expressed in term of the graphics. If the absolute coordinate system can be transformed to the machine coordinate system, the input coordinate system can be transformed to the machine coordinate system.

### 3.3 Generation of NC Program

By the measured deburring path the deburring tool is selected and the tool path is determined.

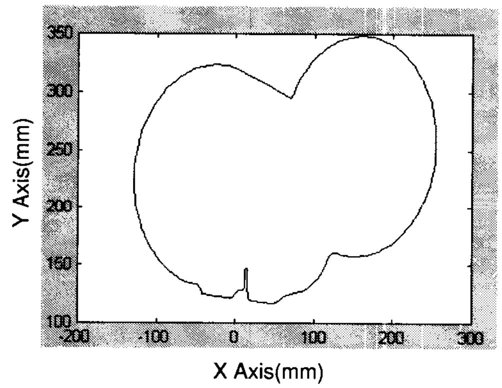



Fig. 6 Deburring path in input coordinate

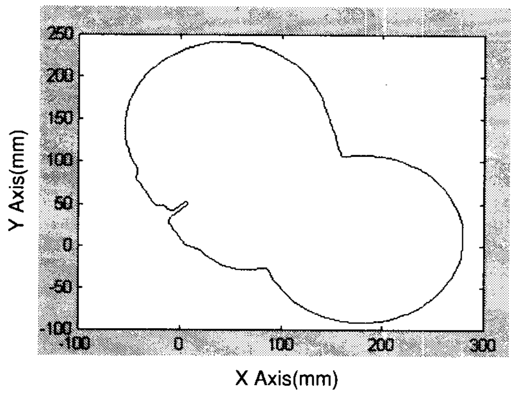


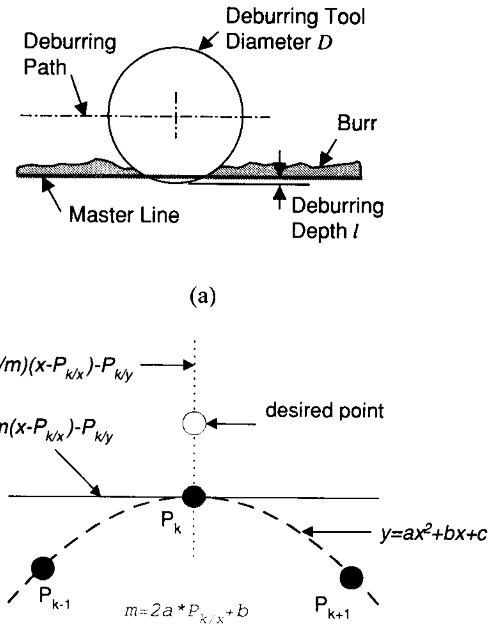

Fig. 7 Deburring path in absolute coordinate

The deburring machine of 5-axis CNC has the structure that three axes are driven in the main body and two axes are driven in the moving table. When the moving table is stopped the deburring machine has the function of 3-axis machining. As the generation condition of NC program the diameter of the deburring tool less than the minimum curvature of tool path is used. And the transformation of the machine coordinate system is done by controlling the moving table of the machine. If these environments is used, the point $P_1$ is arranged as the origin of the machine coordinate system and the point $P_2$ is arranged on the X-axis of the machine coordinate system. In order to make the trajectory of tool by the obtained data of tool path in off-line, the curve should be generated. As these methods the interpolation to simply connect every point in each other and approximation are used. Though the method of Beizer, B-Spline and NURBS is used for approximation, the case that the curve is not passed through the measured points is occurred. This is the cause of under-cut or over-cut in deburring. In this study, the method of simply connection is used in order that the tool in deburring path may passe through every measured point.

Under these environments, normal directional vector is driven in order to determine tool path by using tool offset. Fig 8 a) shows offset of tool radius when workpiece is machined in depth $l$ by deburring tool. The example of setting of tool offset to determine deburring path is shown in Fig 8 b). In Fig 8 b) point $P_k$ is used to determine the position of tool to be placed and points $P_{k-1}$, $P_{k+1}$ are the previous and next point. The equation of curve to use these points is expressed as $y=ax^2+bx+c$ and the tangential equation at point $P_k$ is expressed as $y=m(x-P_{k/x})-P_{k/y}\ m$ and the normal equation is expressed as $y=(-1/m)(x-P_{k/x})-P_{k/y}$. Here is the tangential slope and is expressed as $m=2aP_{k/x}+b$. The condition of deburring coordinates to have tool diameter $D$ and deburring depth $l$ is the coordinate to have the distance $(D/2-l)$ from point $P_k$ to be located at the normal line. If the condition is used, two equations are given as the followings.

$$(P_{k/x}-X)^2+(P_{k/y}-Y)^2=l^2 \qquad (19)$$

$$Y=-(1/m)(X-P_{k/x})-P_{k/y} \qquad (20)$$




(b)

Fig. 8 Deburring tool path a) and tool radius offset b)

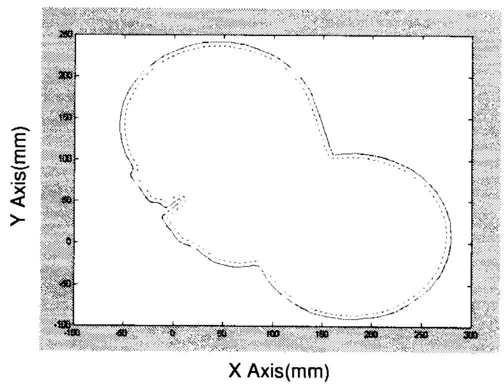



Fig. 9 Tool path for NC program generation

The tool path is obtained by solving equation 19 and 20. When tool diameter 10㎜, measurement precision, deflection of tool due to deburring force and deburring depth 0.2㎜ are considered the obtained NC program is following and the obtained tool path is given in Fig 9.

```
G90F300S2000
G01X24.419Y-2.447Z-0.747
G01X28.728Y-6.595Z-0.765
G01X32.426Y-10.440Z-0.689
G01X37.393Y-14.148Z-0.465
G01X40.965Y-16.704Z-0.140
G01X44.945Y-18.892Z-0.153
        .
        .
        .
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## 4. Application and Evaluation

In order to examine the application of the developed technology the machining experiment is accomplished and is evaluated in comparison with the conventional system and in point of technological, operational and economical view. To examine the general usability of the developed system the machining experiment is accomplished in CNC milling system. The used milling machine is the vertical machining center(DaeWoo FZ25) with FANUC 11MA controller and the deburring NC program is sent to CNC through RS-232C. The machining is accomplished by using HSS endmill of tool diameter 10㎜ and rotation of spindle 1,500 rpm. The photo scene of the machining process is given in Fig 10. The deburring test work shows the good result when the deburring test is observed by applying the general standards to be used in field. These is judged by the base that the function of deburring is the removement of burr rather than the machining precision of deburring. Because of this function, the deburring work can be accomplished by using the robot that has the repeatability of several hundred microns.

In point of technological view, because of collecting the point data in manual on machine the conventional method has the inconvenience that the teaching process is accomplished again when data of deburring path are changed. In point of operational view, though the teaching quality is dependent on the skill of operator in the conventional method but the developed method has the advantage to be independent on it. In the case of the middle class of skilled operator the measuring time is 70 minutes in the conventional method. If the process of the measuring time is classified in detail, it takes 10 minutes to install the probe and 5 minutes to set up the coordinates and 10 minutes dissolute the probe in preparing process. The difference of measuring time between them is increased in the case of increasing the measuring point and size of the object to be measured. This means that the working time of machine will be increased.

In the point of economical view, the chance in the choice of controller will be increased and the cost will be decreased in the optional specification of the function that the measuring data are transformed to NC program. In the conventional method the controller and probe of measuring system should be installed on every machine. But in the developed method the cost is decreased by using the digitizer of the general use. If it is assumed that 3 machines are operated, the effect of investment of the developed system is 15 % of the machine cost. If it is classified in detail, the cost is the followings. In the case of the conventional method, the manufacturing cost of the exclusive probe is 5 millions won, the manufacturing cost of the probe controller is 4 millions won, the cost of

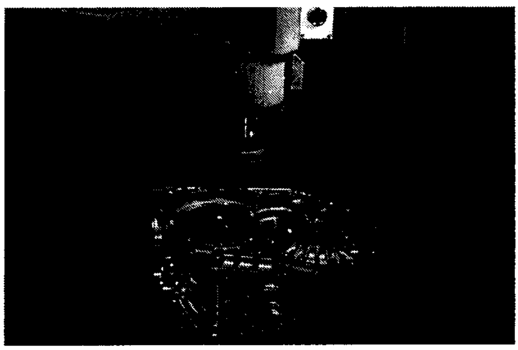

Fig. 10 Photograph of machining

optional specifications of NC is 7 millions and the cost of the related PLC is 3 millions. And the total cost per machine is 19 millions won. In the developed system the cost of PC and digitizer is 8 millions won. Therefore, the cost down is 15 % in the case of 150 millions won per machine. The analysis result of the developed system is given in Table 1.

Table 1. Classification of Off-Line Teaching

| Classification | Contents of Technology | Characteristics | |
|---|---|---|---|
| | | Conventional Method | Developed Method |
| Point of technological view | Definition of deburring path | Manual input on machine | Data collection in off-line |
| | Processing technology of data | Teaching is required for changing data | -Computation of optimal tool diameter<br>-Changeability of program due to wear of tool and diecasting<br>-Adjustability of amount of overcut |
| Point of operational view | -Teaching method<br>-Measuring time (minute) | -Dependence on expert<br>-70 minutes (in middle class of expert) | -Independence on expert<br>-5 minutes (in middle class of expert) |
| Point of economical view | -Applied Controller<br>-Controller of measuring probe<br>-Measuring probe | -Exclusive (Option of NC program generation)<br>-Installation on machine and supplement PMC is required<br>-Manufacturing of exclusively usable probe | -General use (Independence on maker and machine type)<br>-Installation on external side<br>-Application of general useable digitizer |

## 5. Conclusion

In order to effectively remove the burr occurred in diecasting process the generation of NC program in off-line teaching process and the machining of burr are studied by using 5 axis NC machine. For these, the teaching technology to input data of deburring path in off-line, the technology of coordinate transformation in consideration of the environments of the deburring machine and the technology of post processing for generating NC program by using teaching data are developed. In order to evaluate the capability and generality of the developed technology the machining experiment is accomplished by using the general usable CNC milling and it shows the good result. These developed technologies have several advantages in point of technological, operational and ecological view. In point of technological view the flexibility of working is guaranteed by the easiness of changing of data and machining process that can cope with the change of the machining condition and working environment. In point of operational view the measuring time, non-machining time, is decreased by off-line teaching with using the master and being independent of expert of operator. In point of economical view the developed system has the advantage that it is not dependent on the CNC specification and it is not required to install the special measuring system in every machine.

## Reference

1. Park, K. T., "A Study on Intelligent Robot System for Deburring," Proceeding of KACC, pp. 256 - 263, 1993.
2. Kramer, B. M. and Shim, S. S., "Development of a system for robotic deburring," Robotics and Compute -Integrated Manufacturing, Vol.7, No.1, pp.291-295,1990.
3. Yasuda Ltd., Debax-I user's manual, 1997.
4. Lee, M. H., Park, K. T. and Kim, S. H., Deburring system for die-casting bur, Technical report, 1999.
5. Shin, S. W., Gal, C. S., Kang, G., T. and Ahn, D. S., "Automation of deburring process using vision sensor and TSK fuzzy model," Journal of Korean Society of Precision Engineers, Vol. 13, No.3, pp. 102-109, 1996.

6. Shin, S. W. and Ahn, D. S., "Transfer deburring skills to robot using vision system," Journal of
skills to robot using vision system," Journal of
Korean Society of Precision Engineers, Vol. 15, No.9, pp. 93-100, 1998.
7. Tsai, D. M. and Lu, W. J., "Detecting and locating burrs of industrial parts," International Journal of Production Research, Vol.34, No.11, pp.3187-3205, 1996
8. Asada H. and Arai, Y., "The direct teaching of tool manipulator skills via the impedance identification of human motions," Proceedings IEEE Int'l Conference Robotics and Automation, pp. 1269 - 1274, 1998.
9. Simokura K. I. and Liu S., "Programming Deburring Robots based on human demonstration with direct burr size measurement," Proceedings IEEE Int'l Conference Robotics and Automation, pp.572-577, 1994.
10. FANUC Ltd., FANUC 20 series maintenance manual, 1991.
11. Kim, S. H., "Development of a distributed numerical control system," Journal of Korean Society of Precision Engineers, Vol. 12, No.12, pp. 19-29, 1995.
12. Zeid, I, CAD/CAM Theory and Practice, McGRAW-HILL, 1991.