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Breakage Detection of Small-Diameter Tap Using Vision System in High-Speed Tapping Machine with Open Architecture Controller

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In this research, a vision system for detecting breakages of small-diameter taps, which are rarely detected by the indirect in-process monitoring methods such as acoustic emission, cutting torque and motor current, was developed. Two HMI (Human Machine Interface) programs to embed the developed vision system into a Siemens open architecture controller, 840D, were developed. They are placed in sub-windows of the main window of the 840D and can be activated or deactivated either by a softkey on the operating panel or the M code in the NC part program. In the event that any type of tool breakage is detected, the HMI program issues a command for an automatic tool change or sends an alarm signal to the NC kernel. An evaluation test in a high-speed tapping machine showed that the developed vision system was successful in detecting breakages of small-diameter taps up to M1.

Key Words : Tool Breakage, CMOS Image Sensor, Vision System, Slit Beam Laser, Threshold Filter, Centroid

1. Introduction

Tapping work, which is one of the most difficult machine cuttings, is the process of making threads for a screw with a tap and the objective of tapping is to make the best threads. Tap breakage or enlargements of threads have occurred due to various factors such as bad working conditions, insufficient discharge of chips, or misalignment of the tapping and drilling axis. Because tapping is the final process of the machine cutting in most cases, if a tap is broken in cutting then a workpiece is wasted. And if the tap breakage is not appropriately detected before the subsequent tapping process, it can bring about a much greater loss of money and time. Recently IT industries that are remarkably developing need many M3 and smaller diameter tappings in the cutting of portable devices such as PDAs, cellular phones and IT devices such as HDDs and notebooks and so on. For example, 3.5″ HDD has about 20 M3 taps. And because it takes relatively a lot of time to perform this small-diameter tapping, the high speed for the improvement of productivity is rapidly progressing. As a result, recently a 10,000

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rpm ultra high-speed tapping machine has been developed. But this high speed and the use of a small-diameter tap inevitably have given rise to an increase of the probability of tap breakage. Therefore the detection of tool breakage in tapping is one of the key technologies for the increase of productivity and is the problem awaiting to be solved (Kim et al., 2002).

As the cutting process of a tap is more complicated than that of a drill or an endmill and the cutting force is relatively very small, monitoring for tap breakage is very difficult. So, although many studies to detect wear or breakage of drills and endmills have been done, research on taps have seldom been carried out. But recently some studies on monitoring the condition of taps have been conducted. Yoshinori Yamaoka (2000) showed that up to M4 tap could be monitored in the tapping of S45C and Al5052 with the internal sensor (current sensor) and that adaptive control skill could be applicable in preventing taps from breaking. Y. B. Chen (1990) worked out a way to monitor the condition of taps with a dynamometer, dividing the breaking parameters into some categories. R. Du (1995) presented a method to monitor tap condition with AE (Acoustic emission) sensor. But although these methods have been studied, they have some weak aspects that can be applied only to taps larger than M4. And they also have some limitations in real cutting processes owing to the jig fixture for sensor installation and cannot guarantee the repeatability of the sensor signal due to factors such as machine and sensor aging. As a direct method, there is a touch probe that can detect exactly a yes or a no of tap breakage by directly touching the tap with a small wire. But because of the increase of machine down time generated by moving to a special point in order to detect tap breakage, this is not an efficient method. Moreover, it is true that applying these methods described above to real machining environments is very difficult. This is because conventional machine tools have adopted the closed controller. Because the closed controller doesn't open the inner information of the NC kernel, interface the between the machine tool and the monitoring system is very difficult. Therefore a PLC I/O that has time delays or an additional PC to process sensor signals for tap breakage detection is generally used. Recently, an open architecture controller has been used more and more as an alternative in order to solve these problems.

In this study, we have developed the vision system to detect tap breakages with a CMOS image sensor that is free from the limitations above noted, and this developed system was embedded into a high-speed tapping machine (Komatec Co.) that adopted an open architecture controller for performance testing and was evaluated about M1 and M3 taps.

2. Vision System

2.1 Hardware of vision system

Figure 1 shows a photograph of the vision module, that is, the hardware of the developed vision system for tap breakage detection. The vision module consists of a CMOS image sensor that has an effective pixel array 642×482 VGA format, a slit beam laser generator and a telescopic lens. The lens has a focal length of 25 mm, an angle of view of 13.3 and an F number of 2.5. Because a telescopic lens can show a more magnified image

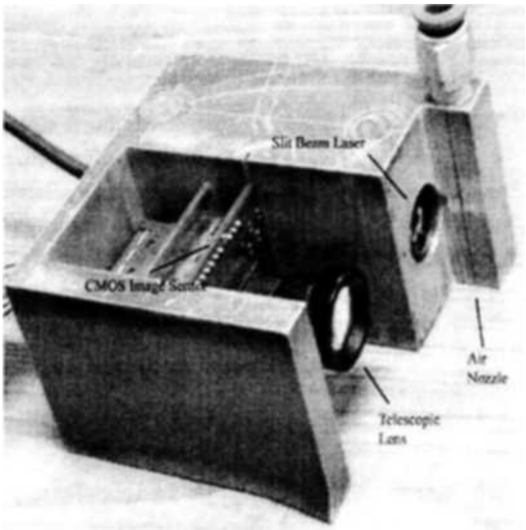


Fig. 1 Structure of the vision module

than a wide angle lens, its usage makes tap breakage determination more easy and accurate. The slit beam laser generator emits the red lights on the tool surface in parallel with the tool axis. Because slit beam illuminate only the tool in the form of slit, slit beam lighting didn't give any influence on the other objects. Therefore it helps the tool geometry to be discriminated well from the complicated background by increasing the light intensity of the tool surface. And a long air nozzle was devised to prevent the vision system from being contaminated by scattered coolant or cutting chips in the tapping process. It jets high-pressure air in front of the telescopic lens to build an air curtain. The image capture is triggered by the signal of the softkey in the operating panel or the M code in the NC part program and then the captured image is saved to the memory which is mapped to the video memory area on a PC in 256 gray levels for subsequent signal processing on the grabber board.

2.2 Software of vision system

A simple Windows program for image processing and display was developed to test the operation of the vision system. This program brings the captured image of the tap from the memory of the grabber board and displays the image. Two filters were applied to the captured image for the detection of tool breakages. One was the median filter to get rid of some noise from the captured image ; the other was the threshold filter to distinguish the tool geometry from the background. Because the color of the slit beam laser is red, the filter was applied to the R component of the image. Generally because this process requires very complicated image processing such as pattern recognition to know the tool shape itself, it requires very much computation time. But, because this system will be embedded into a machine tool, it should recognize the tool shape within a short time. So we tried to recognize the tool shape by computing only the centroid coordinate value of the R Component in the filtered image and this value was used as an indicator to determine whether the tool was broken or not.

3. NC Embedding

As mentioned in the introduction, because so far the developed system for detecting the tool breakages has usually been tested on a PC, it has been very difficult to apply this system to actual manufacturing environments. So in this study, the HMI (Human Machine Interface) program was developed as a goal for NC embedding. The 840D, an open architecture controller of Siemens Co., was used as a controller for the NC-embedding test.

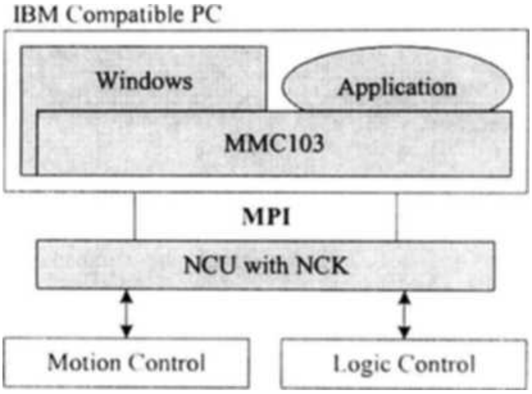


Fig. 2 Control architecture of 840D

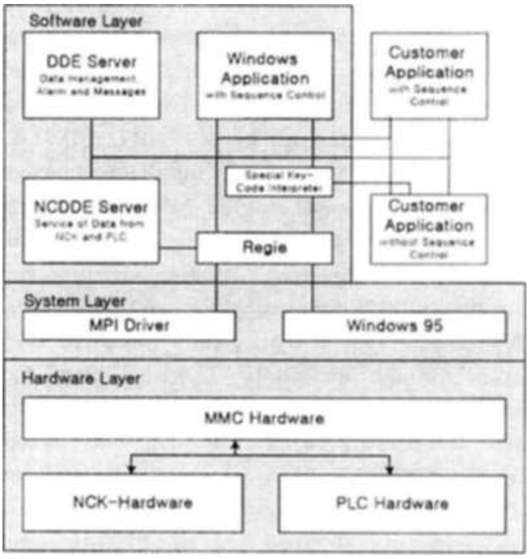


Fig. 3 MMC software organization

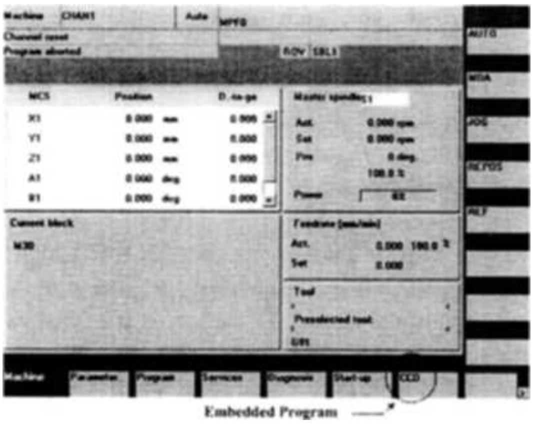
3.1 Siemens open NC controller, 840D

Figure 2 shows the control architecture of the 840D based open NC. As seen in the Fig. 2, the 840D consists of the PLC based on Step 7 to deal with logic controls, the NCU in charge of motion control and interpolation of each motor axis, and the MMC which helps the operators to use the machine tool easily.

The MMC is a standard PC and can operate various OSes such as DOS, WINDOWS 95, WINDOWS NT and others. And it has a conventional HDD, two serial ports, one parallel port and PCI/ISA slots into which many standard PC interface cards can be inserted. The MMC can give and take various data with the NCU in serial communication through an MPI card. Figure 3 shows a schematic diagram of the MMC's different software layers from the applications viewpoint.

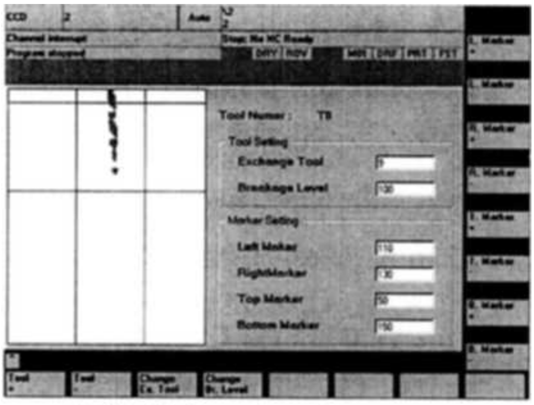
3.2 HMI program for NC embedding

The OEM Package that is operated under the MMC103 is the developmental environment for the 840D HMI program. The OEM Package consists of the NCDDE Server, the Alarm Server, the Data Management Server, the Sequence Control and the REGIE. The NCDDE Server performs three jobs regarding data transfer. The first is Variable Service which accesses the NC, the PLC and the drive data. The second is Domain Service that copies files from the MMC to the NCK and vice versa. The third is PI Service which is used for transferring commands to the NC and the PLC such as PISTART, PISTOP, and others. The Alarm Server supplies the current alarms and messages to the MMC. The Data Management Server provides interfaces for handling files and directories creating, deleting and copying and file downloading and uploading. And each server is dynamically linked to each other through the DDE (Dynamic Data Exchange) connection. Sequence Control handles state transition between each state that consists of vertical softkeys, horizontal softkeys and the application screen. It also interprets the vertical and horizontal softkeys. The REGIE is a super ordinate program for flexibly managing user auxiliary programs, area applications, dynamic link libraries and VBX files. So it allows the developed user HMI Program to be embedded into the Siemens Standard User Interface as in Fig. 4.



Embedded Program

Fig. 4 Standard user interface of 840D



Tool Number : T8

Tool Setting

Exchange Tool 8

Breakage Level 130

Marker Setting

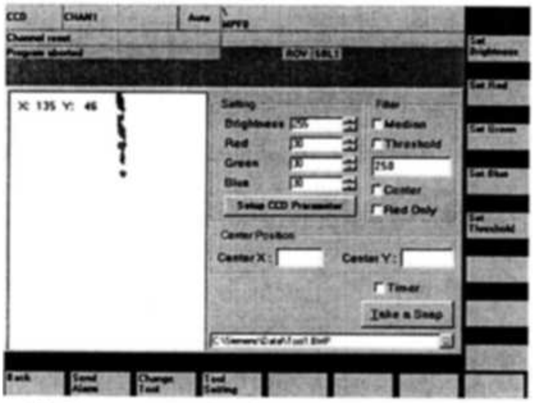
Left Marker 110

RightMarker 130

Top Marker 50

Bottom Marker 150

(a) Tool information and management



X: 135 Y: 46

Setting

Brightness 255

Red 130

Green 130

Blue 130

Filter

☐ Median

☐ Threshold

250

☐ Center

☐ Red Only

Center Position

Center X :

Center Y :

☐ Timer

(b) Image processing for tap breakage detection

Fig. 5 Developed HMI programs

In this study, two HMI programs satisfying Siemens Standard User Interface Rules was developed. Fig. 5(a) shows the tool setting screen that has input boxes of two categories. One is for the tool exchange number in cases of tool breakage and for the tool breakage level ; the other is to set the area that the tool takes up in the captured image. Because generally it takes much time to do image processing, this can decrease processing time by computing only the area that the tap practically takes up in the image. Figure 5 (b) is the screen to capture the tap image and process the image and to send an alarm and issue a command for the tool exchange using the tool setting data that was input in Fig 5(a). Each screen was executed by a vertical/horizontal softkey on an operating panel or the M code in the NC part program. The developed HMI program was embedded into the 840D by the REGIE.

4. Experiments and Results

Figure 6 shows the experimental setup to test the developed vision system. The machine tool used in the experiment was the vertical high-speed tapping machine that consists of XY-axes bed, a Z-axis column and a built-in spindle. The developed vision system was installed at a center axis line on the z-axis column where it could always watch the tool regardless of the movement of the tool. Therefore this system could monitor the condition of the taps without any increase of machine down time because there was no need to move to a special point to monitor the tool. Some tests were executed to evaluate the performance of the developed vision system.

Two simple tests were executed in order to perceive the effectiveness of the slit beam laser on the captured tool image. Fig. 7 and 8 are the raw image of M1 and M3 taps with and without the slit beam laser respectively, before the application of the Median Filter and the Threshold Filter. As can be seen in the picture, we could easily find the tool in Fig. 8 but could not in Fig. 7. It is not clear in the black and white image. As a result, it can be concluded that the illumination of the slit beam laser helps to effectively separate the tool geometry from the inner complex background of

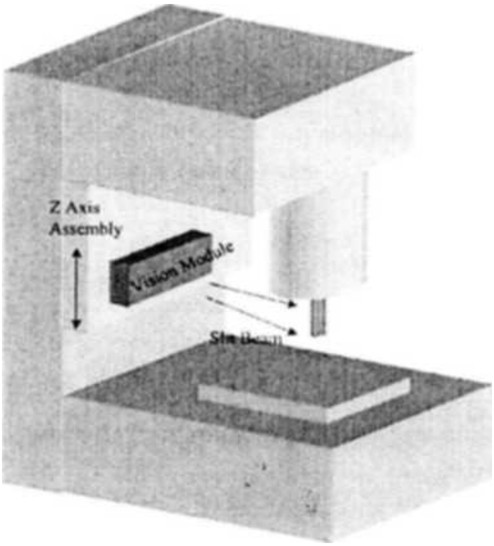


Fig. 6 Installation of the vision system

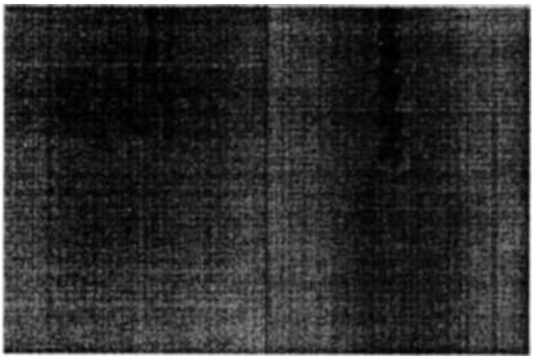


Fig. 7 Image without slit beam laser

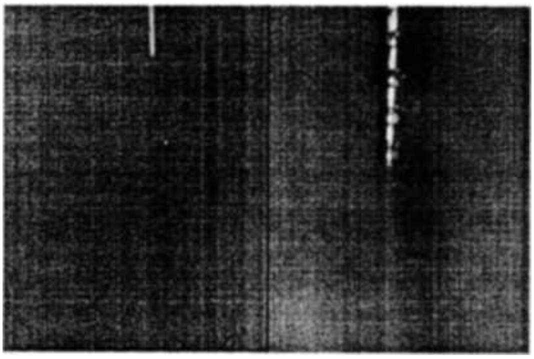


Fig. 8 Image with slit beam laser

a machine tool.

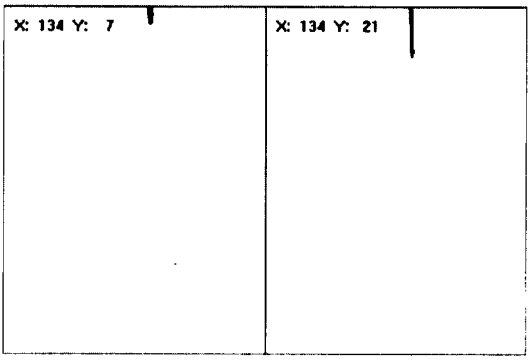
Figure 9 and 10 show the normal and broken tool images after the application of the two filters to M1 and M3 taps respectively. We can easily know that the parts that look black in the figure is the tool. When two figures of Fig. 10 were compared, left figure is one about broken tool. But to discriminate breakage quantitatively, image processing algorithms such as pattern recognition is required and because these are greatly complex and difficult, additional hardwares for signal processing are needed. In this study, we introduced the concept of centroid to decide tool breakage simply. In the Fig. 11, when brightness of each pixels are Vij, centroid for the brightness are expressed like below,

$$C_x=\frac{\sum_{i=1}^{N_c}\sum_{j=1}^{N_r} j\times V_{ij}}{\sum_{i=1}^{N_c}\sum_{j=1}^{N_r} V_{ij}} \tag{1}$$

$$C_y=\frac{\sum_{i=1}^{N_c}\sum_{j=1}^{N_r} i\times V_{ij}}{\sum_{i=1}^{N_c}\sum_{j=1}^{N_r} V_{ij}} \tag{2}$$

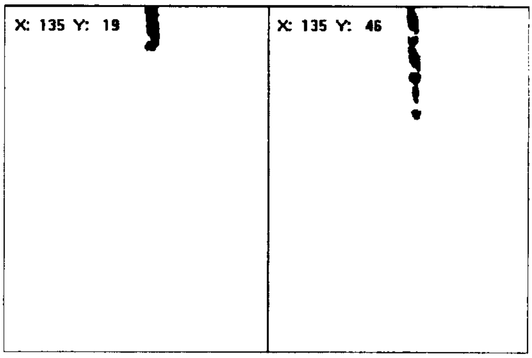
Here, Nc : Number of column
Nr : Number of row
Cx : X coordinate of centroid
Cy : Y coordinate of centroid

The coordinates of Fig. 9 and 10 show computed coordinates of centroid. According to the repetitive experiments, computed coordinate of centroid was very similar to the coordinate of tool center. Therefore, it can be known that it is capable to decide tool breakage by comparing y coordinate of centroid. In the Fig. 9 about M1 tap, Y values of the left and right images are 7 and 21 respectively and we can decide that the case of left image is broken tool. Fig. 10 about the M3 tap shows the same result as Fig. 9. As a result, we know that this system can detect breakages of taps up to M1. The total time to detect a tap breakage was about 1 second. This time is not fast enough to apply the developed vision system to a practical cutting environment. But it is thought that this problem can be solved by the code optimization of the HMI program and an upgrade to a PCU50 that is being used largely now. And because this system uses an image sensor, when an outer strong light source was directly inserted into the sensor, it became saturated and recognition of the tap was impossible. But because this problem doesn't happen in general work environments, it is thought that it can be neglected.



(a) Normal tool (b) Broken tool

Fig. 9 Captured image of M1 tap



(a) Normal tool (b) Broken tool

Fig. 10 Captured image of M3 tap

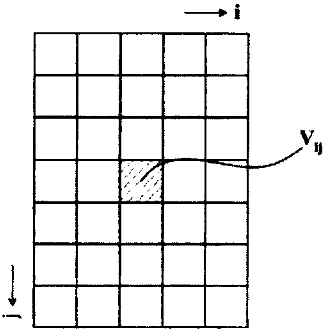


Fig. 11 Definition of the pixel brightness

4. Conclusions

In this paper, we studied a small-radius tap breakage detection system which is one of the most important technologies in automation of the cutting lines using machine tools and we obtained the following results.

(1) We developed the vision system that can exactly detect breakages of the small-diameter taps without the increase of machine down time.

(2) Two HMI programs for the NC embedding of the developed vision system into a Siemens 840D were developed.

(3) The developed vision system and two HMI programs were successfully embedded into a ultra high-speed tapping machine; an evaluation test for M1 and M3 taps was executed and we could know clearly the yes or no of the tool breakage of taps up to M1 within 1 second.

References

Chen, Y. B., Sha, J. L. and Wu, S. M. 1990, "Diagnosis of the Tapping Process by Information Measure and Probability Voting Approach," *J. of Eng. for Ind.*, Vol. 112, pp. 319~325.

Choi, M. S., 1994, "A Study on Tapping Torque in High Speed Tapping," *KSME*, Vol. 18, No. 12, pp. 3195~3201.

Curt, E. and Everson, S. Hoessein Cheraghi, 1999, "The Application of Acoustic Emission for Precision Drilling Process Monitoring," Int. J. Mach. Tools & Manufact. Vol. 39, pp. 371~387.

Du, R., Elbestawi, M. A. and Wu, S. M., 1995, "Automated Monitoring of Manufacturing Process," *J. of Eng. for Ind.*, Vol. 117, pp. 133~141.

EL-Wardany, T. I., GAO, D. and Elbestawi, M. A., 1996, "Tool Condition Monitoring in Drilling Using Vibration Signature Analysis," *Int. J. Mach. Tools & Manufact.*, Vol. 36, No. 6, pp. 687~711.

JAE S. Lim, *Two-Dimensional Signal and Image Processing*, Prentice Hall.

Kim, S. H., Kim, D. H., Kim, S. M., Lee, D. J., Lee, S. K., Ahn, J. H. and Lee, S. G., 2002, "Development and Evaluation of Ultra High-Speed Tapping Machine," *KSPE*, Vol. 19, No. 11, pp. 221~227.

Kwon, O. D. and Yang, M. Y., 1993, "Tool Condition Monitoring Technique Using Computer Vision and Pattern Recognition," *KSME*, Vol. 17, No. 1, pp. 27~37.

Li Xiaoli, 1999, "On-Line Detection of the Breakage of Small Diameter Drills Using Current Signature Wavelet Transform," *Int. J. Mach. Tools & Manufact.*, Vol. 39, pp. 157~164.

Lorenz, G., 1980, "On Tapping Torque and Tap Geometry," Annals of CIRP, Vol. 29, pp. 1~4.

Mauri Routio, Matti Saynatjoki, 1995, "Tool Wear and Failure in the Drilling of Stainless Steel," *J. Mat. Processing Tech.*, Vol. 52, pp. 35~43

Rafael C. Gonzalez, Richard E. Woods, *Digital Image Processing*, Addison Wesley.

Sa, S. Y., Yu, E. Y. and Ryu, B. H., 1997, "A Study on the Tool Fracture Detection Algorithm Using System Identification," *KSME*, Vol. 21, No. 6, pp. 988~994.

Siemens, *SINUMERIK 840D OEM-Package MMC User's Manual.*

Yoshinori YAMAOKA, Yoshiaki KAKINO, Yasuhiko SUZUKI, Akimitsu NAGAE, Toshiyuki MURAKI, 2000, "High Speed, High Productive Tapping by Intelligent Machine Tools (1st Report)-Automatic Detection of Tool Failure and Chip Jamming," *JSPE*, Vol. 66, pp. 1922~1926.

Yoshinori YAMAOKA, Yoshiaki KAKINO, Tomonori SATO, 2002, "High Speed and High Productive Tapping by Intelligent Machine Tools (3rd Report) Prevention of Tap Tool Breakage and Monitoring of Tool Failure for Difficult-to-machine Materials by Realtime Adaptive Control," *JSPE*, Vol. 69, pp. 1226~1230.

Youn, J. W., Yang, M. Y. and Park, H. Y., 1992, "A Study on Detection of Cutting Tool Fracture by Dual Signal Measurements," *KSME*, Vol. 16, No. 4, pp. 707~722.