Japanese Metal Cutting Research in the '80s

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This report is a survey which focuses on papers dealing with metal cutting in Japan between 1980~1989. The sources are The Journal of The Japan Society of Precision Engineering and The Transactions of The Japan Society of Mechanical Engineers. The former contains two hundred fifty one papers and the latter does one hundred thirty one papers. In all, three hundred eighty two papers were classified into eleven categories. The largest number of the papers, one hundred forty one, were classified into the category of "machining by non-turning", this is because fundamental research on conventional cutting process had already been published by 1980. It is apparent from this survey that in the last decade there has been two main trends, which are actually common world wide. They are automation in machining and ultra precision cutting. Neither of these trends are represented as a category title, however, they are closely related to such categories as cutting mechanism, tool, chip, and machinability.

1. *Inroduction*

In recent years there has been a very rapid development and implementation of new machining technology designed to increase the efficiency, in other words to reduce the costs of material removal process, and to advance the accuracy of machining. New trends,which are different from those in the '70s, can be found in Japanese metal cutting papers in the last decade. First, however, Japanese metal cutting papers published in the '70s should be reviewed. Trends prior to the '70s are as follows: fundamental studies on chip formation mechanism had been done by 1970. Some of them employed visio-plasticity method with computers to analyse chip fomation mechanism. Tool wear mechanism had also been investigated with the aid of accurate analysis of cutting temperature and diffusion region using electron probe micro analyzer (EPMA).

In the '70s computer techniques had advanced to a great extent. Computer techniques were widely applied to the analysis of metal cutting process accordingly. Consequently, a variety of researchers tried to examine chip formation process quantitatively without conducting the cutting experiment, one of the typical analysis was finite element method (FEM).

However, experimental techniques, particularly observation techniques, had also made appreciable progress. Microscopic observation of the chip and the machined surfaces was made possible by means of scanning electron microscope (SEM), which is ideally suited for this purpose. Therefore the effects of the physical properties of the work material on the cutting event were determined from various point of view. Because SEM promises fine observation of the work material and the chip at the magnifications up to 10,000×,with large depth of focus which is more 300×than that of light optical microscope. Some researchers conducted cutting experiments inside SEM in order to observe the cutting event directly utilizing these advantages.

2. *Data Source and Classification*

This report is a survey which focuses on papers adopted from two journals dealing with metal cutting in Japan between 1980~1989. The sources are The Journal of The Japan Society of Precision Engineering and The Transactions of The Japan Society of Mechanical Engineers. In all, three hundred eighty two papers were classified into eleven categories. The categories are:

1 cutting mechanism
2 tool (tool wear, performance on newly developed tool material, chipping of tool edge, tool fracture, etc.)
3 precision cutting (ultra precision cutting, cutting for accuracy rather than high efficiency, micro machining, etc.)
4 machinability (newly developed work materials, difficult-to-machine materials, free machining metals, etc.)
5 chip (chip disposal methods, chip breaker, chip control, etc.)
6 cutting fluids
7 cutting temperature
8 vibration (chatter)
9 un-conventional cutting (ultra high speed machining, hot machining, vib-

ration cutting, etc.)

#10 non-turning (drilling, milling, reaming, honing,etc.)

#11 sensing (detecting tool fracture or tool wear by new devices, detecting something useful for adaptive control, etc.)

There is no doubt that some papers are closely related to more than two categories, and it was not easy to classify these papers. Eventually, the papers were classified according to main subject as recognized by author of this paper. For example, although some research involved a series of papers, every report was not absolutely classified into the same category. But it rather depended upon the main subject in each report.

3. *A Survey of The Journal of The Japan Society of Precision Engineering*

Two hundred fifty one papers which described metal cutting were published in The Journal of JSPE in the '80s. Table 1 summarizes distribution of the papers in every category and each year. Table 2 shows volume ranking of the category. Fig. 1 graphically represents the total amounts of papers in each category in the '80s.

Table 1 Distribution of Metal Cutting Paper in The Journal of The Japan Society of Precision Engineering

	80	81	82	83	84	85	86	87	88	89	TL
(1) cutting mechanism	2	4	2	2	3	1	1	4	3	1	23
(2) tool	5	6	8	4	6	6	7	7	3	9	61
(3) precision cutting	0	0	0	0	0	1	0	4	2	2	9
(4) machinability	1	2	1	0	0	0	2	7	1	2	16
(5) chip	0	3	0	1	1	1	3	1	2	0	12
(6) cutting fluids	0	2	0	0	0	0	0	0	0	1	3
(7) cutting temperature	0	0	0	0	0	0	0	1	0	0	1
(8) vibration	0	1	5	1	3	0	1	0	0	2	13
(9) un-conventional cutting	3	2	1	0	0	0	0	3	2	6	17
(10) machining by non-turning	5	10	13	8	5	4	10	8	10	5	78
(11) sensing	6	1	3	1	1	0	2	1	2	1	18
Total	22	31	33	17	19	13	26	36	25	29	251

Table 2 Volume Ranking of Category in The Journal of The Japan Society of Precision Engineering

Volume Ranking of Categories	Retes (%)
1. machining by non-turning	31.1
2. tool	24.3
3. cutting mechanism	9.2
4. sensing	7.2
5. un-conventional cutting	6.8
6. machinability	6.4
7. vibration	5.2
8. chip	4.8
9. precision cutting	3.6
10. cutting fluids	1.2
11. cutting temperature	0.4

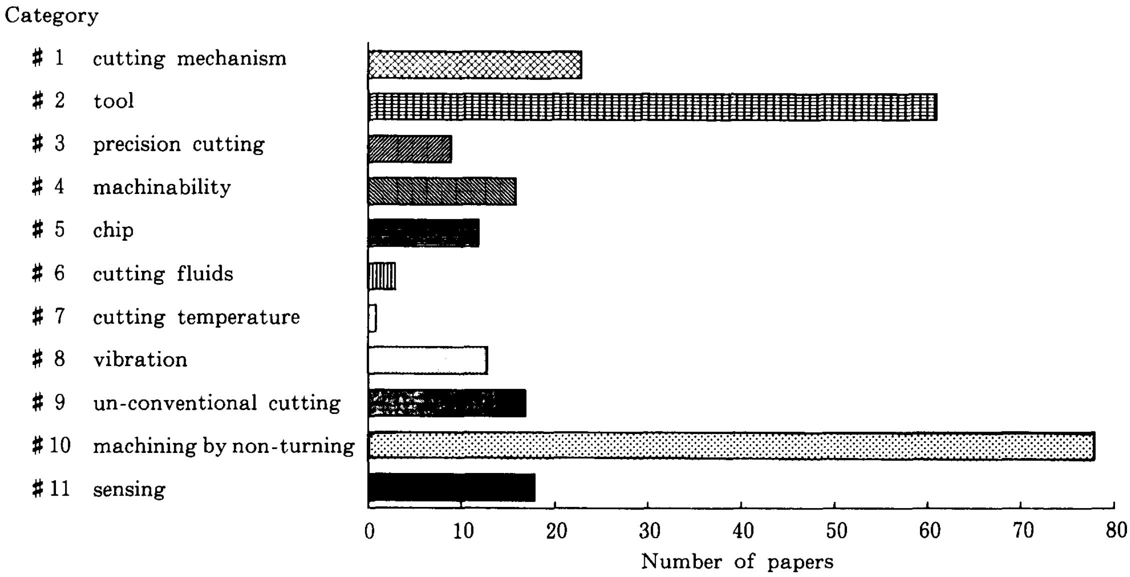

Fig1. Classification of Metal Cutting Paper in The Journal of The Japan Society of Precision Engineering

The category of #10 non-turning and # 2 tool have many more papers than the others. The numbers are 78 and 61 respectively. They accounted for 31.1 and 24.3% of the total respectively. The reasons why both categories have a large number of papers are as follows:before the '80s many researchers studied conventional cutting process and published the papers, leaving the more difficult problems for later analysis. Cutting mechanism in turning which has already been explained could be applicable to that in non-turning processes. Newly developed tool material such as cBN, sintered diamond, and ceramic began to be employed in manufacturing plants, which produced a need for a better understanding of tool performace. Furthermore, the demand for unmanned machining systems requires the prediction of tool failure or wear and a variety of researches on tool fracture mechanisms were consequently done. It was found that linear fracture mechanics are powerful strategies to analyse failure mechanisms.

Category # 1 cutting mechanism, #11 sensing, # 4 machinability and # 5 chip belong to second largest volume group. Category # 1 cutting mechanism includes that of three dimensional cutting, analysis of component of cutting forces, saw-toothed chip formation, burr formation, effects of tool geometry on surface finish, screw thread turning mechanism, etc. The total number of papers was 23 or 9.2% of the total.

Category #11 sensing covers many fields such as in-process detection of tool damage by acoustic emission and the dynamic component of the cutting force, analysis of noise emitted in cutting and friction between tool and flank face, stress analysis by caustic method, measurement of tool edge geometry with the aid of digital image processing technique, and measurement for lead error in threaded cutting tools. The total number of papers was 18 or 7.2% of the total.

Category # 4 machinability involves machinability of newly developed materials such as sintered steel, free cutting alloys, cast iron rolls, difficult-to-machine materials, expression of machinability for data base, the role of free machining additives etc. The total number of papers was 16 or 6.4% of the total.

Category # 5 chip means analysis for chip breaking type, pneumatic chip conveying, the monitoring of chip flow, chip disposal, chip control and new chip breaker. The purpose of most papers was for unmanned machining. The total number of papers was 12 or 4.8% of the total.

Category # 8 vibration and # 9 un-conventional cutting have thirteen and seventeen papers respectively, being 5.2 and 6.8% of the total respectively. The first half of this decade provided some papers about chatter stability, regenerative chatter, suppression of chatter using high damping materials, forecast of chatter stability etc., while the last half of this decade offered only one paper about vibration. Un-conventional cutting includes vibration cutting, plasma hot machining, cutting by self-propelled rotary cutting tool etc., all of which are for the purpose of getting better performance.

Category # 3 precision cutting has nine papers or 3.6% of the total. Before '84 no papers could be found at all. The category of precision cutting means mirror surface cutting, most of which are ultra precision cutting or diamond turning except one paper dealing with the control of accuracy in turning by piezo-electric actuater. Mirror surface technology by ultra precision machines is established now, that is to say, it is not difficult to obtain mirror surfaces which have $1/1000\mu m$ order R_{max} by highly sophisticated precision machines.

Category # 6 cutting fluids and # 7 cutting temperature have three and one paper respectively. The former were published in '81 and '89, and the latter can be found in '87. Before the '80s fundamental analysis of both categories had already been done. Original methods for measurement or analysis of cutting temperature are needed to obtain more precise temperature value and fine temperature distributions.

Table 3 shows rates of the papers published in each year comparre to all the papers in the '80s. In the last half of this decade, after '86 in particular, more papers were published than in the first half.

Table 3 Change of Rates in Number of Paper in The Journal of The Japan Society of Precision Engineering

Year	80	81	82	83	84	85	86	87	88	89
Rates (%)	8.8	12.3	13.1	6.8	7.6	5.2	10.4	14.3	10.0	11.6

4. *A Survey of The Transactions of The Japan Society of Mechanical Engineers*

Table 4 shows result of literature survey in "The Transactions of The Japan Society of Mechanical Engineers (JSME)". Table 5 shows volume ranking of each category. Fig. 2 graphically represents the total number of papers in each category in the '80s. Comparing the two publications, the total number of metal cutting papers in The Transactions of JSME is approximately half of that in The Journal of JSPE. The number of papers in category #10 machining by non-turning in JSME was about 50% of all the papers, which value is greater than that in JSPE. Actually, JSPE has 31.1% of all. Also worthy of note is category # 8 vibration, this category occupied 12.2% of total, which was much more than that in JSPE. The reason why category #10 machining by non-turning is located at the top of the ranking is considered here. Looking into the details of papers in the category #10, more papers dealt with machining of gears in JSME than in JSPE. Researchers in charge of the machining of gears usually tend to submit the papers to JSME, because of a large number of papers about other aspects of gears, for example better contour of tooth for noise reduction, fatigue strength of carburized gears etc., were also published in JSME.

Table 4 Distribution of Metal Cutting Paper in The Transactions of The Japan Society of Mechanical Engineers

	80	81	82	83	84	85	86	87	88	89	TL
(1) cutting mechanism	0	2	1	1	1	3	2	0	1	0	11
(2) tool	0	1	4	0	0	0	1	3	3	0	12
(3) precision cutting	0	0	0	0	0	2	0	1	0	0	3
(4) machinability	0	0	0	0	0	1	0	2	0	1	4
(5) chip	0	0	1	0	0	0	0	0	0	0	1
(6) cutting fluids	0	1	1	0	1	2	0	0	0	0	5
(7) cutting temperature	0	0	0	0	0	0	0	1	1	0	2
(8) vibration	0	0	3	1	0	2	2	0	6	2	16
(9) un-conventional cutting	0	0	1	0	0	0	0	1	0	1	3
(10) machining by non-turning	6	3	5	2	7	10	8	6	6	10	63
(11) sensing	0	1	1	1	0	3	2	2	0	1	11
Total	6	8	17	5	9	23	15	16	17	15	131

Table 5 Volume Ranking of Category in The Transactions of The Japan Society of Mechanical Engineers

Volum Ranking of Categoris	Rates (%)
1. machining by non-turning	48.1
2. vibration	12.2
3. tool	9.2
4. cutting mechanism	8.4
5. sensing	8.4
6. cutting fluids	3.8
7. machinability	3.1
8. precision cutting	2.3
9. un-conventional cutting	2.2
10. cutting temperature	1.5
11. chip	0.8

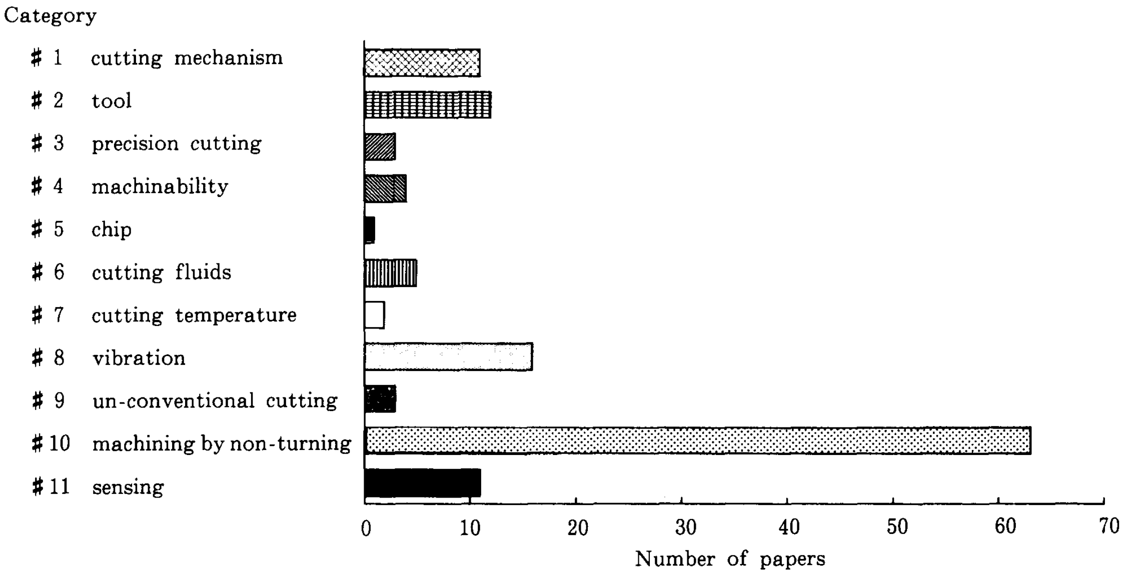

Fig. 2 Classification of Metal Cutting Paper in The Transactions of The Japan Society of Mechanical Engineers

Category # 2 tool in JSME accounted for approximately half of The JSPE rate, which is contrary to the case of category # 8 vibration. Un-conventional cutting contained in category # 9 has same tendency as category # 2 tool. The papers in category # 1 cutting mechanism are constantly issued almost every year in both journals. Category #11 sensing is ranked at medium class in both volume rankings.

Table 6 shows rates of the papers published in each year compared to all the papers published in the '80s. In the last half of this decade, after '85 in particular, more papers were issued than in the first half. In the case of JSPE, the papers promptly increased after '86.

Table 6 Change of Rates in Number of Paper in The Transactions of The Japan Society of Mechanical Engineers

Year	80	81	82	83	84	85	86	87	88	89
Rates (%)	4.6	6.1	13.0	3.8	6.9	17.6	11.5	12.2	13.0	11.4

5. *A General Survey of the '80s*

General speaking, there are two main thrusts, world wide, in advanced manufacturing. They are automation of manufacturing and manufacturing with higher precision. All the papers, a total of three hundred eighty two, are reviewed in general here. It is concluded from this survey that one of the most distinctive features in the '80s is research for the purpose of automation in machining, which is related to many categories such as machinability[1], tool[2], chip[3], sensing[4], cutting mechanism[5] and vibration[6].

Among them category # 2 tool is the most helpful field for automation in machining. The criteria to determine cutting parameters is tool life. In other words, it is important to ensure efficient tool operating during long machining sequences without human attendance (for fully automated machining systems). The prediction of brittle failure of the tool edge is necessary for unmanned machining. The failure analysis of tool edge[2] has particularly advanced in this decade.

Optimum cutting conditions for each work material should be established for unmanned machining. It is, therefore, urgently needed to establish a reliable system of correlation between cutting data and metallurgical aspects of work material and tool material to avoid conducting individual experiments with new materials.

Small broken chips are urgently necessary for automatic and unmanned machining systems. They are influenced by cutting data and tool geometry. Chip control is performed mainly by chip breaking, grooves, and the technical problem most urgent to be solved is chip breaking and control.

Recognition is made of the importance of using available sensors for in-process measurements. Reliable control systems and processing on line are to be developed. Processing of cutting forces on line and its feed back for automatic machining should be further developed, as for example adaptive control. Based upon the current research activities it appears that the most critical needs relate to development of sensor techniques for monitoring tool life and controlling chip formation. A sensor to determine tool failure prior to its breakage is particularly desirable.

The other distinctive feature is ultra precision cutting. After the Apollo program, manned space flight to the moon, had successfully been completed, the USA has been planning the SDI (Strategy for Self Defence Initiative) program. As a result of the SDI program and New Frontier Program for flight to other planets, it is inevitable that the manufacturing technology of ultra precision parts such as electrical devices, and optics will develop much more than expected in the last decade. The needs for ultra precision cutting have been recently increasing. Ultra precision cutting techniques have been attracting special attention from not only scientific but also industrial points of view. Typical examples of the ultra precision products are aluminum disks for computer memory devices, large metal mirrors for the laser fusion reactor and X-ray space telescopes.

The research of ultra precision cutting is closely related to not only category # 3 precision cutting[7] but also # 2 tool[8] and # 7 cutting temperature[9]. Neither journals provided a large number of papers describing ultra precision cutting. However, across the industrial world, ultra precision cutting is increasingly seen as a trend of manufacturing that is the key to successful international competitive development. This is because many advanced technology products need manufacturing processes and machine operating in the regimes of precision engineering, micro-technology and nanotechnology. It is important to recognize that precision cutting is work at the forefront of current machining.

Acknowledgement

This report was started at Dr. Jack T. Black's request. Dr. Black who is a professor of industrial engineering and a director of advanced manufacturing technology center of Auburn University is interested in the situation of Japanese metal cutting paper in the '80s.

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