Chapter 1 Machine Tools

1. The Machine Tool Industry Outlook

Recent conditions in the machine tool industry are favorable, compared to other industries, due to the health of the major customer for machine tools, the automobile industry, and the booming United States market, a major importer and the biggest Japanese machine tool customer (Table 1-1). Total orders received in the first half (January-June) of '97 were ¥560.1 billion. This was a 23% increase over the same period the previous year, the third consecutive year of increase for that corresponding period since '95, and the highest level reached since '91. Total orders received in '97 are also expected to exceed ¥1 trillion for the first time in six years. A closer look at the orders received reveals that domestic demand over this period was ¥315.2 billion, a 28% increase over the same period the previous year, and amounting to 56.3% of all orders received. In addition foreign demand was ¥244.9 billion, a steady increase of 17% over the corresponding period the previous year. Foreign demand was 43.7% of all orders received.

Production was ¥478.4 billion, marking a 16% increase over the same period the previous year. The NC tool share of production reached 83.3%. Exports of machine tools reached ¥308.9 billion. This 13% increase in exports over the corresponding period the previous year can be attributed to favorable conditions in the European, Asian, and most notably the American market, to the increase in demand among the Japanese-affiliated companies overseas, and in demand for used machinery, all of which were influenced by the continued stability of the depreciated yen rate. In contrast, machine tool imports amounted to a mere ¥30 billion, an 8% decrease from the same period the previous year.

Table 1-1 Recent Machine Tool Industry Demand

¥100 millions; lower figures show comparison to the same period the previous year in %

Category \ Year		1990	1991	1992	1993	1994	1995	1996	1997 Jan-June
Total Orders Received		14,121	11,412	7,102	5,318	5,731	7,755	9,382	5,601
		111	81	62	75	108	135	121	123
	Domestic	10,388	8,482	4,746	3,226	3,155	4,072	5,098	3,152
		112	82	56	68	98	129	125	128
	Ratio of Domestic Demand (%)	73.6	74.3	66.8	60.7	55.1	52.5	54.3	56.3
	Overseas	3,733	2,930	2,357	2,092	2,576	3,683	4,284	2,449
		111	80	89	123	123	143	116	117
	Ratio of Foreign Demand (%)	26.4	25.7	33.2	39.3	44.9	47.5	45.7	43.7
Production		13,034	12,656	8,311	5,927	5,541	6,994	8,375	4,784
		114	97	66	71	93	126	120	116
	NC Machine Tools	9,864	9,174	6,023	4,584	4,388	5,757	6,979	3,983
		119	93	66	76	96	131	121	116
	Ratio of NC Machine Tools (%)	75.7	72.5	72.5	77.3	79.2	82.3	83.3	83.3
Exports		4,558	4,119	3,303	3,061	3,288	4,781	5,917	3,089
		106	90	80	93	107	145	124	113
	Export Ratio (%)	35	32.5	39.7	51.6	59.3	68.4	70.7	64.4
Imports		686	585	410	252	252	410	644	300
		136	85	70	61	100	163	157	92
	Import Dependence Ratio (%)	7.5	6.4	7.6	8.1	10.1	15.6	20.8	15.0

Note: Ratio of Domestic Demand = Domestic Orders Received / Orders Received Total; Ratio of Foreign Demand = Overseas Orders Received / Orders Received Total

Source: Orders Received: JMTBA; Production: MITI "Annual Report on Machinery Statistics", 1995 Edition (referred to MITI "Monthly Report on Machinery" for figures of 1996 and Jan-Mar 1997); Export and Import: MOF "Trade Statistics"

2. Conditions and Problems Facing Machine Tool Manufacturer Management

(1) Machine Tool Manufacturer Profits

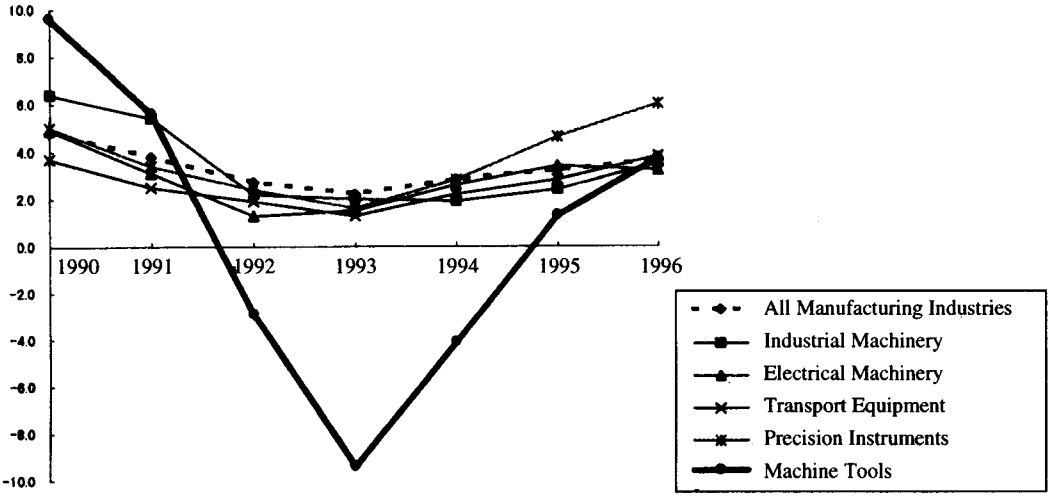
According to a survey of management conditions administered by the Japan Machine Tool Builders' Association, in '96 the profit indicators of machine tool manufacturers (41 companies) showed a growth of about two points, in comparison to '95, with the percentage for operating profits increasing from 1.4% to 3.6%, the rate of ordinary profit from 1.3% to 3.7%, and the rate of net sales profit (tax excluded) from 0.6% to 2.8%. Backed up by a prosperous demand trend, the earnings of individual companies are also recovering, resulting in increases in operating and ordinary profit. This was due to the favorable transition of the overseas market, namely the United States market. Also, demand for machine tools grew stronger as the domestic economy gradually recovered. The automotive industry, the largest buyer of machine tools, invested greater sums in equipment in an effort to shorten their production process and improve production efficiency, with an eye to the development of environment-friendly products.

In March 1997, sales volumes and profits passed the previous term for machine tool manufacturers. However, ordinary profit for Toshiba Machine Co., Ltd. and Hitachi Seiki Co., Ltd. was reported in negative figures for three consecutive terms, revealing the differences in management base and competitiveness among companies.

(2) Increasing Demand for Higher Profitability — The Need to Develop New Products and New Ventures

Figure 1-1 compares the profit trends (percentages of ordinary profit) in the machine tool industry against the entire manufacturing industry, and also against four other machine industries. Although the profitability of the machine tool industry, after hitting bottom in '93, has improved greatly in recent years, it still remains low in comparison to other industries. Also, compared to other industries, the profitability of the machine tool industry is seeing unsteady trends, urging manufacturers to stabilize their profit bases.

Figure 1-1 Profit Trends in the Machine Tool Industry (Percentages of Ordinary Profit)



Source: Based on MOF "Financial Statistics of Incorporated Business, Quarterly" and JMTBA source materials.

To improve profits and stabilize the profit base, two things need to be done. First, each company should conduct continuous development of new products peripheral to its accumulated technology, and promptly introduce those new products to the market in order to create well-established products for the future.

Second, new fields of business should be developed to expand sales volumes. Considering the scale of the machine tool manufacturing industry and its diverse product mix, however, rather than to blindly implement diversification strategies it is more effective to move into fields related to their main business technology and markets to improve profitability. In the domestic machine tool market there will be greater demand for sales of replacement equipment than for new purchases. Therefore, firms wishing to increase sales volume and profitability should take advantage of their unique strengths and focus on one or two specific fields for new business efforts.

3. Trends and Problems Facing Machine Tool Manufacturers In New Product Development

(1) Trends In High-Speed Machine Tool Development

The development of new machine tool products is the history of the pursuit of higher speeds. In this section, let us look at the trends in the development of new, higher speed technology for 1) traverse and 2) spindles/tools.

① Present High-Velocity Traverse Technology and New Product Trends

There are two types of technology that speed up the traverse rate: 1) the use of linear motors, and 2) the combination of the high-lead ball screw and servo motor. In conventional machine tools, the traverse was achieved by converting the rotational movement of the servo motor to linear movement via a ball screw, thus moving the spindle vertically or horizontally. Using this method, however, the frictional heat and vibration at the contact surface and the abrasion of the ball screws prevented further speed enhancement. The recent trend toward linear motor usage is an effort to overcome these limitations.

Among the machine tools using the linear motor introduced in the Machine Tool Fair in Autumn '96, Mitsui Seiki's precision jig grinder was the earliest to reach the actual commercial market. This grinder uses a linear motor for its Z spindle, and not only does it achieve twice the speed of conventional grinders at 400 cycle/25m/min, but also costs only 5-10% more. Although a prototype machining center (MC) developed cooperatively by Mori Seiki and Kyoto University was also introduced at this autumn '96 Fair, the drawback there being the complex movement of its main spindle and its expense. Mori Seiki, however, is aiming to introduce the first Japanese linear motor MC in Spring '98, under technical collaboration with the Ingersoll Milling Machine Company, the first company in the world to commercialized the linear motor MC.

At the same time, there is also a trend toward enhancing speed by making full use of the existing technology. The reasons that conventional technology is not being entirely substituted by the linear motor drive are: there still is room for improvement in existing technology for enhancing speed, machine tool manufacturers can take advantage of existing technology accumulated within their own firms, and equipment based on this technology can be introduced to the market at a low cost.

The reason for using ball screws in machine tools is the improvement of the accuracy of positioning and to cope with the higher speeds. Adoption of high-lead ball screws and hollow ball screws for forced cooling is attracting attention. In the latest technology trends, it has become possible to achieve traverse rates of 44-72m/min by combining high lead with a 20-30mm lead, dual-thread screw, and a low-inertia, high-speed servo motor that runs at 3,000 rpm. Some examples of new machine tool products that implement this technology

are: Mori Seiki, which has succeeded in developing a general-purpose MC with a maximum spindle speed of 30,000min^{-1}, a tool changing time (tool to tool) of 1.5 seconds, and a traverse rate of 60m/min. Also, Yamazaki Mazak Corporation, which has achieved a 60m/min rapid traverse rate, a 40m/min regular traverse rate, 1G acceleration of X, Y and Z spindles, a 1.8sec/15,000min^{-1} spindle acceleration, and a 6.3 second two-pallet changing time with MCs for mass-produced parts processing.

② Present High-Velocity Spindle/Tool Technology and New Product Trends

To cope with the above high-velocity traverse technology, speed enhancement of spindles and tools is also being required. Main spindle rotation speeds of about 20,000-100,000min^{-1} have been reached at present. Following this trend, machines implementing new technologies such as magnetic bearings and static air pressure bearings are being developed in addition to machines implementing conventional technology using high-speed ball bearings as their main bearing. Impediments to speed enhancement are lower process precision and shorter bearing life due to a temperature rise in the bearings caused by frictional heat, deterioration of rigidity caused by low preload settings used to avoid spindle expansion due to centrifugal force, and bearing instability. Although the present state of ball bearing use is prevalent due to lower cost and greater ease of use, it has such setbacks as heat generation caused by friction between the balls, the retainer, and residual foreign matter such as oil residue. Since magnetic and static air pressure bearings are discontiguous, they are able to eliminate these problems. One example of machinery implementing static air pressure bearings is the precision processor developed by Toshiba Machine Co., Ltd. This processor, which mounts on proprietary static air pressure bearings, enables superspeed end mill processing of 50,000min^{-1} with high-hardness materials. An example of machinery developed using magnetic bearings is Mori Seiki's vertical MC. The velocity of this MC reaches the very high speed of 70,000min^{-1} using magnetic bearings made in Switzerland. Its major purpose is the processing of aircraft components.

To revamp the speed of machine tools, the speed enhancement of tool-related technology is also vital. Here let us take a look at the latest trends in tooling systems. There are some problems regarding high-speed processing. One is that displacement at the tool point becomes greater as stronger moment is applied to the main spindle. Another is that since the taper hole widens as a result of centrifugal force generated by the high-speed rotation of the main spindle, the holding rigidity deteriorates. The widening of the taper hole also results in the generation of clamping force, which in turn makes detachment of the tools more difficult. Yet another problem is the vibrations caused by the machine rocking. In order to cope with these problems the following are required in a tooling system: 1) high tool-holding precision, 2) high tool-holding rigidity during high-speed operations, 3) balance characteristics that

suppress irregular vibrations during high-speed operations, 4) rigidity in the face of cutting resistance, 5) high-precision attachment to the main spindle, and 6) high performance in high-speed tool changing.

A specific idea to deal with these problems, called tooling for hollow taper shanks with flange contact surfaces, has been proposed by such countries as Germany, the US, Switzerland, Sweden, Japan, etc. Tooling for hollow taper shanks with flange contact surfaces is a method different from conventional shanks, and in this method both ends of the main spindle contact the taper surface. It utilizes a new technology in which a 1/10 short taper is used in place of the 7/24 taper. This has enabled: 1) drastic improvement in recurrence precision during repetitions of the radial direction during tool changing, 2) higher processing surface precision and prolonged tool life through the strengthening of the hardness, thus suppressing chattering caused by micro-vibrations during processing, 3) prevention of lowered processing precision from contacted end faces and elastic deformation, 4) shorter tool-changing time due to shorter shank parts.

Speed enhancement of machine tools is a never-ending challenge, and as the speed increases, the role of the tooling systems also becomes more significant. To take full advantage of the tooling for hollow taper shanks with flange contact surfaces, the machine tool manufacturers from now on will be required to develop a tool interface that will join tool and shank with higher precision, and provide close cooperation with tool makers to make the tooling system standards used in Japan the international standard.

(2) Trends In Multi-Task Machine Tool Development

As the economic environment matures, the significance of introducing a wider variety of products to the market in shorter cycles has grown. This has resulted in increased need for more flexible production lines that can deal promptly with drastic changes in production volume. More specifically, where traditional production lines mainly consisted of single-purpose machines, the recent trend is to combine several general-purpose, multi-task machine tools into one group, and put such groups together to compose one product line. This is where a multi-task machine tool that can handle various processes by itself comes into play. The essence of multi-tasking is to decrease non-processing time by centralizing the production processes, and manufacturers are developing new products in line with that trend.

One example of the multi-task tooling machine is a turning center with Y-axis control developed by Okuma which is a combination of an MC and a lathe. This machine incorporates ATC and a Y-axis with two-plane slide system, and enables fullback machining and heavy turning. Okuma has also developed a twin-spindle CNC lathe with sliding headstock, accomplishing a high-speed built-in type spindle of 6,000min^{-1} and rapid traverse of 24m/min. The horizontal Y-axis control CNC lathe developed by Yamazaki Mazak

Corporation realized continuous unmanned operations on work pieces of different diameter. Also, its adoption of a heavy-duty spindle for 12-inch chuck and revolving tools with Y-axis control enables multiple works to be processed with a single chuck.

The opposed two-spindle CNC turning machine developed by Murata Machinery has realized the reduction of idling time by incorporating a gantry loader and high-speed servo turret. Star Micronics has developed a sliding headstock CNC automatic lathe. The lathe is a high-efficiency multi-processing machine built with high-precision, complex processing of hard-cutting materials in view, enabling a variety of processing by incorporating two types of tool rests, gang type (tool post) and turret, together with multi-axis, multi-path control with eight spindles in all. Okuma & Howa Machinery's vertical turning center has made it possible to process cutting and milling sequentially in one chuck by adopting a single-tool tool rest which does not have tool interference. Tsugami Corporation's CNC precision automatic lathe is equipped with functions of both a lathe and an MC by combining Y.C axis and subspindle. The horizontal MC developed by Niigata Engineering is an MC with boring and facing capabilities, and enables such processing as boring, stepped hole, gaining, spot-facing, and tapering. Since the machine has a U-axis mechanism, a single tool can handle all types of processing from rough processing to finishing, contributing to the reduction of the number of tools involved.

(3) Trends Toward Environment-Friendly Machine Tool Development

The machine tool users' efforts to work using environment-friendly production systems have recently come to the fore, and greater demand for future development of environment-friendly machine tools to cope with this trend is predicted. The problems of machine tools use, from an environmental protection point of view, involve the disposal of processing fluids, swarf, and heat, which are used or produced in the cutting and grinding processes. Among these, the most significant is the disposal of processing fluids such as coolant, and lubrication fluids. Possible processing fluid environmental contamination may occur with: 1) disposal of sludge, a mixture of used processing fluid and swarf, 2) contamination of the underground water table by oil solutions which penetrate the factory floor, and 3) worker safety and work environment risks from vaporized fluid.

In an effort to address these problems, machine tool manufacturers are working toward the development of machines that do not require processing fluid for cutting or grinding. Some notable examples of technologies to realize such machines are: 1) machining with minimal quantities of lubricant machining, 2) machining with ester cutting fluid, and 3) dry-cutting. Here, let us take a close look at development of machine tools utilizing dry-cutting, a highly advanced method that does not require any processing fluid.

Enshu has incorporated a nitrogen gas generator into a vertical MC to develop a coolant-

free machine. This machine can be operated without any coolant because the process space is filled with highly pure nitrogen gas which prevents oxidization. This coolant-free environment cuts energy consumption by as much as 50%, realizing environment-conscious machine operation. The absence of coolant usage also avoids material deformation by preventing spark discharge, and doubles tool life. This machine is currently undergoing tests, and there still are obstacles to overcome before it can be released as an actual product. A completely dry-cutting hobbing machine developed by Mitsubishi Heavy Industries has achieved twice the usual cutting speeds, five times greater tool life, and tool costs per gearwheel 40% less than conventional processing methods which use processing fluid. Many manufacturers had attempted to develop dry-cutting hobbing machines, but the high cost of the tools used and a tool life totally dependent on the cutting conditions both prevented the manufacturers from actually introducing their machines on the market. Mitsubishi has overcome these setbacks by utilizing a proprietary specially-processed high-hob cutter. Also, Toyoda Machine Works is developing an environmentally conscious machine which eliminates the use of coolant by blowing -30℃ cryogenic gas on the grinding surface of a cylindrical grinder. However, further research is required to accumulate needed knowledge and know-how, including whether cryogenic gas at such low temperatures is really necessary.

Many manufacturers are enthusiastically working on the development of environment-friendly machines with dry-cutting technology, and there are some problems that need to be overcome. For instance, three major reasons for using processing fluid are: 1) lubrication, 2) cooling, and 3) processing waste disposal, and in reality, processing fluid is indispensable, albeit in very small amounts, for lubrication. Also, when gas is used for cooling, the disposal of process waste becomes difficult since the momentum of gas is not as strong as for fluids. Furthermore, the cutting tools for dry cutting need improvement, measures must be taken to prevent the thermal deformation of the machine tools, and more work needs to be done on basic research of cutting conditions, including the measurement of cutting temperatures and simulations. To achieve the above, the following will be required: 1) Conduct further basic research on cutting conditions and tools. 2) Free research from the idea of "a completely fluid-free environment," and develop machines with the basic design principle of "easy process waste disposal". 3) Maintain close relationships with Europe, where environmental consciousness is the most advanced, especially with the German machine tool manufacturers and university laboratories.

4. New Venture Trends In Machine Tool Manufacturer Developments

Overall attitudes of the machine tool industry towards new fields of business is one where manufacturers tend to expand their businesses into fields very closely related to their primary businesses in both technology and marketing, based on such concepts as "workpiece cutting" and "material processing." In addition to the technology for machine tool mechanisms, machine tool manufacturers are also learning and accumulating a wide range of knowledge and know-how concerning production processes, materials, tools, and controls by maintaining close contacts with users and suppliers in the process of developing new products. Some companies are taking advantage of such know-how to spin off their engineering divisions as independent businesses, providing their users with advice, consultation and know-how for production process systematization.

One example of a leading medium-sized machine tool manufacturer is a case in point. The company set up a database containing the technology and processing know-how that had been accumulated during the development of a new product, and started a business venture dealing in production assistance systems, utilizing that database in a CAD/CAM system. The previous tendency for the users to accumulate the processing know-how of tool characteristics, etc. has weakened as the users started to expand their businesses abroad, and this field of business is predicted to prosper.