

Visit to Yamazaki Mazak Tokyo Sales Office (July 10, 1991) and Nagoya HQ (July 24, 1991)

Background

My host for both visits was Mr Awane, formerly of Hitachi PERL, now director of Mazak's new Tsukuba R&D Center. Mazak is a privately held company and no sales figures are available. It has only 4200 employees worldwide, 2600 in Japan. Of these, about 400 are designers, split evenly between electronic and mechanical. The main products are NC lathes and milling machines, machining centers with ability to work on several parts in series, plus complete FMS (Flexible Manufacturing Systems) including large parts stockers and transfer robots. About 7000 - 8000 machines are made each year.

The company is known for its advanced computer-controlled manufacturing systems. Many of the parts-making facilities operate unmanned over night and require little tending during the day, a major reason why output per employee is so high. Unlike most machine tool builders, especially in the US, Mazak is both a pioneer in FMS and a large scale user of them. Mazak is also responsible for a number of important machine tool design innovations, such as the integral cutter spindle and drive motor. The integral spindle runs faster and with less vibration since there are no gears or belts between the spindle and its drive motor. The machine's accuracy is thus greatly improved.

Given this background, it is surprising to learn that Mazak is relatively primitive in its use of CAD and CAE. Design of new machines "takes a long time. This is a problem for our president." Like other Japanese companies, Mazak relies heavily on the experience of its senior employees, and some senior managers do not trust computers in design roles. In this sense, Mazak is typical of conservative machine tool makers world wide. Mazak recognizes the importance of CAE but is not satisfied with software currently available from commercial sources.

Mazak would like to sell more FMS but finds customers reluctant. Initial investments are large, and senior customer executives must approve such purchases. So the Tokyo office has been set up with plush sitting rooms and a fancy auditorium so that customers' executives can be wooed in style. A showroom of machines used to be enough, since the buyers of lower cost single machines were engineers who just drooled and bought.

Design of FMS

An FMS is a group of 5 to 15 NC machine tools connected by a parts conveyor. Each machine is equipped with many cutting tools and can change tools automatically. Parts to be machined typically visit several of the machines in a system in order to receive all the required cuts. Each part may have widely

differing cutting requirements, which the machines accommodate by using their NC and tool-changing capabilities.

Mazak is such a heavy user of FMS that it is much more sophisticated about their proper use than most of its customers. Deciding what range of product types and production volumes is most suitable for FMS has been the main technical and sales challenge since the idea was born at Cincinnati Milacron and the University of Stuttgart in the middle 1960's. The goal was to meet the needs of diverse manufacturing that lies between mass production of almost identical parts and low volume piecework production of single individuals. Economics and efficiency completely determine the choice since any of the methods is technically capable of making the parts.

However, the choice has never been easy to make and is a subject of intense ongoing research at universities and head-scratching at machine tool makers and users. The FMS easily solved the first-order problems faced by the alternatives. NC made it possible to change from one part to another, which ordinary mass production machine systems cannot do. But stand-alone machine tools, NC or not, are utilized only about 5% of the time since the machine bed is used to set up fixtures and cutting tools for the next part. The FMS solved this by permitting fixtures and tools to be set up in a separate facility equipped with good measuring tools.

With the first-order problems solved, the FMS now faces second-order problems that make the difference between economically successful and unsuccessful installations. The major issues are keeping all the machines busy when a variety of parts is moving through the system, and keeping the machines provided with all the different cutting tools that such a range of parts needs. A poorly designed system will have too many machines, some of which are idle, or too many parts waiting for a machine to become available. Typical economic criteria include cost per part, including labor cost and payback of the initial investment, and, in Japan, return per square foot since land is so expensive.

The traditional approach in research and most FMS makers was to look for scheduling methods that would sequence the parts into the system so that workloads on the machines were balanced. Another approach was to develop FMS design software that would survey candidate sets of parts and decide the right number and mix of different kinds of machines that should comprise the system. The criteria were that all the required cuts could be made, there was space for all the required tools, and all the parts could be processed in the required span of time. Such problems are typically solved using complex math programming methods. [Draper]

When the required number of tools could not be made to fit in a machine's tool storage racks, "tool management systems" were proposed. Since a part

could need 10 or 20 tools, the logistics of tools far exceed the logistics of the parts themselves. Tool management systems thus can cost more than they are intended to save.

As far back as 1981 Mazak took a completely different approach toward FMS for in-house use. It decided to make partially specialized FMS comprising only 3 or 4 machines. These machines were chosen to be identical and were capable of machining a small set of parts, and perhaps only a small fraction of the cuts those parts needed. Scheduling and sequencing problems essentially disappeared. A part entered the system, visited one machine where it got all its work done, and left. It then visited another small system and received more cuts.

The range of required tools was limited by the "given tool method." That is, the part designers were given a stable of tools to use and told to design the parts so that set of tools would be sufficient. For many FMS, this method eliminated the tool logistics problem. For other situations, group technology was used to find a group of parts that used 80% of the defined tool set for a particular FMS, and a tool management system was used to provide the rest. Portions of this story appear in [Jaikumar].

These two efficiencies have permitted Mazak to employ FMS very effectively in-house without needing solutions to the long-term scheduling and tool management problems. However, the discipline required to use the "given tool method" cannot be forced onto customers, so the easy design and highly efficient FMS operation achieved by Mazak is not always available to customers.

CAD, CAE, CAM

The company relies on CADAM and microCADAM, which runs on about 72 total terminals, of which a small number are IBM 5080 graphics terminals. Most of the CAD work is drafting, preparation of 2D drawings for part manufacture, making shop floor instructions and user manuals, and so on. There is essentially no CAE, in spite of obvious potential applications. It is up to Mr Awane in his new post to introduce CAE.

Design Methodology for Machine Tools

The rhythm of the machine tool industry is driven by the occurrence of the major machine tool shows. These occur every two years in Tokyo, Chicago, and Hannover, effectively meaning a show every year or less. New machines cannot be created that fast, and the typical cycle is about two years. Totally new machines or technological innovations take longer. The shows are used to get customer input, look over the competition, and show your latest. In addition, at Mazak, most designers have visas up to date for most countries where the

company sells, and are ready to fly the moment a customer needs something. Customer input and minor changes are thus the main forces governing typical design cycles.

A major design strategy at Mazak, and probably most other companies, is "series design," meaning a series of machines based on one principal design with many variations such as number of tool storage places, size of bed, and so on. New designs are apparently not too hard to create within a series family. Information about existing machines, their drawings and their performance, is kept in computer files. Five mechanical and one electrical engineer can turn out a new lathe design in two years. Improvements may include faster tool changing, higher RPM, or a new spindle design.

The integral spindle-motor took five engineers two years to design, during which 5 prototypes were made. A similar one can now be turned out in a man-month (200 hours). The main problems in such units are dissipating the heat from the motor and obtaining the correct preload on the bearings. Motor heat will cause the spindle rotor to distort, causing vibration and poor machining accuracy. Incorrect preload either causes poor accuracy or low bearing life.

Predicting heat, distortion, vibration, bearing wear, and so on are obvious candidates for CAE. However, Mazak does none of them. Motor heat and its effects are predicted by the motor manufacturer using its own CAE, and Mazak merely designs a cooling system to take away the heat. Bearing design is done at Mazak and checked by the bearing manufacturer, who has extensive CAE for this purpose. This method of farming out the hard parts is used often in Japan.

Advanced bearings such as magnetic or ceramic are used sparingly or not at all. Magnetic bearings are the subject of some Mazak-sponsored university research, while ceramic balls are used with steel races in some high speed applications.

Integral motor-spindle design is now so well understood that a routine has been established. The overall diameter of the rotor is decided by the size of chuck it will hold and the size of any hole inside the spindle. Spindle speed, motor horsepower, and required rigidity also contribute to sizing the shaft diameter. The front bearings and their preload are chosen almost straight from the handbook to support cutting loads. Required horsepower determines motor diameter, which determines the overall size and length of the spindle. The rear bearing is chosen to hold up the shaft, nothing else. This preliminary design is checked by Mazak for rigidity and by the motor and bearing manufacturers for heat and bearing stiffness and life. The rest is pretty routine.

Assembly of such a unit is driven by the need to install the rotor on the shaft and achieve the bearing preload. Balancing the rotor also is important and must be done at the right time during assembly. Mazak's engineers did not feel that there was much room for flexibility or innovation in this assembly sequence.

Cost-estimating of new or series designs is important, because the market and competitors often set prices. Their main cost estimating technique is to consider four factors: cost of purchased parts, amount of material (usually measured by its weight), machining costs, and assembly costs. The first two dominate the final total and are calculated very carefully using past data. The other two fluctuate too much to be of great use. CAD does not play much of a role in cost estimating except that CADAM can calculate volumes of parts easily. Cost of new entries in a series is determined by altering the data from the parent machine, which has been in production for a while.

Future Computer-Design Needs

Mazak is unclear about what it needs in the future. It has a mild anti-computer frame of mind in the design department and relies on its experienced people, some of whom have been with the company decades. One identified need is to calculate machine bed and column deflections under cutting loads and (at my suggestion) under thermal distortion. Other companies sell machines with built-in temperature sensors and heaters that deliberately introduce compensating distortions to keep the machine accurate. Such companies must be ahead of Mazak in applying computers to design.

Mazak also would like an automatic design system that would take in a set of specs for a machine tool and spit out a complete design. Such statements are heard at other companies and are not totally whimsical. However, they are totally out of step with the state of the art. Prof Kimura notes that many companies do not have clear plans or coherent explanations of what they want. Visiting them every month for a year is often not sufficient to figure out what they are thinking, even when the company is Toyota, whose thinking would seem to be fairly systematic.

References

[Draper] Staff of Charles Stark Draper Laboratory, Inc., Flexible Manufacturing Systems Handbook, Park Ridge: Noyes Publications, 1984

[Jaikumar] R. Jaikumar, "Post-Industrial Manufacturing," Harvard Business Review,