Flexible Manufacturing System for Agile Production

MITSUYUKI KONISHI*1
TAMAYA SUGANO*1

The diversification of customer needs in recent years has brought about a shift in manufacturing systems in the automotive industry from "mass production" based systems to "Various kinds and medium volume production" and still further to "agile production (flexible kinds & volume)". Accordingly, there is a growing need in the industry for flexible production lines that are capable of easily coping with design changes and equipment conversions. Further, there is also increasing demand for the placement of high speed, highly reliable, and low cost metal cutting machines on production lines. To meet these needs, Mitsubishi Heavy Industries, Ltd. (MHI) has developed a commercialized machining center for mass production. An overview of this system and its recent application in a flexible manufacturing system are introduced here.

1. Introduction

Since the adoption of the "mass production of limited goods" approach in the field of mass production as represented by the production of automobile parts, production has mainly consisted of using manufacturing systems with an emphasis on productivity based on transfer machines in which multi-spindle type special-purpose machine are arranged in series to produce the desired item.

The diversification of customer needs these days has resulted in a successive shift from mass production and "Various kinds and medium volume production" of approaches to what is known as agile production. Accordingly, there is an ever greater need for flexible production lines equipped with high-speed, compact machining centers capable of easily dealing with design changes and equipment diversions.

This report first introduces the M-CM4A machining center for mass production, which has been commercialized by MHI as a metal cutting machine that can be readily installed on a flexible production line. Recent examples are then presented of flexible manufacturing systems that utilize the machining center.

2. M-CM4A machining center for mass production

A view of the external appearance of the standard M-CM4A machining center for mass production is shown in **Fig. 1**. Machining processes in this machine tool are limited to the machining of aluminum or cast steel parts such as engines, transmission cases, suspensions, and other automotive parts to increase productivity, flexibility, and maintainability, particularly in rough finishing and semi-finishing.

After it was first released at JIMTOF2002 (the 21st Japan International Machine Tool Fair), the machining center has since earned a good reputation from automobile manufacturers and related manufacturers. In the last two years, a cumulative total of 250 units of the system have been adopted in more than 10 projects (based on orders received as of 31 May 2005).

The main specifications of the M-CM4A are shown in **Table 1**.

The major features of the system are outlined below.

(1) High productivity due to a reduction in production time

The feed speed for all travel axes X, Y, and Z has been set to a rapid rate of 50 m/min with a rapid feed acceleration of 1 G in order to shorten non-machining time. A rapid feed speed of 60 m/min with a rapid feed acceleration of 1 G can also be selected optionally.

Fig. 1 View of M-CM4A machining center for mass production.

*1 Machine Tool DIvision

Table 1 Specifications of M-CM4A Machine Body

Specifications of Machine Body			
Item			M-CA4 A
Travel stroke of axis	X-axis	(mm)	700 (standard) /600 (op.)
	Y-axis	(mm)	610 (standard) /600 (op.)
	Z-axis	(mm)	650 (standard) /600 (op.)
	B-axis	(deg)	360
Rapid feed rate (acceleration)	Rapid feed rate (X,Y,Z)	(m/min)	50(1.0 G) (Standard) 60(1.0 G) (op.)
	Rapid feed rate (B)	(min^{-1})	33.3
Spindle	Taper of spindle		BBT 40 (Standard) HSK-A 63/KM 6350 (op.)
	Maximum speed	(min^{-1})	12 000
	Output power of motor	(kW)	15/11/7.5 (10 min/30 min/ continuous)
Automatic tool changer (ATC)	Stored capacity of tools	(piece)	24 (standard) /32 (op.)

(2) Construction of manufacturing system in a small space

In the standard system model, the strokes of the feed axes are set to 700 mm for the X-axis, 610 mm for the Y-axis, and 650 mm for the Z-axis. This range of strokes thus makes it possible to accommodate the machining of most major automotive parts. On the other hand, a compact model with strokes of 600 mm for all axes can be optionally prepared for those users who place importance on the need to save space.

(3) Stable sustainment of high productivity based on high reliability and maintainability

● Center trough structure

A central trough structure has been adopted for the bed of the machine (**Fig. 2**) in which an opening for recovering chips is formed at the center of the bed just below the spindle in order to increase the chip discharging capability of the system. This also helps to suppress any machine problems that could occur due to the accumulation of chips during mass production operations.

● Increased reliability of major devices

The reliability of the major components of the manufacturing system (machining center) such as the spindle, turn table (B-axis), ATC (Automatic Tool Changer), and other devices has been further enhanced to increase the time period during which the system can operate without any trouble (Target MTBF [Mean Time Between Failures]: 5000 hours).

● Improved maintainability (**Fig. 3**)

The following measures have been taken to improve the maintainability of the system in order to reduce the time required for maintenance (Target MTTR [Mean Time To Repair]: 0.5 hours].

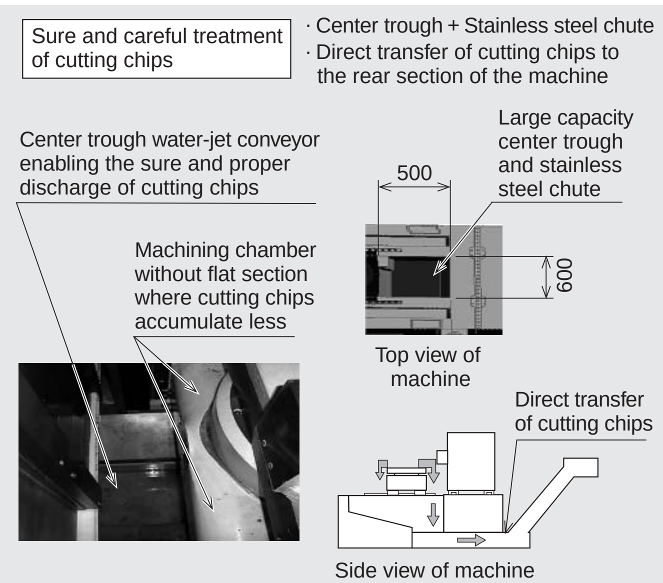


Fig. 2 Bed of center trough structure

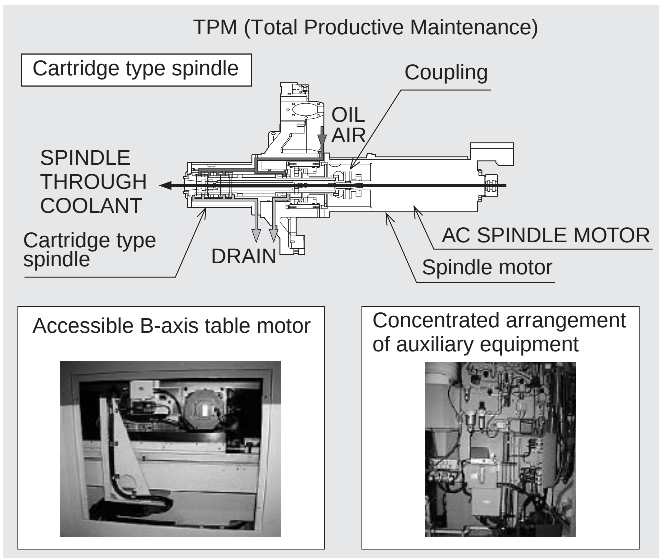


Fig. 3 Stable sustainment of high productivity through high maintainability and high reliability

(a) Cartridge type spindle

A cartridge type spindle structure has been adopted to facilitate the replacement of the spindle in the event of failure.

(b) Accessible B-axis table motor

The B-axis drive motor has been arranged on the outer circumference of the machine to improve accessibility and maintainability. This has also been done with the X-axis motor and Z-axis motor.

(c) Collective arrangement of auxiliary equipment

Equipment for controlling hydraulic pressure, pneumatic pressure, lubrication, and coolant has been collectively arranged in the maintenance zone at the rear of the machine center to improve maintainability, such as routine inspections and ease of servicing and repairs.

(d) Spare tool change device (optional) (**Fig. 4**)

A spare tool change device has also been prepared as an option. It can be used to replace a worn out tool in the tool magazine with a spare tool or new tool on the outside of the machine during machining.

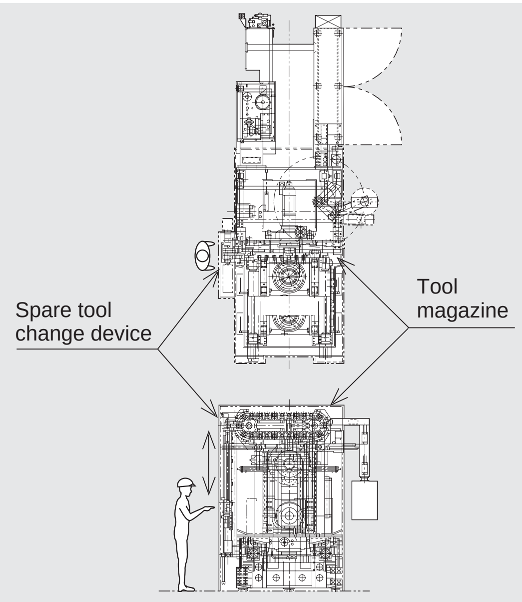


Fig. 4 Spare tool change device

(4) Convert ability and flexibility for agile production

- Accommodation of various part transfer systems

Part transfer systems that match all types of specifications and line configurations such as (a) manual loading, (b) manual loading + APC, (c) gantry loader, and (d) gantry loader + APC can be selected (**Fig. 5**).

- Matching of table type with various part fixture jig patterns

Although the turn table (B-axis) is generally adopted as the standard table, other types of tables such as the tilt table (A-axis), turn table (B-axis) + tilt table (A-axis), tilt table (A-axis) + turn table (B-axis), and other arrangements can also be optionally adopted (**Fig. 6**). These tables can be selected arbitrarily according to the type of work process being done and type of part fixture jigs being used.

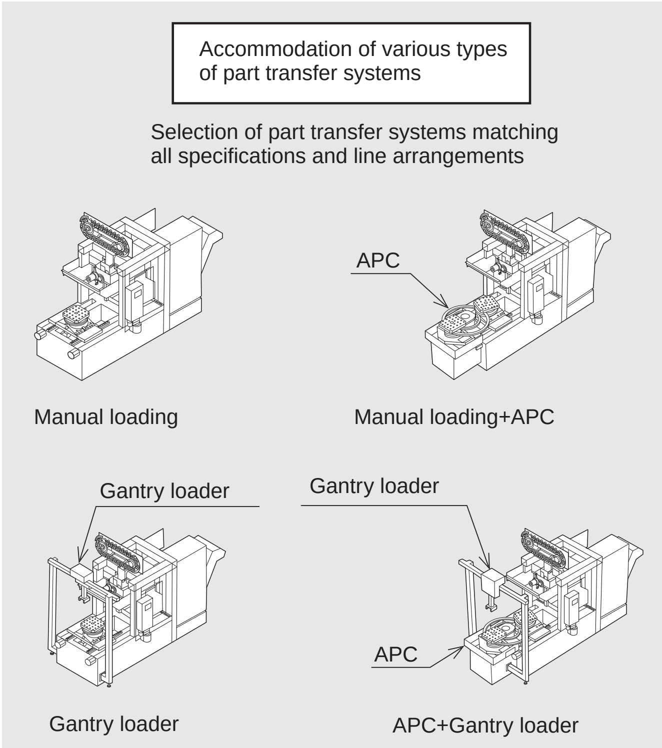


Fig. 5 The system can accommodate various types of part transfer systems

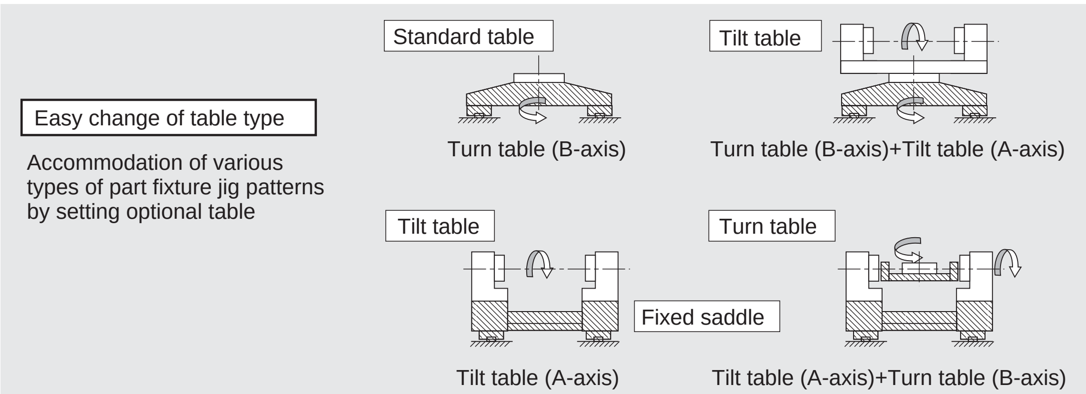
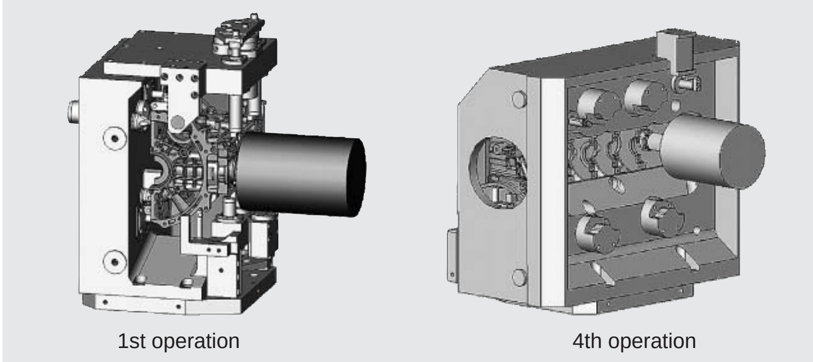


Fig. 6 A diverse range of table types allows ready accommodation of various types of part fixture jig patterns

Fig. 7 Layout of machining line for leading U.S. automobile manufacturer (Rough machining line using several machining centers).



(a) Upper surface, cylinder bore, rough boring, rough milling of front and rear surfaces

(b) Boring of front and rear surfaces, rough milling of lower surface

Fig. 8 Vertical type part fixture jig for rough machining line for leading U.S. automobile manufacturer
Installed on the B-axis turn table; Part to be machined: engine cylinder block

3. Example applications of flexible manufacturing systems

This section introduces two example applications in which the M-CM4A machining center for mass production described above has been adopted in recent flexible manufacturing systems.

(1) Parallel process type serially arranged production line

A brief overview is presented here of the cylinder block machining line for automotive engine that was delivered to a leading U.S. automobile manufacturer last year (August 2004).

This machining line consists of two parts: a rough machining line in which several of the machining centers for mass production described above are arranged in series (**Fig. 7**, photo showing the line under construction), and a finishing line in which special purpose machines (transfer machines) are arranged in series. The rough machining line is mainly formed of the machining centers so as to cope flexibly with changes in machining patterns. The finishing line consists of special purpose machines, since emphasis is placed on accurate machining and production efficiency in critical processes (finishing of crank bores, cylinder bores, front and rear faces, as well as finishing of top faces).

Both the rough machining line and finishing line are comprised of two rows of lines with similar capacities. The main types of parts machined on this line consist of aluminum cylinder blocks, with a throughput (production time for each part) in the two rows of lines of the manufacturing system of approximately 35 seconds.

The rough machining line consists of thirty-eight M-CM4A machining centers. The rough machining line is divided into five serially arranged operations (five operations for each row x 2 rows). The same part fixture jigs and tooling arrangements are mounted on the corresponding centers of the same type on each operation row. Thus, this machining line adopts a parallel process type arrangement using the same types of machining centers in series on each respective operation row.

Since the jigs (**Fig. 8**), tooling, and a portion of the optional devices must be changed for each operation, five types of machine variations are used in the overall rough machining line.

In the sequential process line (process distributed type line) which has been the mainstream approach used for conventional mass-production lines, all machining processes are completed after a part has passed through all of the machine tools. However, there is a risk that the entire line could be stopped if any of the machine tools fail.

Adoption of a parallel process type approach in this production line can eliminate the risk of stoppage of the entire line, even if a machine tool fails, since production can be continued by the same type of machine in a parallel operation row, though the volume of overall production will be reduced. Another advantage of this type of line is that machine tools can be suitably adjusted, added or converted to accommodate increases or decreases in the volume of production required.

Parts are conveyed on the line by high-speed gantry loaders that are installed for each conveyor operation, in which the high-speed gantry loader feeds the part to each machine tool (**Fig. 9**).

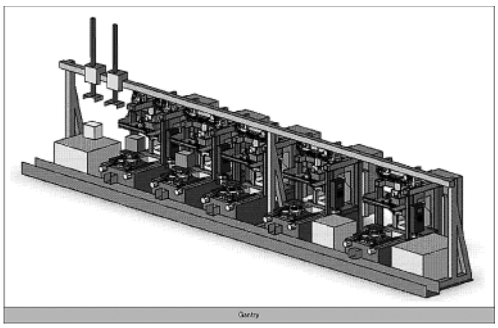


Fig. 9 Gantry loader

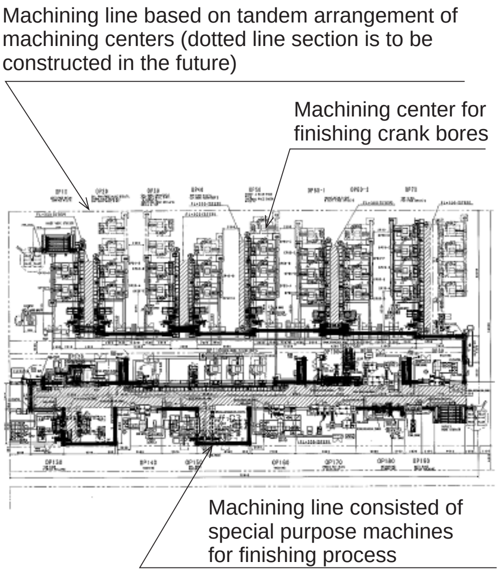


Fig. 10 Layout of machining line for leading automobile manufacturer in Malaysia

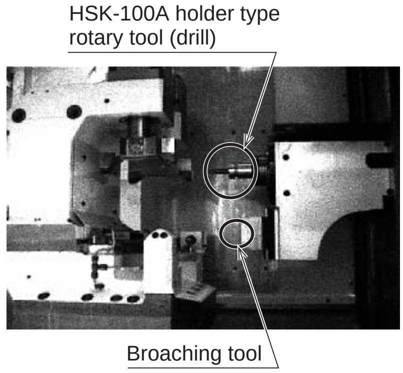


Fig. 11 Spindle head (with broaching tool)

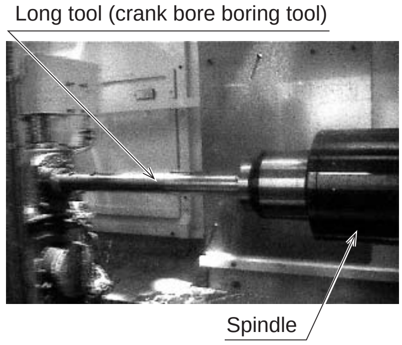


Fig. 12 Line bar for crank bore finish boring being inserted into part

(2) Parallel process type tandem-arranged production line

Figure 10 shows the engine cylinder block machining line for automobiles delivered to a leading automobile manufacturer in Malaysia at the end of 2004.

This production line consists of a rough machining line, in which twenty-one machining centers for mass production are arranged in tandem, and a finishing line, in which two special machining centers and a special purpose machine are arranged in series. Parts machined on this line are cast iron cylinder blocks with throughput of approximately 100 seconds per block.

Since the tandem arrangement has been adopted in the rough machining line, additional machines can be easily added or removed according to variations in the volume of production desired.

By partially modifying mainly the machining centers on the line, machining operations that normally could only be performed using special purpose machines can be accomplished with the machining centers.

In finishing the sides of the seat face of a bearing cap, for example, broaching can be done using a machining center by adding a broaching tool holder to the spindle head of the machining center, even though this operation can usually only be performed with a specialized broaching machine (**Fig. 11**).

Further, the critical process of crank bore finishing can be accomplished using a special tool magazine (known as a blade hooking device) which is capable of automatically replacing a long tool (app. 1000 mm in length) such as a boring bar that is added to the machining center in addition to the conventional magazine (**Fig. 12**). Since the machining center can be partially modified with additional functions, both accurate machining and flexibility can be achieved that are compatible with each other, while also facilitating ready servicing and maintenance.

4. Conclusion

Some typical examples of application of the M-CM4A machining center for mass production and the flexible manufacturing systems using it were introduced above.

There are moves afoot among the world's leading automobile manufacturers having tie-ups with each other to integrate production models as a part of efforts to globalize their operations. At the same time, however, manufacturers are also accelerating the conversion to production lines capable of accommodating agile production. Accordingly, it is thought that there will be an ever-increasing need for production systems that make it possible for often conflicting requirements such as high productivity and flexibility to be compatible with each other.

Based on its long and extensive experience in the production of both special purpose machines and universal type machining centers, the Machine Tool Division of Mitsubishi Heavy Industries, Ltd., firmly believes that it is well placed to take on the mission of positively proposing and realizing optimal manufacturing systems that best meet the unique and specialized needs of each individual customer.


Mitsuyuki Konishi


Tamaya Sugano