Ultra-Flexible Manufacturing Line with a Finishing Machining Center for Cylinder Blocks

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The mass producers of equipment for automotive parts increasingly need to acquire and effectively use parallel process flexible lines for the manufacture of variable products in variable quantities. Mitsubishi Heavy Industries, Ltd. (MHI) has been responding to this need by actively proposing and developing a line composed of machining cells for mass production processing. While this type of line has many advantages, its flexibility in manufacturing is still limited by the use of special purpose machine tools for the final finishing processes. Quite recently, MHI has constructed an ultra-flexible manufacturing line composed of machining cells with performance equivalent to that of special purpose machine tools for the finish processing. Production with this line requires no special purpose machine tools whatsoever.

1. Introduction

MHI started to manufacture special purpose machine tools in 1950 and developed Japan's first transfer machine in 1953. The company has continued to manufacture mass production machining equipment for automotive manufacturing ever since. Even since spinning off Mitsubishi Motors Corporation in 1970, the company has effectively responded to the needs of auto and auto parts manufacturers by introducing FTL (flexible transfer line) and machining cells (machining centers exclusively for mass production lines).

This report is organized into three main parts. First, it describes tendencies, case examples, and challenges for automotive parts production lines. Second, it introduces the features and performance of the finishing machining center developed for cylinder blocks. Lastly, it proposes a new flexible production line using this finishing machining center developed.

2. Changes in the automotive parts production line

In earlier years, conventional production lines for automotive parts were required to produce small numbers of products in large quantities. The mainstream units for these lines were transfer machines with multi-spindle special purpose machine tools designed with priority on productivity. Nowadays, however, carmakers are producing a wider range of car models to meet diversifying customer needs. Though the total output remains unchanged, the number of cars produced per model has suddenly decreased (**Figs. 1 and 2**).

Meanwhile, customer preferences are changing faster than ever and product lifecycles have noticeably shortened. The auto industry has been responding by shifting from the manufacture of small numbers of products in large quantities to the manufacture of wide varieties of products in medium quantities, or to the manufacture of variable products in variable quantities.

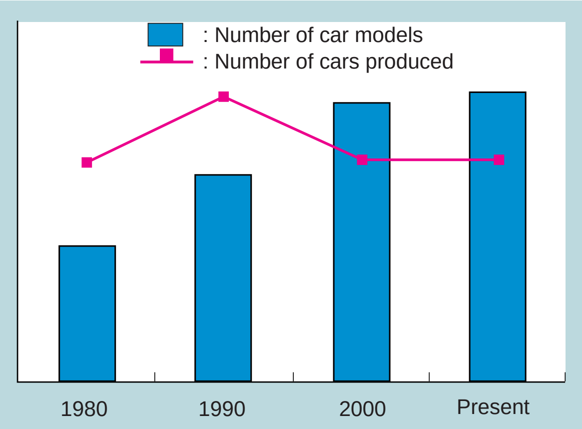

Fig. 1 Changes in the number of cars produced by major car companies and the number of car models
More car models are now being produced, the number of cars produced remains unchanged.

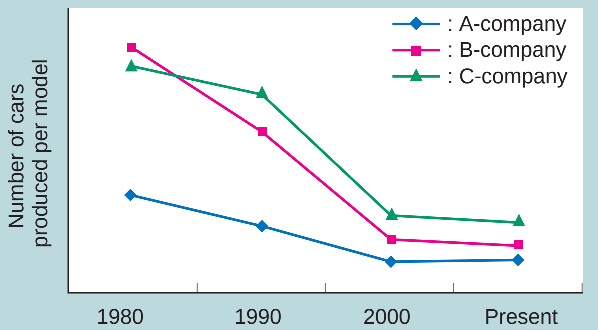

Fig. 2 Number of cars produced per model
The number of cars produced per model has decreased greatly.

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This has generated an increasing need for flexible production lines capable of easily responding to design changes and equipment diversions.

And with the shortening of lifecycles, automakers need to adopt parallel process production lines to reduce the risks of production line investment. Conventional serial process type production lines require special purpose equipment for each process. As these lines require maximum production sizes to gain economic advantage, the costs are substantial during production startup, periods of decreased production, and production wind-down.

In contrast, the parallel process type allows a single machine to engage in multiprocess machining, thus enabling production startup with minimum equipment according to the required production quantity, as well as ongoing production according to the volume of sales with phased investments.

Better still, this type of system also helps manufacturers equalize production equipment among different lines in anticipation of equipment diversion. One challenge with parallel process lines is machining quality. If multiple machines do the same machining in parallel, accuracy variations among machines may lead to deviations from unit to unit. When this is the case, high-grade production equipment also needs to be introduced for these lines (**Fig. 3 and Table 1**).

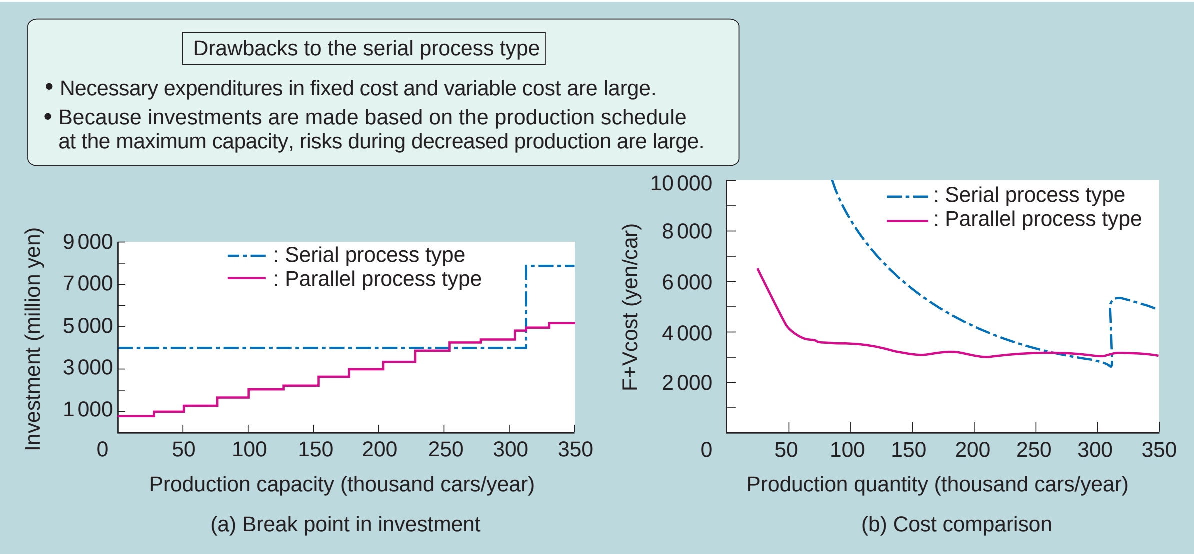

Fig. 3 Comparison of production systems: 1
The figure shows drawbacks to the serial process type production system.

Table 1 Comparison of production systems: 2

Evaluation item		Serial process type		Parallel process type	
Quality	Stable quality	△	A workpiece must be frequently installed and removed.	○	Machining is possible with chucking done only once. This eliminates the need for frequently installing and removing a workpiece.
	Quality control	○	Quality control is easy.	△	The use of multiple machines for machining makes quality control difficult.
Cost	Amount of investment (Fixed cost)	△	The amount of contingent time, such as transportation time, is large. The number of machines installed is therefore increased.	○	The amount of contingent time, such as transportation time, is small. The number of machines installed can therefore be reduced.
	Variable cost	△	Due to the above, more machines are installed. The necessary expenditures are therefore large.	○	Due to the above, fewer machines are installed. The necessary expenditures are therefore small.
	Handling of loss cost during decreased production	△	Only the operation time is adjusted.	○	The operation time and number of equipment units in operation are both adjustable. The rate of line capacity use can be easily maintained.
Flexibility	Ease of variable-quantity production	△	Linearity for variation in the number of machines is insufficient.	○	Variation in the number of machines can be implemented linearly.
	Equipment diversion during decreased production	△	Equipment diversion is difficult because equipment is directly connected by one line.	○	Equipment diversion is easy because multiple machines are used.
Management	Investment risk	△	Investments are made based on the production schedule at the maximum capacity. This increases risks during decreased production.	○	Phased investments can be made. This lets automakers spend more time to assess the investment timing.

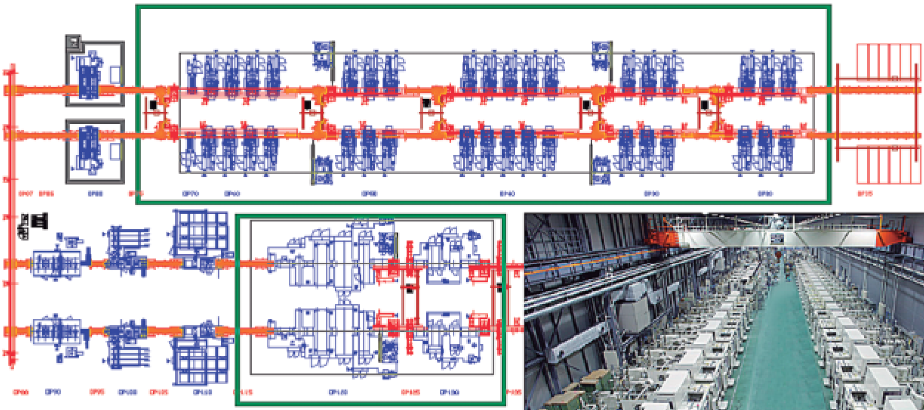

Fig. 4 Case example of car production line
Special purpose machine tools are used for the finishing process.

3. Recent production lines for automotive parts

Fig. 4 is a layout diagram of a machining line for aluminum cylinder blocks that MHI delivered in 2004. This line is made up of two parts: a rough cutting line with machining cells for mass-production machining arranged in series, and a finish cutting line with special purpose machine tools (transfer machines) arranged in series. The machining cells in the rough cutting line are capable of flexibly adapting to changes in machining processes. The special purpose machine tools (transfer machines) in the finish cutting line are arranged with a priority on high-accuracy machining and production efficiency in important processes (crank bore finishing, cylinder bore finishing, finishing of front and rear surfaces, top surface finishing, etc.). Customers have highly evaluated the flexibility, machining accuracy, and productivity of the latest production lines designed to exploit the advantages of both the machining cells and transfer machines. Challenges with this type of line are foreseen in the future, however, as customers are expected to increasingly request "parallel process lines" and the "manufacture of variable products in variable quantities."

The rough cutting line is a parallel process line consisting entirely of machining cells capable of producing a mix of multiple models and flexibly responding to changes in workpiece design with relative ease. The finish cutting line, on the other hand, is a serial process type line consisting of special purpose machine tools. For this reason, the latter can handle only a limited variety of workpiece types and sometimes requires substantial modification for workpiece design changes.

4. Production lines for automotive parts in the future

The key to realizing "parallel process line" capable of "manufacturing variable products in variable quantities" is to use machining cells for the processes now handled by special purpose machine tools. This will require the development of machining cells that provide the same functions as special purpose machine tools. MHI has accomplished this finishing machining cell into practical use. The following section introduces some of the characteristics and achievements of this equipment.

4.1 Features of the machining cell for finish cutting of cylinder blocks

The M-CM5AL is a machining cell for finish cutting of cylinder blocks. This machining cell is capable of carrying out multiple processes conventionally only possible with conventional special purpose machine tools designed exclusively for finishing.

- Finish boring of crank bores using a long boring bar (About 850 mm in length)
- Accuracy measurement for cylinder bores and a crank bore
- Automatic-correction finish cutting of cylinder bores
- Finish milling of top surfaces
- Finish reaming of dowel holes in each surface

Fig. 5 shows a view of the machine plan. The M-CM5AL has the characteristics shown below.

- The machine is equipped with a special tool changer capable of exchanging long boring bars automatically. The long boring bar is a special tool for the finishing of crank bores, as shown in **Fig. 6**.
- The Z-axis stroke is 1200 mm, enabling automatic exchange of long boring bars and machining.
- The machine is equipped with two measurement systems, one for measuring cylinder bores and one for measuring crank bores.
- The machine is equipped with a tilt index table capable of machining five workpiece surfaces (Fig. 6). Because the machine is capable of providing arbitrary positioning, it can also handle a wide variety of different workpieces, such as V6 engines and V8 engines.

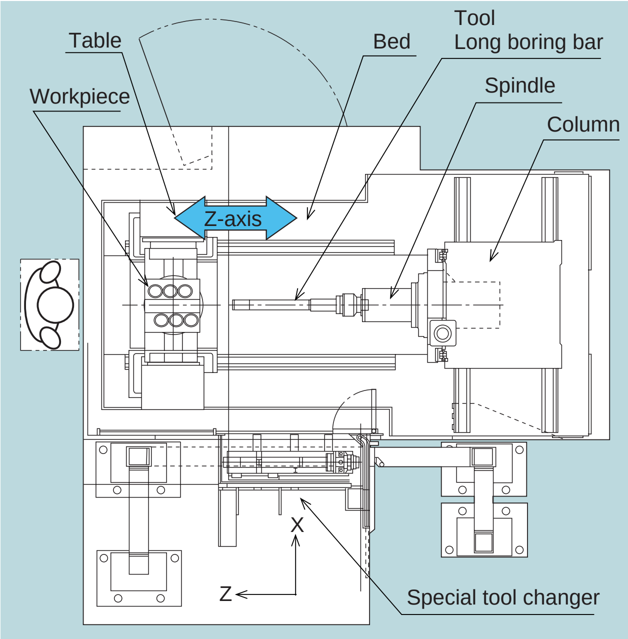

Fig. 5 Structural diagram of machining cell for finish cutting cylinder blocks
The machining cell is made up of the machining units and special tool changer.

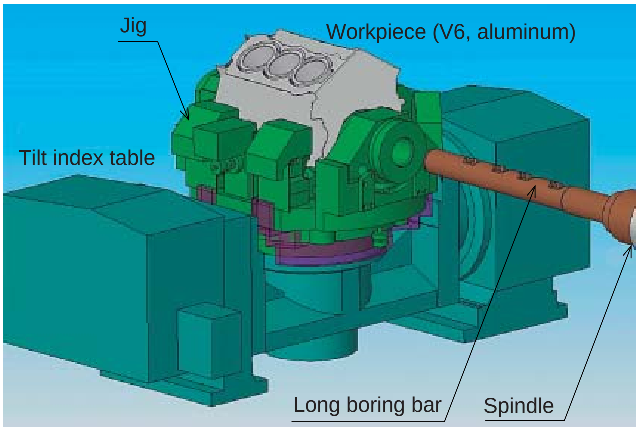

Fig. 6 Long boring bar
The long boring bar is used for finish cutting crank bores.

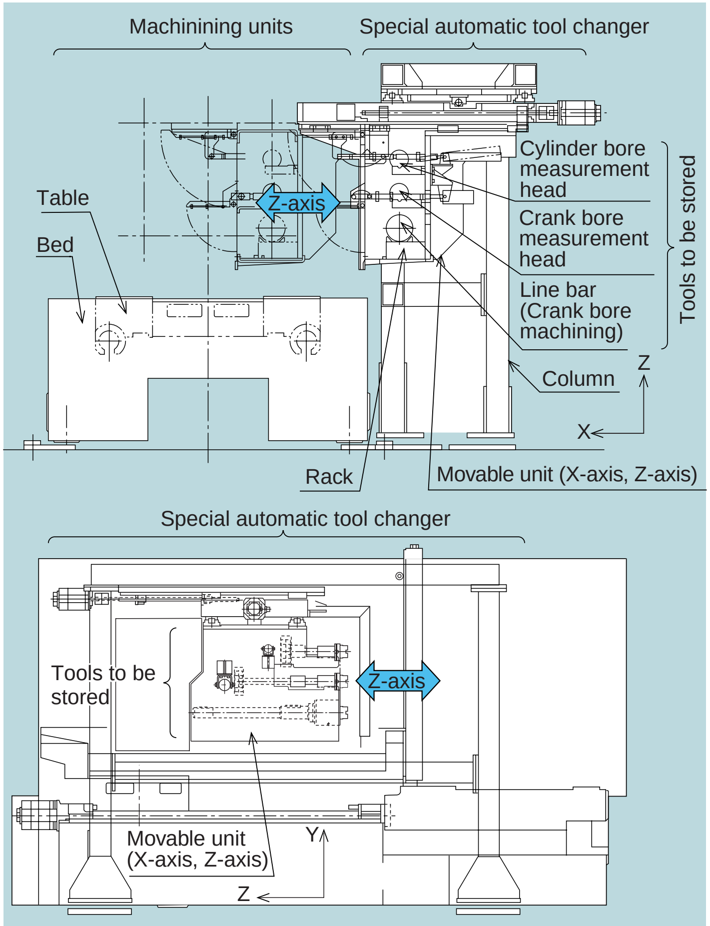

Fig. 7 Structural diagram of special tool changer
The apparatus has two movable shafts and accommodates three special tools.

- The control axes for high-accuracy positioning enable the use of MHI's own scale (MP scale) for all straight and rotary axes.

The following section describes the special tool changer and measurement system, the key technologies for this machine.

4.2 Special tool changer

Fig. 7 outlines the features of the special tool changer recently developed by MHI. The apparatus is installed on the side surface of the machine body and is equipped with a biaxial movable unit and a rack for storing up to three tools. The body of the rack moves directly into the machine and carries out tool exchange with the spindle. The method for tool exchange is shown in **Fig. 8**. In the example given here, the three tools installed in the rack are a line bar for machining crank bores, a head for measuring crank bores, and a head for measuring cylinder bores. The servomotor used to drive the apparatus ensures a high-speed response and good positioning accuracy.

To keep the unused tools clean, the special tool changer is provided with a shutter designed to separate the tool rack and machining chamber. **Fig. 9** shows the structure of the shutter. The shutter in this machine is divided into three parts to shorten the tool exchange time by realizing concurrent motions and increasing the opening and closing speeds. Two design features have made it possible to reduce the tool exchange time to as little as eight seconds: shutter A is opened and closed by a servomotor-driven cam, and shutters B and C open and close as they move with the rack into the machine.

4.3 Measurement system

MHI has developed a system capable of making measurements in two lines for the measurement of crank bores and of cylinder bores after finishing. The present machine is equipped with an A/E converter, control devices, and two measurement heads, one exclusively for cylinder bores and the other exclusively for crank bores. Using this system, machining results are measured on the machine immediately after machining to check if the machined products conform to specifications. And with regard to cylinder bores, the machine also feeds back the change in the hole diameter due to tool wear and carries out corrective machining for the next workpiece.

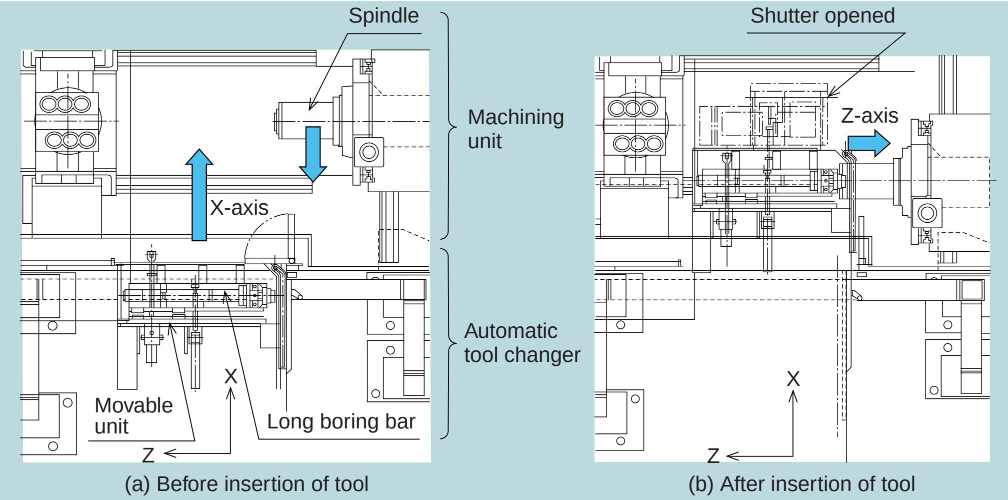

Fig. 8 Tool exchange procedure
The body of the special tool changer moves into the machine and delivers tools to the spindle.

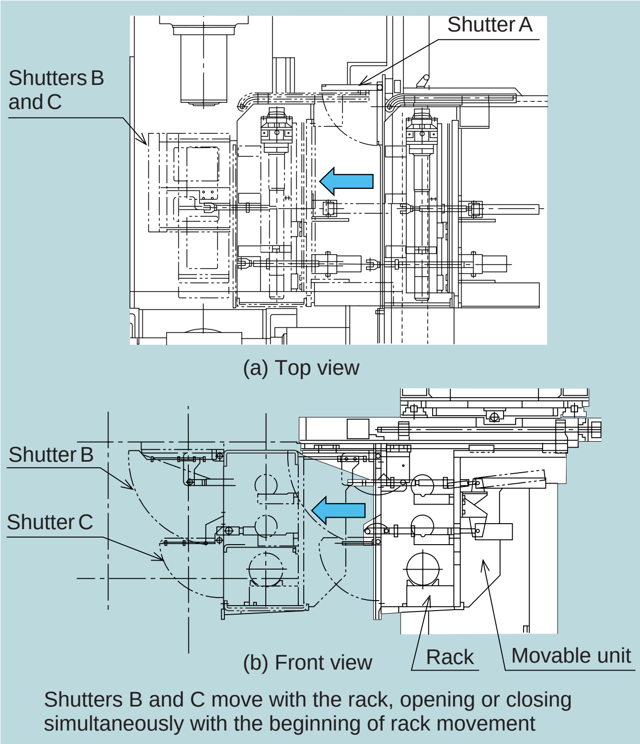

Fig. 9 Structural diagram of shutter
The shutter is divided into three parts and opens or closes simultaneously with the movement of the special tool changer.

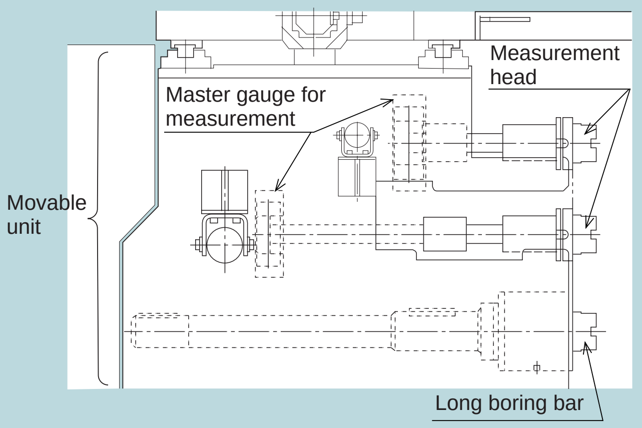

Fig. 10 Measurement head as stored
The measurement head, inserted into the master gauge for measurement, is stored in the special tool changer.

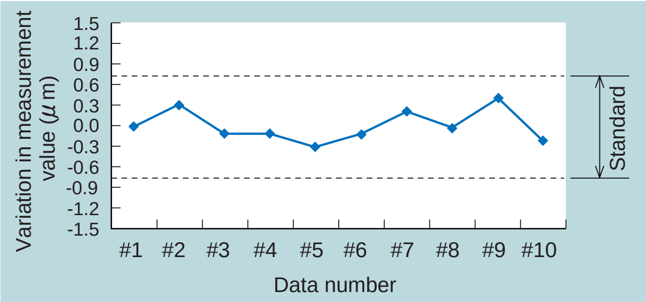

Fig. 11 Repeated measurement accuracy of measurement device
Shows actual measurement values when ten successive measurements are taken.

This measurement data is strung to the workpiece ID information and sent to the quality control system in the factory. The use of this measurement system enhances traceability, one of the main challenges for the parallel process line, to a level where it can be controlled by customers.

The measurement head, inserted into the master gauge for measurement, is stored in the special tool changer described above. With comparative measurements of the master gauge for measurement and workpieces, the temperature changes can also be factored into the measurement calculations. Moreover, the master gauge is measured every time the measurement head is mounted on the spindle, to confirm normal mounting and to ensure measurement reliability. As the measurement head is stored together with the master gauge, this confirmation can be quickly executed during a series of tool exchange motions to further ensure measurement accuracy and save time (**Fig. 10**).

Fig. 11 shows the repeated accuracy of the measurement device of this machine. The measurement device itself has a guaranteed accuracy of 1.5 micrometer or less. With this system, MHI has been able to confirm the reliability of the tool changer.

4.4 Machining accuracy

Figs. 12, 13 and **14** show actual measurement values of the accuracy of cylinder bore and crank bore machining, an important finishing process for cylinder blocks. A machining accuracy equivalent to that of conventional special purpose machine tools is confirmed, a high Cpk is achieved, and the quality requirements for cylinders are fully met.

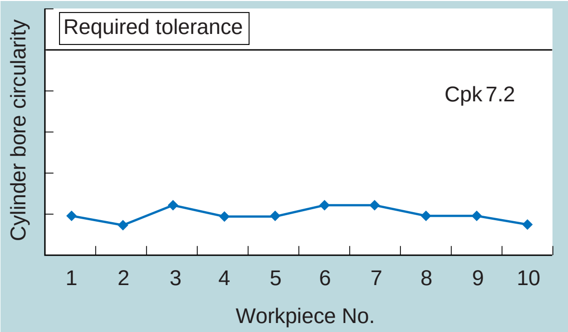

Fig. 12 Cylinder bore machining accuracy (Circularity)
Shows actual measurement values of machining accuracy when ten Cylinder bores are machined successively.

5. Proposal of new production lines

The use of this machining cell for finish cutting makes it possible to construct production lines far more flexible than the lines of the past. **Fig. 15** shows one example. The upper and lower sections show a line using the conventional special purpose machine tools and a line using the machining cells for finish cutting described here. The following processes are set up in this example.

OP120: Finish milling and reaming of front and rear faces, Crank bore finish boring and accuracy measurement

OP130: Cylinder bore finish boring, Accuracy measurement, Corrective machining, Upper face finish milling

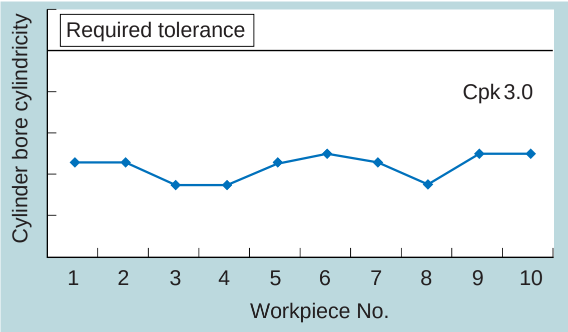

Fig. 13 Cylinder bore machining accuracy (Cylindricity)
Shows actual measurement values of machining accuracy when ten cylinder bores are machined successively.

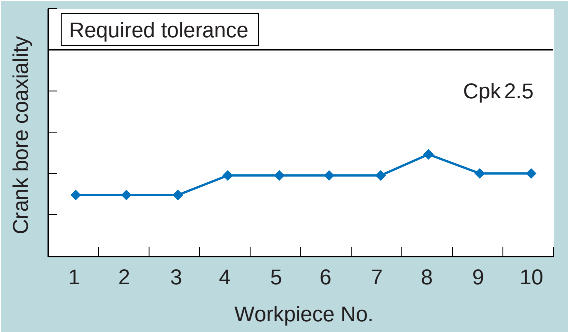

Fig. 14 Crank bore machining accuracy (Coaxiality)
Shows actual measurement values of machining accuracy when ten crank bores are machined successively.

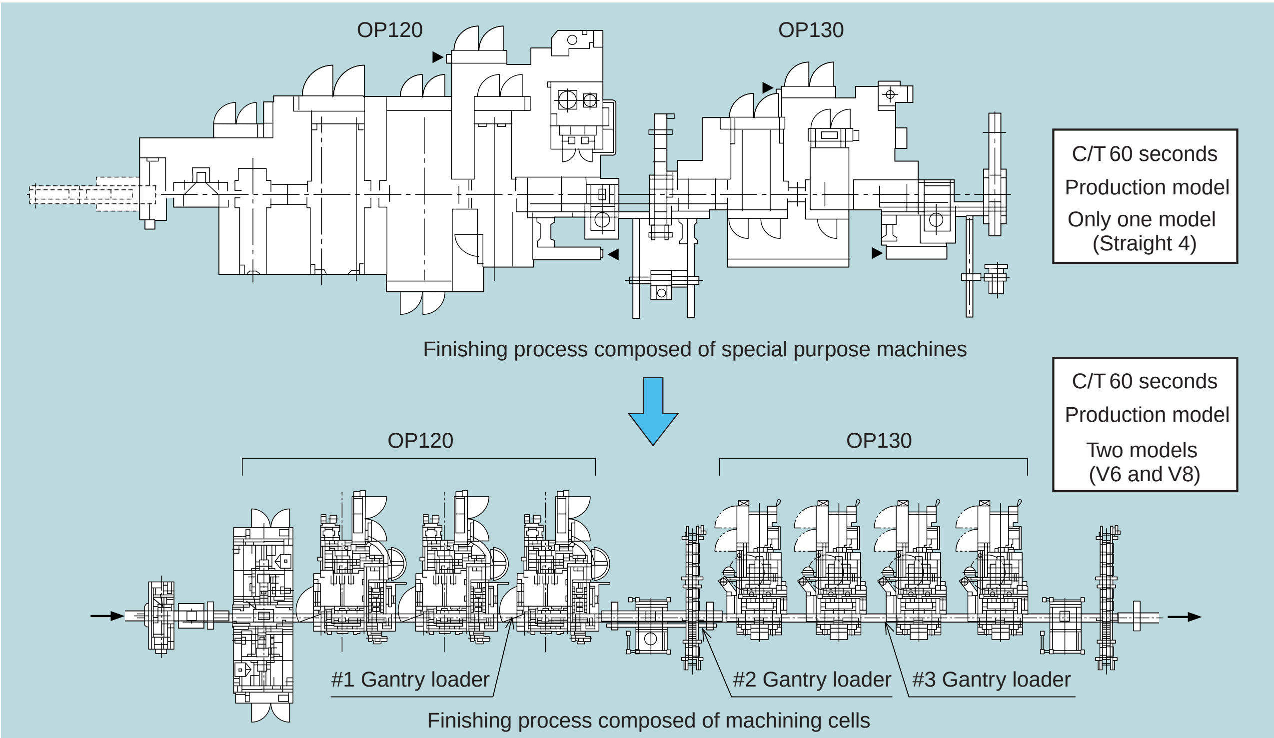

Fig. 15 Case example of new production system
The finishing process is composed of machining cells for finish cutting.

With this proposal, we have been able to obtain the following effects.

(1) Cylinder blocks with completely different shapes, such as the parts for V6 or V8 engines, are difficult to machine with conventional special purpose machine tools. With this developed machining cell, those cylinder blocks can be easily produced with other cylinder blocks in the same line.
(2) As with rough process, the finish cutting process line can now be parallel process.
(3) Flexibility has been improved with no increases in line cost above the level with special purpose machines. This improves the cost performance.


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6. Conclusion

Parallel process flexible lines composed of machining cells are now the mainstream as production lines for automotive parts. While this type of line has many advantages, its flexibility in manufacturing was still limited by the use of special purpose machine tools for the final finishing processes. MHI has introduced machining cells for finish processing capable of replacing the conventional special purpose machine tools. With these cells, it has become possible to build parallel process ultra-flexible lines.

MHI excels not only in the manufacture of machine tools, but also full-turn type design and manufacturing, including systems for entire lines. If you send us a request specifying the type of workpiece, production quantity, and future plan, we can propose an optimum line configuration to meet your requirements. In today's vertiginously changing business environment, we at MHI hope to continue supporting the auto industry and growth of automotive manufacturing technologies.