Development of Next-Generation Gear-Machining Line for Electrification

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Abstract

In recent years, the automotive industry has been rapidly shifting from conventional gasoline-powered vehicles to electric vehicles, such as electric cars and hybrids, and the business environment is changing rapidly. To cope with this change, the conventional production system was replaced with a shop production system, in which each process is performed individually. The new system enables a company to respond flexibly to fluctuations in the number of units produced, increase the efficiency of capital investment, and shorten the production preparation period. In this paper, we report on this development.

1. Introduction

In line with the shift to electrification in the automotive industry, JATCO has transformed from an existing production system centering on a continuously variable transmission (CVT) to electrification (EV and HEV). In addition to changes in the external environment, such as environmental regulations and policy support caused by progress in electrification, many new companies are entering the market. Therefore, in the production of transmissions (drivetrain components), there is a need to respond to fluctuations in production volume, adapt to diverse customer specifications, and secure cost competitiveness, which is different from the past.

JATCO’s production system is based on its JATCO Excellent Production System (JEPS)(1), which aims to improve competitiveness and contribute to profitability. In JEPS, the conventional production method (synchronous production line) is regarded as the ideal production system. However, it cannot respond flexibly to changes in production volume. Consequently, it is difficult to fully respond to customer needs, such as investment plans and delivery dates. Additionally, it is necessary to increase cost competitiveness by effectively utilizing existing equipment to machine CVT parts. To solve these problems, a new production system was developed and tested.

2. Problems of synchronous production lines

Figs. 1 and 2 show the problems associated with synchronous production lines. The vertical axis indicates the number of units produced, the horizontal axis indicates the year, the black line indicates the conventionally planned number of units, the red line indicates the projected number of units, reflecting fluctuations in the supply of electrified parts, and the blue line indicates the conventional line capacity.

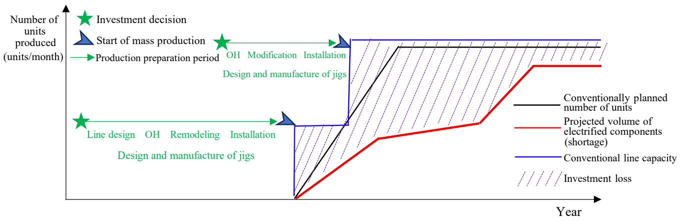

Fig. 1 Demand v.s. Line capacity (Demand decrease)

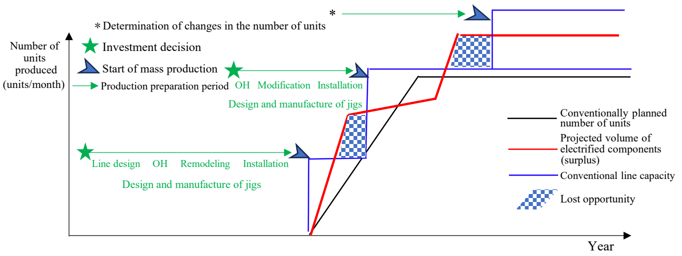

Fig. 2 Demand v.s. Line capacity (Demand increase)

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*Machining Process Engineering Section No.2

The synchronous production line has a long production preparation period (green line) and numerous units per line. Therefore, when the number of units falls short of the planned number (Fig. 1), there is a surplus in line capacity, resulting in an investment loss (diagonally lined area). However, when the number of units exceeds the planned number (Fig. 2), the line capacity cannot be increased over time, resulting in opportunity losses (cross-hatched area). To address these problems, we studied a production system that minimizes excess line capacity and shortens the production preparation period.

3. Study of new production methods

In response to the transition to electric power, JEPS has maintained the philosophy of synchronous production and, simultaneously, has been overhauled using synchronous production in a more flexible way to systematically stock inventory items. This makes it possible to select a production system that can achieve line capacity and stability under changing environments.

Based on this strategy, manufacturing processes with similar characteristics (turning, gear cutting, grinding, etc.) are grouped together, and their smallest units are defined as a "shop." A production system that provides inventory between these shops can increase the production capacity in small increments. Fig. 3 shows an overview of the conventional synchronous and shop production lines considered in this study.

In a synchronous production line, each process is connected in series such that there is little or no inventory and the flow between processes is smooth. The capacity of each line must be large to match the capacity of each process. To increase production capacity, a similar production line must be added. The capacity N of the entire line is determined by the capacity of the process with the smallest capacity in the line (the finishing process in Fig. 3).

Conversely, in a shop production line, each process is organized as an independent shop with inventory between them so that the production capacity can be increased on a shop-by-shop basis. In this example, the capacity of the finishing shop is 0.5 N, which means that the line can be operated as a production line with a capacity of 0.5 N.

If a finishing shop of 0.5 N is added, a lathe shop with a capacity of 0.75 N defines the line capacity. Therefore, a shop production line can increase its capacity by adding shop units. Hence, the line capacity can be increased in small increments to avoid creating excess line capacity. In addition, because capacity can be increased by shop units, the production preparation period can be expected to be shortened.

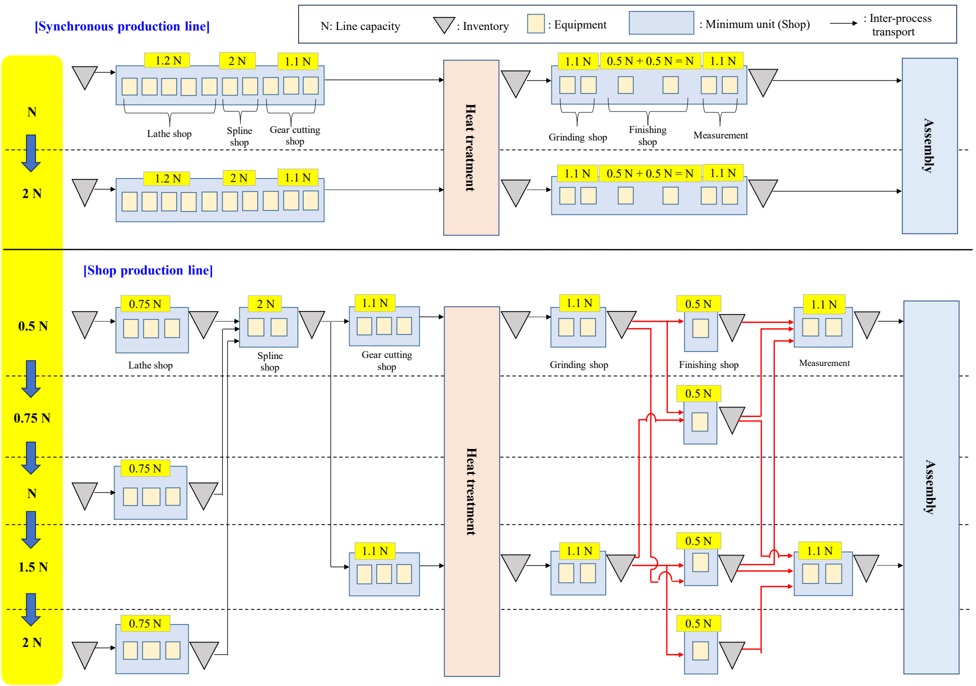

Fig. 3 Differences between Synchronous Production Lines and Shop Production Lines

4. Initiatives for using a shop production line

As described in Section 3, a shop production line can be expanded using units of equipment and shops, thus increasing its capacity in small increments. However, to use a shop production line, it is necessary to solve problems such as the increased complexity of inventory management and increased workload of inter-process transportation. This chapter explains the efforts to solve these problems.

4.1 Design, management, and operation of inventory

In a synchronous production line, inventory exists only during the final process. However, in a shop production line, the inventory is held between shops. In the present example, the number of inventory locations was approximately three times larger (Fig. 3), complicating the inventory management. To address this issue, a new inventory management method was developed.

(1) Designing the optimum quantity of inventory

In a shop production line, it is important to avoid stopping at the shop with the longest cycle time (called the “neck shop” . For this purpose, there must be an inventory of the front-end process. The concept of optimum inventory is illustrated in Fig. 4.

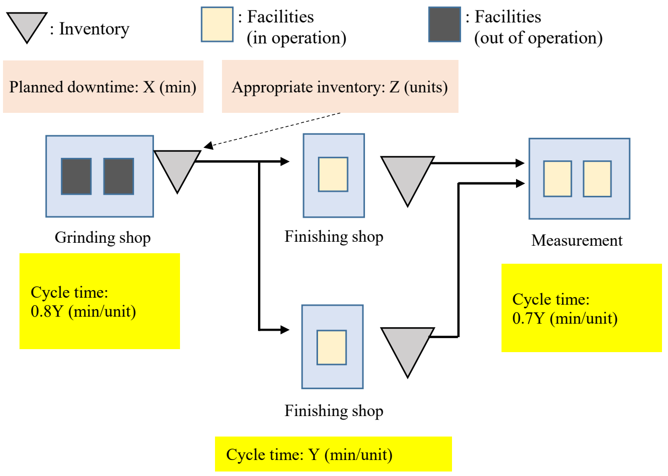

Fig. 4 Model for calculating the optimal inventory

Assuming that the cycle time of the finishing shop, which is the neck shop, is Y (min/unit), the planned downtime of the grinding shop, which is the process before the neck shop, is X (min), and the appropriate inventory is Z (units), the relationship between them can be expressed as follows:

Z (units) = X (min) / Y (min/unit)

The downtime X (min) is defined as the longest duration of planned stops, such as the model setup and tool change. Even when the grinding shop is stopped, the finishing shop, which is a bottleneck shop, is not stopped because inventory has been supplied to the finishing line. The required number of inventory units other than in the neck shop is defined as the standard number of packages (SNPs) of the cart. The operation of the part cart is described in (2).

(2) Methods to transport inventory

In a shop production line, the production sequence and processes vary widely, making the transport flow line complex (red line in Fig. 3). Therefore, if the conveyor transport method is used in synchronous production lines, setting up transportation routes and operating transportation onsite becomes difficult. To solve these problems, transportation by car has been investigated. The advantages of the cart transportation method are as follows:

Flexibility: Carts have no restrictions on route setting, and routes can be easily modified.

Investment and cost: Initial investment and running costs are lower compared to conveyors and production preparation period can be shortened.

Inventory management efficiency: Inventory can be managed on a cart, eliminating the need for refilling and facilitating easy transportation.

(3) Methods to manage the optimum inventory number

In inventory management, when the number of items in stock exceeds the optimum number, inventory costs increase, whereas when it falls below the optimum number, the neck shop stops and productivity declines. Therefore, maintaining an optimal number of inventories is important. Because the optimum inventory number can be maintained by controlling the number of carts, the appropriate inventory number was set by rounding Z (units) as a multiple of the SNP of the carts. Overstocking was prevented by managing each cart at a fixed quantity and position between shops and by stopping the grinding shop when the number of carts reached a set value.

4.2 Implementation of an automated transport system

As described in Section 4.1, the shop production line has complex transport flow lines because of the inventory stocking between shops. Transportation using a conventional manual cart may result in lower work efficiency, higher labor costs, and quality risks such as part mix-up. Therefore, an automatic transfer system was introduced to stabilize and improve the efficiency of transportation operations.

(1) Selection of transport methods

The specifications for automatic cart transportation were studied for autonomous mobile robot (AMR) and automated guided vehicle (AGV) types. The carts were transported between shops by under-cart crawling, towing, or lift-up. AMRs can move freely without being tied to a predetermined route. However, it is necessary to install sensors, AI control, and an integrated system. In this study, AGVs were selected because of their high cost advantage. Moreover, the route design was possible for AGVs owing to the fixable transportation route, and the cost of obtaining new AGVs could be eliminated by reusing the AGVs already owned by the company.

(2) Design of AGV path

As described in (1), the inventory between shops was loaded onto carts, which were transported by AGVs. To maintain uninterrupted production, a cart carrying parts must always be present in the downstream shop. In addition, the use of a single cart between two shops causes shop downtime during the replacement of carts. Therefore, it was designed to provide space for two carts between the shops. Furthermore, because it is important not to stop at the neck shop, the transport route of the AGVs was designed as shown in Fig. 5. When the cart in the finishing shop becomes empty, the AGV swaps it with the cart in the grinding shop (Fig. 5 [1]). When two carts are loaded with parts in the finishing shop, the carts in the grinding shop are transported to the planned stock yard (Fig. 5 [2]). The inventory in the stock yard is supplied to the finishing shop when the grinding shop stops (Fig. 5 [3]). Thus, the downtime loss in the finishing shop, which is a bottleneck shop, can be minimized, enabling uninterrupted production and stocking.

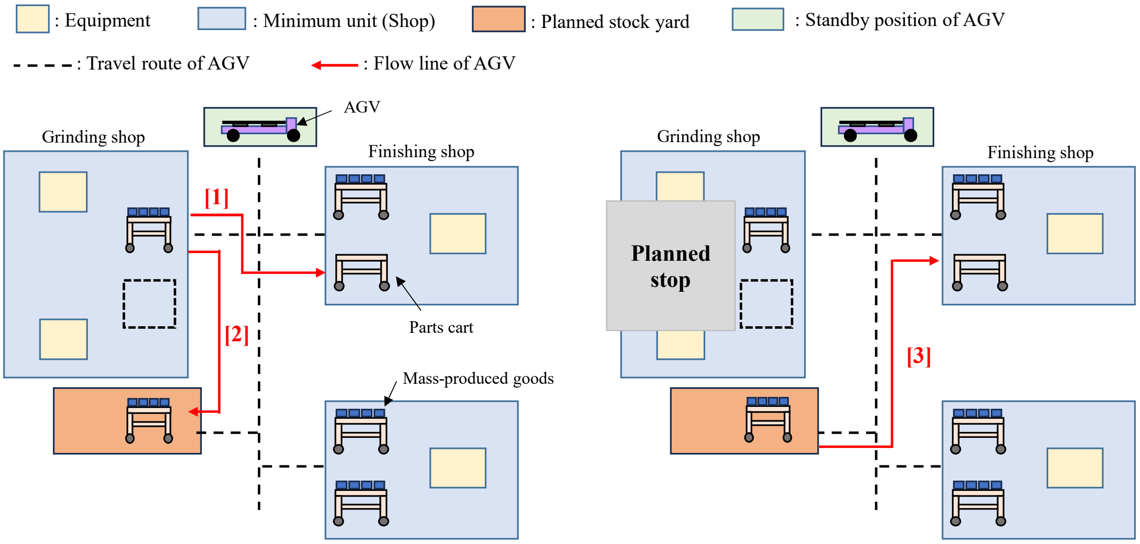

Fig. 5 Diagram of AGV and inter-shop parts cart

(3) Linking of AGVs and robots

To continue uninterrupted production, carts must be precluded from being on the neck shop when empty. Therefore, it is necessary for the AGVs to automatically detect the state of the cart (full, empty, etc.) and link the cart with the in-shop transfer robot. To detect the state of the cart, an imaging device is installed on top of the cart. Each time the robot picks up a part on the cart, the state of the cart is imaged. When the cart becomes empty, information is transmitted from the in-shop transfer robot to the AGV, preventing the cart in the neck shop from becoming empty.

In addition, a cooperative, rather than industrial, robot was used as the in-shop transfer robot to reduce the downtime loss during the changeover of carts. When an AGV enters a shop, industrial robots cannot distinguish the AGV from the worker, causing the equipment in the shop to stop for safety reasons and resulting in downtime loss when replacing a cart. However, cooperative robots can continue production even when changing carts, thereby reducing the downtime.

The actual automatic transfer system introduced is described next. Fig. 6 shows the cart transport specification described in “(1) Selection of transport method.” Fig. 7 shows the imaging equipment and cooperative robot described in “(3) Linking of AGVs and robots.”

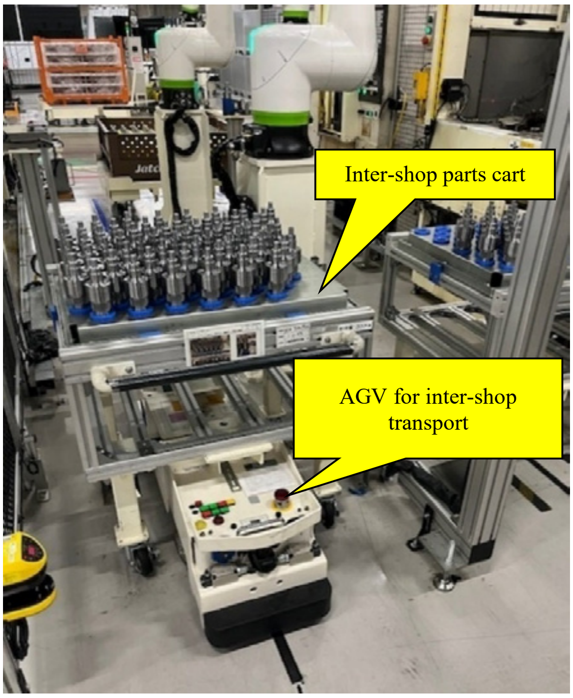

Fig. 6 Parts cart transport using AGV

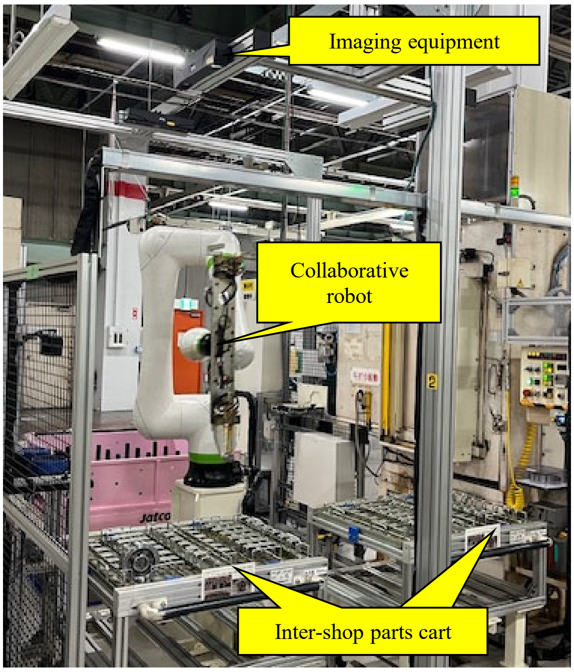

Fig. 7 Parts cart detection camera and collaborative robot

5. Confirmation of effectiveness

For a synchronous production line, when the number of units falls short of the planned number, there is a surplus in line capacity, resulting in a large investment loss (diagonally lined area). The investment loss (diagonally lined area) can be reduced using the shop production line, which can keep up with the change in the number of units (Fig. 8).

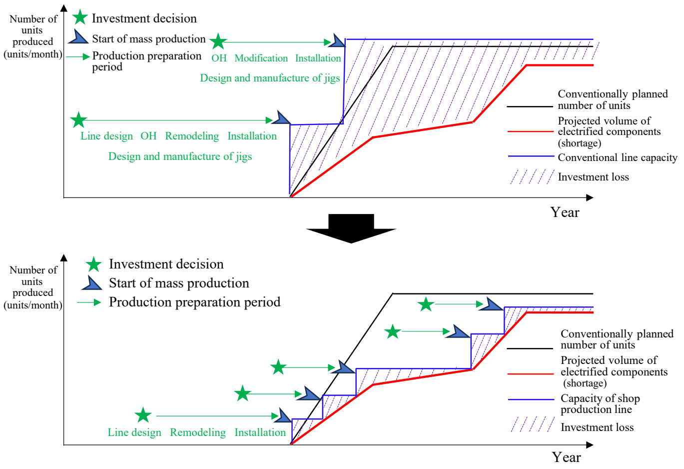

Fig. 8 Effect of shop production line, when the number of units decreases

In addition, in the case of a synchronous production line, when the number of units exceeds the planned number, the line capacity cannot be increased over time, resulting in opportunity losses (cross-hatched areas). However, using a shop production line shortens the production preparation period and reduces the risk of opportunity loss (Fig. 9).

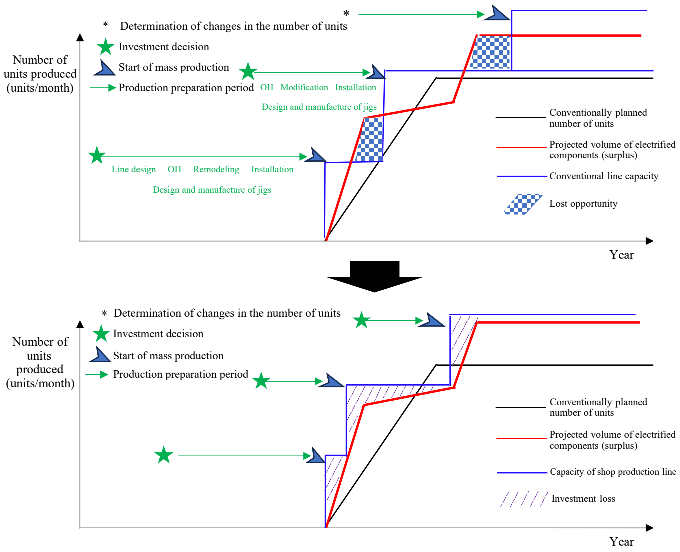

Fig. 9 Effect of shop production line, when the number of units increases

6. Discussion

In this study, a shop production line was introduced to overcome the inability of a synchronous production line to respond to fluctuations in production volume, thereby strengthening its ability to respond flexibly and shortening the production preparation period. This enabled the company to build a foundation for a production system that can respond to environmental changes associated with the transition to electrification.

Although a pilot line is effective for launching new parts, it is also useful for accommodating changes in production volume during production scale-up. Therefore, the use of synchronous production lines may not lead to major problems. In this regard, the shop production line is not always the optimal production system. In the future, we will develop a system that allows for the selection of appropriate production methods.

7. References

(1) Koji Watanabe and Masahiro Matsumoto: Global deployment of the JATCO Excellent Production System, JATCO Technical Review No. 14, pp. 65-70, (2015).

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