# Research and application of hot stamping flexible production line based on queue balance

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With the aim of investigating the optimization of hot stamping flexible production lines through queue balancing, this paper explores line balancing, mixed-line production, and the application of mixed-line production in hot stamping lines. The discussion begins with an examination of work balancing, inherent balancing, and queue balancing, highlighting the importance of understanding these factors when selecting balancing methods. Subsequently, the paper elaborates on the advantages of mixed-line production for hot stamping lines, such as the avoidance of time overhead during product schedule changes and the enhancement of productivity by fully utilizing intermediate gaps in the production beats. This study holds theoretical significance for guiding the optimization of hot stamping flexible production lines and contributes valuable insights for further research in related fields.

*Keywords*: Hot stamping of high-strength steels; Queue balancing; Flexible production line; Mixed line production; Multi-component integration.

## 1. Introduction

The advancement of press hardening technology has propelled the expansion of hot stamping production from simple single-piece production to multi-part integrated (MPI) hot stamping. The diverse requirements of different components necessitate the integration and scaling of production lines [1,2]. Conventional production lines are often ill-equipped to meet this diverse demand, as they are typically designed for part-specific, high-volume production. With the market's increasing emphasis on individualized products and flexible production, flexible production systems and mixed-line production have emerged as prominent research areas in hot stamping.

A flexible production system denotes a production system that facilitates rapid adjustment and adaptation to different specifications and types of components. It utilizes modular and programmable equipment and tools, enabling quick line changeovers and adaptability to the flexibility requirements of diverse products. Such systems can enhance productivity and economic efficiency by reducing production changeover time and resource wastage.

Mixed-line production entails the simultaneous production of multiple parts of varying sizes and types on the same production line. Traditional production lines often necessitate


Y. Zhang and M. Ma (eds.), *Proceedings of the 7th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU 2024)*, Atlantis Highlights in Materials Science and Technology 3,
https://doi.org/10.2991/978-94-6463-581-2_59

downtime and adjustments to accommodate the production of different products, resulting in wasted production changeover time and inefficient utilization of production capacity.

In the context of flexible production systems and mixed-line production, the adjustment time of the production line is significantly reduced, enabling rapid switching and flexible production, and maximizing the production line's capacity utilization.

Hence, the development of flexible production systems and the realization of mixed-line production mode are of paramount significance in meeting diverse product demands, enhancing production efficiency, and reducing costs. This study aims to explore the practical impact and potential of this production mode in the production of high-strength steel parts through the research and application of a double press-roller-hearth furnace hot stamping flexible automated production line.

The origins of mixed-line production can be traced back to the 1960s, when certain manufacturing industries began producing different specifications and types of products on the same production line. With the evolution of computer technology and automation, mixed-line production has gained wider usage and popularity.

An exemplary instance of mixed-line production is the flexible production system in the automotive manufacturing industry. Automobile manufacturers concurrently produce multiple car models on a production line and can swiftly make production adjustments. For instance, the Toyota Production System (TPS) employs mixed-line production as a successful production model, achieving efficient and flexible production of automobile production lines through the introduction of flexible assembly cells and robotic automation technology. Through mixed-line production, automakers can better address diverse consumer demands and improve production line utilization.

These notable examples of mixed-line production demonstrate that with flexible production systems and the mixed-line production model, manufacturers can achieve rapid changeovers, flexible production, and heightened production efficiency. This production mode has been widely adopted across various manufacturing industries and is pivotal in meeting diverse product demands, enhancing line utilization, and reducing production costs.

## 2. Balancing of production lines

For nearly 80 years, Henry Ford's "highly balanced assembly line" has been the dominant production model. However, as technology progressed, such lines suffered from a lack of production flexibility. Most short cycle lines that appear to be balanced actually have a large loss of balance. A line can have perfect average or static balance, but be highly unbalanced (dynamically balanced) from cycle to cycle. These factors are very important when choosing a balancing method [3].

Line balancing is a technical tool and method used to analyze the load of all processes in a production line, and to balance the capacity of each process by adjusting the load distribution between processes (ensuring similar operating times as much as possible), ultimately eliminating the phenomenon of wasteful waiting and improving the overall efficiency of the production line. This approach to enhancing the production capacity between processes and balancing them is also known as "bottleneck improvement". Another concept associated with the beat and bottleneck is the phenomenon of "idle time" (idle time) [4]. Idle time refers to the time during working hours when no valid tasks are performed, and can refer to either equipment or human time. Idle time occurs in processes other than the bottleneck process when the beats of the processes in a process are inconsistent, necessitating the balancing of the production process.

In manufacturing, production lines are mostly continuous multi-process lines that have been subdivided, simplifying the complexity of the work and facilitating increased proficiency to improve work efficiency. However, after such subdivision of work, the operating times of each process, in theory and in reality, cannot be exactly the same, leading to inevitable inconsistency in the beat between processes and bottleneck phenomena. Apart from the unnecessary loss of man-hours, this inconsistency can also cause a large number of process pile-ups, resulting in the accumulation of slow-moving products and potential production suspensions. To address these issues, it is essential to average the working time of each process and standardize the work to ensure smooth movement of the production line. "Line balancing" is the process of averaging all production processes and adjusting the load of each operation to minimize the time of each operation, and is a crucial consideration in production process design and operation standardization. Line balancing forms the foundation for a new method of flexible production.

Mixed-model manufacturing involves assembling several different types of products on the same assembly line without conversion, and then sequencing these models in a way that smooths upstream component demand [5]. The goal is to smooth upstream work center, manufacturing cell, or supplier requirements, thereby reducing inventory, eliminating conversions, and improving kanban operations. It also eliminates assembly lines that are difficult to replace.

The aim of this study is to develop a flexible hot stamping production system that utilizes a dual press-roller-hearth furnace combination, along with an automated mechanical conveyor system, to achieve small-lot and mixed-line production patterns. The objectives of the study include exploring the suitability of different press sizes and automated distribution of hot blanks, as well as developing a monitoring system for production planning and optimizing the monitoring and management of the production process [6].

To achieve this goal, the following scheme was proposed. First, two hot stamping hydraulic presses of different tonnages are combined with a roller bottom heating furnace. Blanks of different sizes and forming force requirements are automatically allocated and transported to the appropriate presses using an automatic mechanical conveying system. The line has an automatic identification and distribution function that instructs pre-configured manipulators and fixtures to complete the transportation of the billets out of the press.

The design of this flexible production system offers several key advantages. Firstly, by using presses of different sizes, the system can adapt to the production needs of parts of varying sizes and shapes, allowing for efficient production even in small batches or mixed-line production. Secondly, the use of a roller-hearth furnace can achieve rapid and uniform heating, enhancing production efficiency and product quality. Finally, the introduction of an automatic mechanical conveying system enables automatic distribution and conveying of blanks, reducing manpower input and production changeover time, and improving the flexibility and efficiency of the production line.

Through the study and application of the double press-roller-hearth furnace hot stamping flexible automated production line, the aim is to explore the actual impact and potential of this production mode in the production of high-strength steel parts. By realizing small-lot production and mixed-line production attempts, the study seeks to explore solutions to better meet the diverse product demands of enterprises.

## 3. Production Beat and Mixed-Line Hot Stamping Production

In an actual hot stamping line, the production plan involves both large and complex parts and small one-die-multiple-piece production tasks. Large hot stamped parts, such as door rings, have long production cycles (25-35 seconds), while small, one-die, multi-piece parts have shorter production cycles, such as 10-15 seconds for a door bumper.

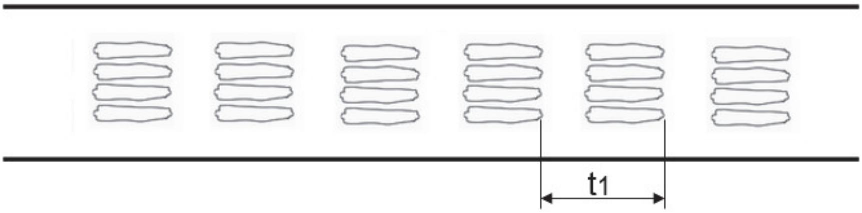


Fig. 1 Conventional production line flow for small one-mold multiple parts with fixed beat time t1

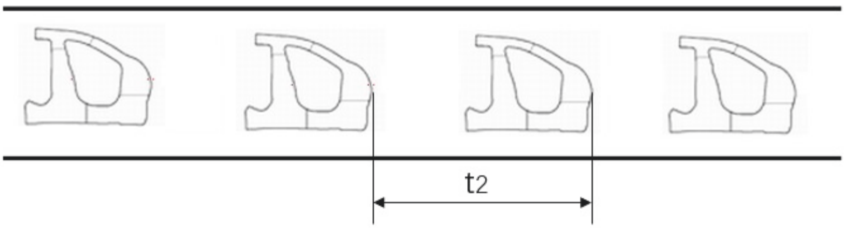


Fig. 2 Conventional large fixed beat for time t2 production line flow

Simultaneous production of 2 or more hot stamped parts of different specifications and types on the same production line improves production productivity, reduce energy consumption per part, and lowers costs. Secondly, compared with the traditional production method, for each type of part produced, it is necessary to replace the raising mold, which requires more production preparation time. According to the concept of group manufacturing, the production of a variety of related parts on a single line is conducive to the realization of the "family of parts" group manufacturing, bringing benefits to production management.

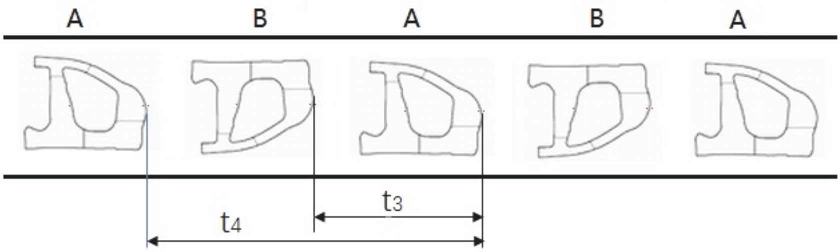


Fig. 3 Heating process for mixed wire production of left and right door ring blanks

For products with short production cycles and longer production cycles, organizing production according to the queue balancing model has many advantages:

1) It can avoid the time spent on changing molds and auxiliary tooling when replacing the product plan.

2) Mixed line production in the production cycle (press forming-holding time) and short production cycles can make full use of the gaps in between the cycles to fully utilize the productivity of the roller-heating furnace and reduce the energy consumption of a single piece, thereby reducing the energy consumption per piece.

As depicted in Fig. 1, the production time for a 4-cavity "door bumper" in one mold is t1 = 14 seconds. The production cycle for the single product of the door ring in Fig. 2 is t2 = 27 seconds. Due to the multi-part integration (MPI) hot stamping, for the left and right parts of the door ring, the welding reference edges and the stamping forming direction are different, so it is necessary to be divided into different molds to achieve the stamping production, as shown in Fig. 3 of the blanks A and B. The beat time for A and B is time t3, and the beat time for the blanks in the same stamping direction (A to next A blanks) is time t4.

## 4. Research on key technologies for hot stamping mixed line production

### 4.1. *Arrangement of production lines*

In this design of mixed line production, the heating process is in series, and the molds are arranged left and right at the exit end of the heating furnace. At the outlet of the heating furnace, under the pick-up robot of the press, there is a CNC centering and positioning table to position different combinations of blanks, which are fed by the corresponding robot to the mold of the corresponding press. The mixed line production mode of the double-press common line heating furnace has the characteristics of group manufacturing. And through the process arrangement and finetuning of the beats of the mixed-line production, it is possible to produce the bumper beams with two stamping beats time (t1+t1) in the gap of the door ring production, and to match with the production beat time t2 of the door ring, as shown in Fig. 4.

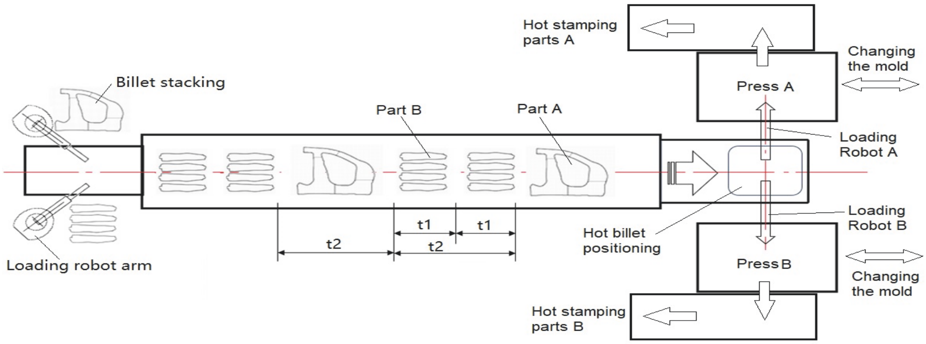


Fig. 4 Schematic diagram of hot stamping hybrid production line

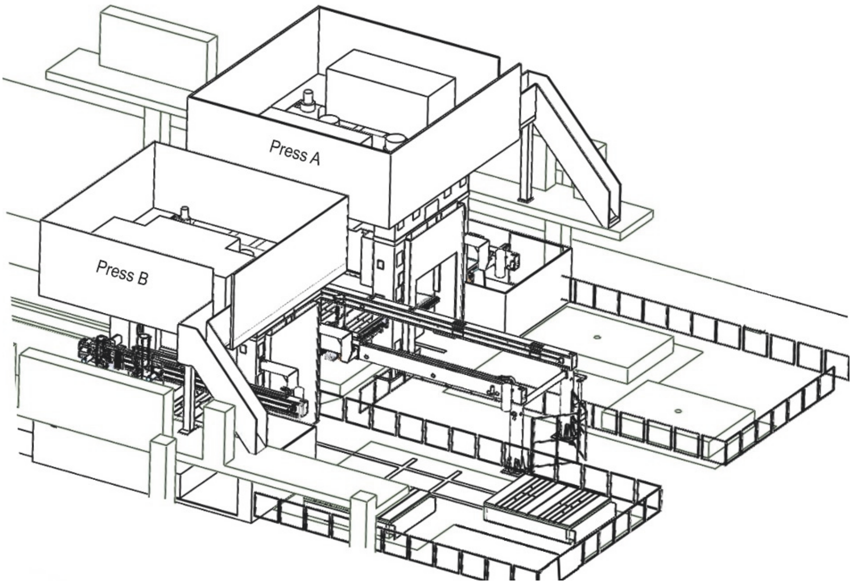


Fig. 5 Double press loading and mold changing work area of the production line

The project can realize double presses as backup for each other, consisting of one set of heating furnace, one set of depalletizing system supporting two presses and two sets of press loading and unloading units. Through the normal production process of one press, the other press replaces the press molds in advance as well as the end pickups of the loading and unloading manipulators and other preparatory work, so as to achieve the purpose of reducing the time of replacing the molds and improving the efficiency of the whole line, as shown in Fig. 5. There are two hot stamping presses (Press A: 2000 ton, Press B:1200 ton) for the molding of mixed line production. Blanks are added to the furnace through a 45-meter-long roller-hearth furnace, and blanks are heated in a heating sequence arranged in accordance with the mixed production flow to ensure that the production process is fast and slow beat to beat.

### 4.2. *Equipment technical difficulties and solutions for mixed-line production*

**1) Production line equipment specifications**

Roller Bottom Heating Furnace: The furnace chamber size is 2400mm wide with an effective heating zone length of 390,000mm. The energy is supplied by electrically heated heaters, and the heating of uncoated high-strength steel plates can be protected by nitrogen gas with a low dew point.

Dual press system: A press has a maximum stamping force of 20,000KN and a table size of 4,000*2,800mm; B press has a capacity of 12,000KN and a table size of 3,200*2,500mm.

Automatic conveyor system for the heating furnace discharge: two robots perform double-station stomp splitting tasks (see Figure 4) for a fixed process of billet loading. For hybrid heating, the principle of queue balancing is implemented with a joint division of labor between the two robots for the dismantling and loading of the billet.

**2) Control flow of automatic conveyor system**

The primary challenge facing the system was the relative positional layout between the twin presses, which directly impacted the structure of the loading manipulator. To solve this problem, the manipulator structure was optimized with a double-joint doubling structure to increase the stroke and improve the dynamic response of the manipulator, increasing the feed acceleration to 10 $m/s^2$.

Another key issue is the safety of the two press loading manipulators when changing positions, where collisions and interferences need to be avoided. To address this issue, the manipulators are capable of automatic position exchange when the two presses change molds or replace production products. In the design of the control system, the system's upper computer, electrical control, and mechanical avoidance are strictly logic closed-loop locking, as shown in Figure 6. When the heating furnace is discharged, the motion logic of the automatic conveyor manipulator is as follows:

i When the heating of the material in the furnace is complete, the discharge conveyor line transports the material from the furnace chamber to the discharge area;

ii The host computer system issues commands to call up the appropriate robots and presses according to the specifications of the hot oven discharge and the production recipe;

iii The electrical system automatically switches the corresponding robot according to the command issued by the host computer;

iv The current hot stove discharge is the B1 robot to carry out the loading action, using the press B to keep the pressure; the next hot stove discharge is the corresponding A1 robot;

v B1 manipulator firstly arrives at B1 standby feeding position after discharging materials, and then lifts up; at the same time, A1 manipulator descends in both standby positions; the two manipulators make use of the height difference to carry out the position exchange in the Y-axis direction; after the Y-axis arrives at the safe position, the two manipulators move up and down in the Z-axis in the wrong position; after the movement, the A1 manipulator is in the middle of the standby feeding position, and the B1 manipulator is in the standby position on both sides;

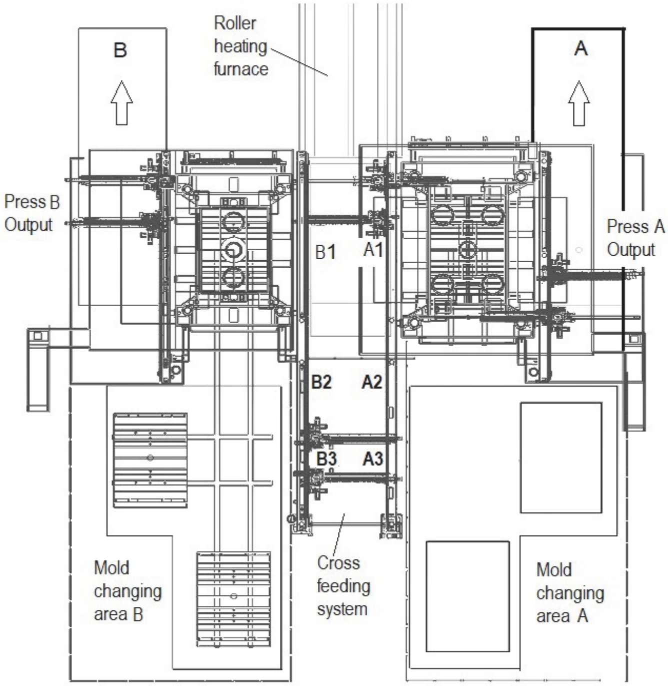


Fig. 6 Automatic die loading conveyor system for blanks on presses

vi The electrical positions of the two groups of manipulators use servo absolute encoders, while external switches do the position confirmation, realizing closed-loop control of the position loop, which ensures high efficiency and safety, and completes the exchange of the positions of the two manipulators within one out feeding beat;

vii At the same time, the automatic blocking stopper at the end of the hot stove discharge line body will automatically adjust the blocking positioning position according to the recipe instruction from the host computer;

viii After the robot finishes exchanging positions, the upper computer will receive a completion signal to ensure that the cycle operation is completed smoothly.

By optimizing the structure and dynamic responsiveness of the manipulator, the automatic conveyor system for heating furnace discharge enables fast and safe position exchange. At the same time, a logical closed loop of upper computer, electrical control, and mechanical avoidance ensures a smooth exchange process. In this way, the double press hot stamping line is able to realize efficient mixed-line production or small-lot trial mold production, improving production efficiency and flexibility. The flexible dual-press hot stamping line put into actual production is shown in Figure 7.

Fig. 7 Double press-roller-hearth furnace flexible production line in actual operation

## 5. Conclusions and outlook

This study aims to thoroughly discuss the hot stamping flexible production line based on queue balancing, to explore the advantages of line balancing, mixed line production, and mixed line hot stamping production, and to propose solutions to the technical difficulties of the equipment. Through in-depth discussion of related content, the study provides theoretical guidance for the optimization of hot stamping flexible production lines and offers useful insights for in-depth research in related fields.

With the continuous development of hot forming technology, the scale of hot stamping production is expanding. However, the traditional production line is unable to meet the diversified needs, so the flexible production system and mixed line production have become a research hotspot. The paper emphasizes the importance of line balancing and introduces the concept of hybrid production and its successful applications in automotive manufacturing and other industries. It discusses in detail line balancing, beat rate, and technologies related to hybrid hot stamping production, and demonstrates solutions to key issues such as job time averaging and beat rate matching. Optimization solutions are proposed for the technical difficulties of equipment specifications and automatic conveying systems, and the design features and advantages of the double press hot stamping production line are described. These measures help to improve production efficiency, reduce costs, and contribute to the development of the hot stamping field. Finally, the effectiveness of the research results in actual production is anticipated, and it is suggested that the application of mixed-line production in other fields can be explored in depth in the future. The efficiency and flexibility of the production line can be continuously optimized and improved in conjunction with the actual production situation.

Overall, this study provides theoretical guidance and application prospects for the mixed-line production of hot stamping flexible production lines, and offers a solid theoretical foundation and practical guidance for further development and application in this field.

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