Comparison of laser cutting technology routes for large-scale integrated hot stamping components

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With the development of automotive lightweight technology, multicomponent integrated hot press forming is an important technology, which can realize lightweight car body forming with complex geometry. In the cutting process of large integrated thermoforming parts, the multi-robot multi-head synchronized cutting route has greater flexibility than the single-head processing method and can improve the cutting efficiency. This paper compares the advantages and disadvantages of the single-head processing method and the multi-robot multi-head synchronized cutting, and introduces the robot characteristics and experimental verification data of the new cutting system. The experimental results show that the multi-robot synchronized cutting route has better flexibility and cutting efficiency in the cutting process of large integrated thermoformed parts, clarifies that the multi-robot synchronized cutting route is suitable for large integrated thermoformed parts, and points out that the new multi-robot synchronized laser cutting system has the characteristics of the industry 4.0 concept.

Keywords: Multi-component integrated hot stamping; Laser cutting; Multi-robot; Multi-head synchronized cutting; Hole to line ratio.

1. Introduction

With the development of the automobile industry, large-scale integrated hot forming parts play an important role in automobile manufacturing. In the face of the increase in the parts of the body structure and the distribution of mechanical properties requires more customization, the multi-component integrated hot stamping has become an important technology, which is a comprehensive technology of laser splicing and welding plate and hot stamping forming[1]. The application of multi-component integrated high-strength steel hot stamping technology can realize the formation of lightweight car body with complex geometry, which is conducive to the improvement of product quality and the optimization of material utilization [2] .

Multi component integration (MPI) hot stamped parts increase more in size compared to conventional body hot stamped parts, and the post-process of hot stamped formed parts is laser cutting, for conventional 3D 5-axis laser cutting machine, the increase in the size space of the cutting machine will increase the cost and footprint, which also faces new challenges. However, different laser cutting technology routes have different impacts on the cutting effect and productivity of integrated thermoformed parts. Therefore, this paper aims to find the most suitable method for cutting large integrated thermoformed parts based on comparing different laser cutting technology routes.

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2. Multi-robot synchronized cutting principles and methods

Conventional laser cutting technology routes for large integrated thermoformed parts mainly include single-head cutting and multi-robot multi-head synchronized cutting in two ways, which have their own advantages and disadvantages.

2.1. *Single-head laser cutting*

Single-head laser cutting is the most common laser processing method, which can be a single robot or a single 5-axis machine with a single laser processing head. It sets the cutting parameters and adjusts the cutting path and speed through the control system and programming commands, thus accomplishing a single cutting task on the workpiece.

Among them, the single-robot single-head cutting technology route has the advantages of simple operation and low cost, and is suitable for small batch production and personalized cutting needs. However, limited by the cutting efficiency and quality issues, mainly used in the less demanding metal covered parts market. For the more demanding thermoformed parts processing market, single-head five-axis machine tool processing is the mainstream way.

Single-head five-axis machine tool machining technology route has high precision, high efficiency, the application of the advantages of maturity, suitable for large quantities of thermoformed parts processing. However, its equipment price is high, in order to maintain the machining accuracy of the late maintenance costs are also very high, and the cost of parts with the downward trend of the trend does not match. On the other hand, when the traditional small thermoforming parts such as A-pillar, B-pillar, to large integrated thermoforming parts such as door ring transformation, the standard single-head 5-axis machine tool machining range cannot meet the requirements of the workpiece, can only be replaced by larger 5-axis machine tools, which is even greater cost pressure.

2.2. *Multi-Robot Multi-Head Synchronized Cutting*

In order to accommodate more types and larger sizes of integrally molded thermoformed parts while increasing production capacity per factory floor space, simultaneous multi-robot cutting has been developed. Multiple lasers cutting robots work in tandem to cut workpieces at the same time to achieve higher productivity and processing speeds. Multi-robot synchronized cutting can reduce the cutting time of a processing cell by dividing the workpiece cutting task among different robots, each of which is responsible for cutting a portion of the workpiece and synchronizing the cutting.

By working with multiple robots, cutting efficiency and quality can be improved. For large-scale integrated thermoformed parts, the simultaneous cutting route of multiple robots is more suitable for integrated thermoformed parts with large "edge-to-hole ratio", which can better meet the requirements of cutting quality and efficiency.

Multi-robot multi-head synchronized cutting has some obvious advantages over single-head cutting methods. First, multi-robot synchronized cutting has higher flexibility, according to the size of the processed product and the layout of the allocation of each robot's processing tasks. Second, the cutting system itself has scalability, such as dual-robot cutting equipment can be later expanded to four-robot cutting equipment or even more robots, to meet the processing requirements of larger size equipment. Third, due to the simultaneous cutting of multiple heads, the overall cutting time of the workpiece can be shortened to improve productivity and meet the needs of high-volume production. At the same time, multi-robot synchronous cutting requires more control technology and overall integration capabilities.

2.3. *Progress in Research and Application of Existing Single-Head/Multi-Robot Laser Cutting Machines*

In existing robotic laser cutting systems, due to the limited accuracy of the dynamic trajectory of the robot arm, most of the applications are for less demanding cutting of automotive sheet metal coverings, and cannot meet the requirements for cutting thermoformed parts. The solution provided by SPA (Shape Process Automation) is to add a 3-axis laser positioner (called NEWTON®) to the end of the robot arm. at the end of the arm. The robot carries the positioner to the desired location, the arm remains stationary, and the cutting is performed by the NEWTON® positioning device. Newton robotic cutting technology achieves higher cutting speeds and accuracy by combining the NEWTON® laser positioner with the advanced technology of the robot arm. However, the positioner is heavy, and although it solves the problem of precision cutting of some holes, it affects its dynamic response and comprehensive performance from "hole" to "edge", and is prone to jitter when cutting the outer frame. It also does not have an advantage in production efficiency for one-piece thermoformed parts with a large "edge-to-hole ratio". On the other hand, its large size also leads to interference with the workpiece during the cutting process, resulting in cutting limitations [2]. The cost of this positioner is expensive, several times more than the robot itself, which also limits its application.

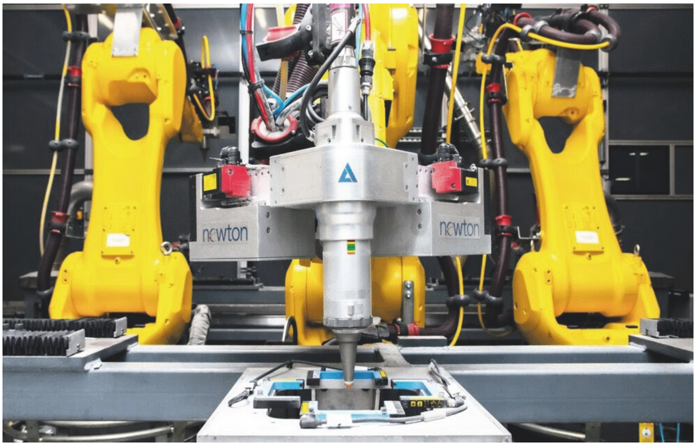
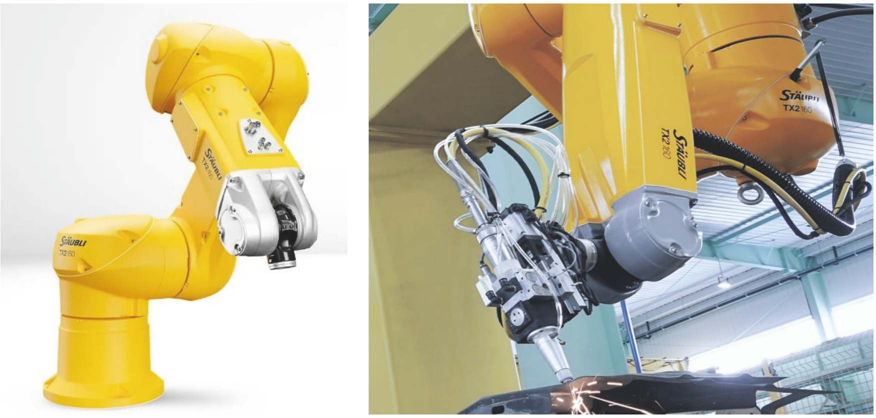


Fig. 1 Newton robotic cutting machine

3. Robotic features of the new cutting system

Stäubli, a supplier of high-precision robots and automation solutions [4], has a high-precision robot and laser cutting system as shown in Figure 2 with the following features:



a) b)

Fig. 2 a) Typical Stäubli high-precision robot; b) Stäubli robotic laser cutting system

(1) High precision: Stäubli robots have excellent repeat positioning accuracy (±0.05mm under ISO9283 standard) and dynamic trajectory accuracy (¢10 small circle error <±0.05mm). It adopts the patented reducer system JCS (shown in Figure 3), which can keep the upper and lower double-layer 32 teeth meshing at any moment, and the backlash is close to 0. Together with the underlying precision motion control system, it can realize micron-level trajectory accuracy and ensure the accuracy and stability of the robot in the process of task execution.

Figure 3 Stäubli JCS patented gearboxes

(2) High speed: Stäubli TX2-160 series robots are equipped with fast action response and high speed movement, the joint speed is shown in the table below. The fastest speed at the center of gravity of the load can reach 12.3m/s.

Table 1 Articular velocity and angular resolution

Axis (TX2-160/TX2-160L)	1	2	3	4	5	6
Maximum speed	210°/s	210°/s	335°/s	530°/s	500°/s	1500°/s
Angular resolution	0.004°.10^{-3}	0.004°.10^{-3}	0.007°.10^{-3}	0.008°.10^{-3}	0.007°.10^{-3}	0.021°.10^{-3}

(3) Multi-joint structure: Stäubli robots adopt multi-joint mechanical structure, which can realize flexible movement and multi-axis control. The multipoint structure enables the robot to move freely in three-dimensional space and adapt to different work scenes and task requirements.

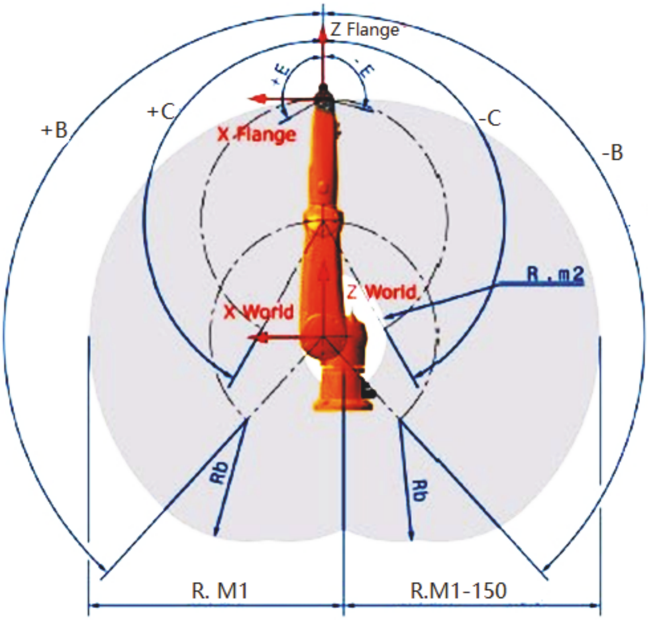


Fig.4 Stäubli TX2-160L operating range diagram

(4) Safety and reliability: Stäubli robots incorporate multiple safety measures with unique modular SIL3-PLe level safety features (the highest safety level) [5]. For example, robots can be equipped with sensors and monitoring devices that detect the surrounding environment in real time to avoid accidental collisions and injuries.

(5) The Stäubli robot arm integrates a number of sensors inside the arm, which can provide information on the utilization status of the arm's core components at all times. It integrates OPCUA communication protocol (OPC UA is the standard communication protocol between equipment, MES, ERP). Both openness and security, for customers to customize the development of functional modules to dock the factory's "Industry 4.0" program.

Fig. 5 Characteristics of digitized devices and industrial connectivity based on the concept of Industry 4.0

4. Actual production data verification

In order to verify the applicability of the multi-robot synchronized cutting route, this paper uses actual production data from Stäubli to conduct a comparative analysis. Thermoformed parts with different "edge hole ratio" sizes were selected and processed by single-head cutting and multi-robot multi-head synchronized cutting, and the cutting quality and cutting efficiency were evaluated. The experimental results show that the multi-robot synchronized cutting route has higher efficiency in the cutting process of integrated thermoformed parts with large "edge hole ratio".

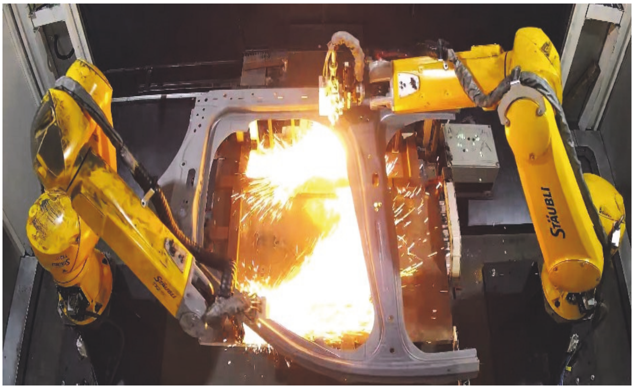


Fig. 6 Twin-robot, two-head cutting system (door ring part cutting)

Figure 6 shows a dual-robot double-head cutting door ring program, using a rotating platform loading and unloading mode, the door ring rotates to the processing station, the two robots synchronized cutting, cutting is completed, the door ring rotates to the lower material position, the other side of the door ring synchronized to reach the processing station cycle production.

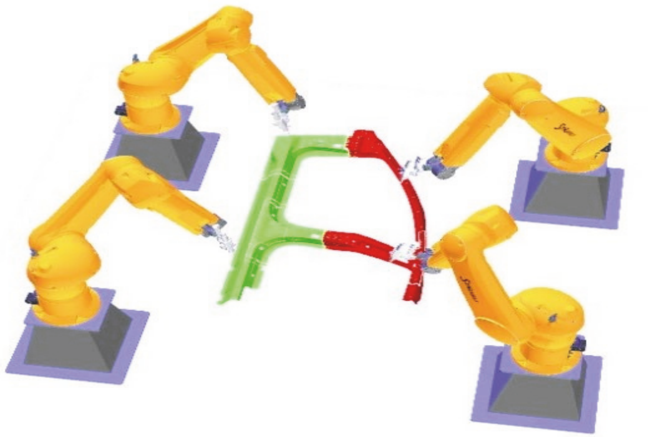


Fig. 7 Four-robot, four-head cutting system (door ring part cutting)

Figure 7 shows a four-robot four-head cutting system, using a mobile platform for loading and unloading. The mobile platform arrives at the processing station with the door ring, the four robots cut synchronously, and after processing is completed, the mobile platform takes the door ring to the discharging position, while another mobile platform arrives at the processing station to circulate the production.

The frame cutting speed of a multi-robot cutting system can be close to that of a 3D 5-axis machine, while the hole cutting speed will be slower because the acceleration of the robot's joints will be less than that of the joints of a 5axis machine. However, the multi-robot cutting system consists of multiple cutting heads synchronized cutting, using dual-head robot cutting system and five-axis machine efficiency is close to, when the thermoformed parts of the frame to hole ratio is greater than a certain value, the efficiency of the dual head robot cutting system is higher than the single-head three-dimensional five axis machine. The following typical B-pillar and door ring products were selected for actual machining tests, and the specific values are in Table 2 and Table 3.

Table 2 A B-column Length of outer frame 4100mm, number of cut holes 33, side hole ratio of about 125

Serial No.	Typology	Cutting time (Sec)
1	Single-head 3D 5-axis laser cutting machine	58s
2	Dual head robot system	61s

Fig. 8 Body B-pillar cutting

Fig. 9 Actual picture of laser cutting of door rings

Table 3 A body door ring Outer frame length 8900mm, number of cut holes 60, side hole ratio of about 148

Serial number	Typology	Cutting time (Sec)
1	Single-head 3D 5-axis laser cutting machine	173s
2	Dual Head Robot Laser Cutting Systems	168s
3	Four-head robotic laser cutting system	85s (analog beats)

Users can be based on the external dimensions of the parts to be processed and the number of holes to calculate a "side hole ratio", and according to the actual production data to measure the equipment "side hole ratio" domain value, such as the domain value of the above test equipment, that is, 140, when When the "side hole ratio" is greater than 140, the parts are prioritized in the double-head robot cutting system to process; and when the "side hole ratio" is less than 140, the zero position is prioritized in the single-head three dimensional five-axis machine tool processing.

The bottleneck of the multi-head robot cutting system is the hole cutting speed, with the upgrade of the robot arm and control technology, the hole cutting speed will be improved accordingly, corresponding to the multi-head cutting system, "edge hole ratio" domain value will also be optimized.

5. Conclusion

A comparative analysis of the different technological routes makes it possible to clarify the characteristics of a laser cutting system for a new hot stamping line for high-strength steels for automotive body structures:

(1) The multi-robot synchronized cutting route is more suitable for largescale integrated thermoformed parts with a large "edge-to-hole ratio", which improves cutting quality and efficiency.

(2) Multi-robot synchronized cutting route can significantly improve the cutting efficiency through the collaborative work of multiple robots, and the key to further improve the efficiency is to improve the robot's hole-cutting beat.

(3) The new multi-robot synchronized laser cutting system, characterized by the industry 4.0 concept, lays the foundation for a robotic intelligent laser cutting system.

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