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Flexible punching system using industrial robots for automotive panels

Guotao Yin[a], Zhenghe Zhu[a], Hu Gong[a,*], Zhenfeng Lu[b], Huashan Yong[b], Lei Liu[c], Wei He[c]

[a] *State Key Laboratory of Precision Measuring Technology & Instruments, Tianjin University, 300072, PR China*
[b] *Tianjin Jiupeng Automobile Equipment Manufacturing Co. Ltd, Tianjin 300399, PR China*
[c] *Mianyang Huarui Automobile Co. Ltd, Sichuan 621000, PR China*

A R T I C L E I N F O

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A B S T R A C T

A new flexible punching system based on industrial robots is proposed for tailor-made automotive panel. A robot end effector for industrial robot punching - punching plier is designed. Meanwhile, according to the shape feature of the punching plier, the interactive tool path generation method is proposed in 2D space instead of 3D space. This system can be adjusted easily to punch all kinds of holes, reducing the cost of developing new cars and shortening the development cycle. Finally, the practicability of this system is verified through application in real production of automotive panels.

1. Introduction

With the popularity of family cars, the trend that consumers prefer their own tailor-made cars becomes obvious, which brings a tremendous market impact on the monotony products under scale production. Based on provided original models by the manufacturers, consumers can freely select alternative configuration according to their own needs and preferences, such as color, interior, skylight, audio and so on [1]. Customized car products often mean that the different interiors are installed at positions specified by customers. This leads to the varying location and variety of sizes and shapes of hole-making on the automobile panels. Traditionally, the special press die of the automotive panels for mass production is very expensive. So, it is not suitable for the punching of customized car products. It is necessary to find a flexible and inexpensive method of making customized holes on automotive panels. In this context, the modular punching technology using punching unit is used, as shown in Fig. 1. It is that several punching units assembled by the plates at particular location are positioned together to punch hole. The location of the punching unit can be readjusted to adapt to different automotive panels, which brings this method with good versatility and adaptability. However, the location of the punching unit requires positioning manually, resulting in a poor positioning accuracy. If the punching units are closely positioned, they will interfere during the installation. That means the modular punching technology is not suitable for the punching of closely spaced holes. In addition, it is difficult to adjust the punching unit in the 3D space position flexibly, just suitable for flat punching, so it is not applicable to punch on the automotive panels in the 3D space. Due to good flexibility and low cost, industrial robots have been widely used in manufacturing fields in recent years [2]. For flexible making holes using industrial robots, most papers focus on drilling [3–5] using twist drill in aircraft manufacturing or medical surgery fields. However, the robotic drilling system is not suitable for making holes on automotive panels. Drilling is easy to generate burrs and edges on both sides of the position of holes on the automotive panels, which is not conducive to the installation of the car-interior, affecting the assembly accuracy. Additionally, because the presser foot unit and the drill bit in the drilling system both apply certain pressure to the automobile panel, coupled with the reason that the panel is generally a sheet of 0.5–1 mm, it is easy to deform during drilling, thus damaging the appearance of the panel. Based on the analysis above, by using punching technology and the industrial robot with good flexibility, a flexible robot punching system will be proposed for tailor-made automotive panels in this study.

The flexible robot punching system extends the application of the robot in automobile industry, especially, provides a new choice for punching thin-wall part and greatly reduces the time of adjustment for different parts or shape features. Gas-liquid supercharging technology [6] is adopted to improve the motion response characteristics, and the disadvantages of the traditional two-stroke-cycle stamping system are overcome. A developed punching plier mounted on the robot tool flange as the end-effector, whose core is the gas-liquid cylinder, synthesizes advantages of both the pneumatic cylinder and the hydraulic cylinder. The pneumatic cylinder provides fast drive; the hydraulic cylinder provides high punching pressure. In addition, compared with twist drill and milling cutter, punching plier is a complex 3D surface instead of a surface of revolution. Therefore, it is impossible to generate tool path using current methods for cutter with surfaces of revolution due to serious collision problem. In order to solve this problem, an interactive tool path

* Corresponding author.
E-mail address: gonghu@tju.edu.cn (H. Gong).

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Fig. 1. The modular punching technology using punching units.

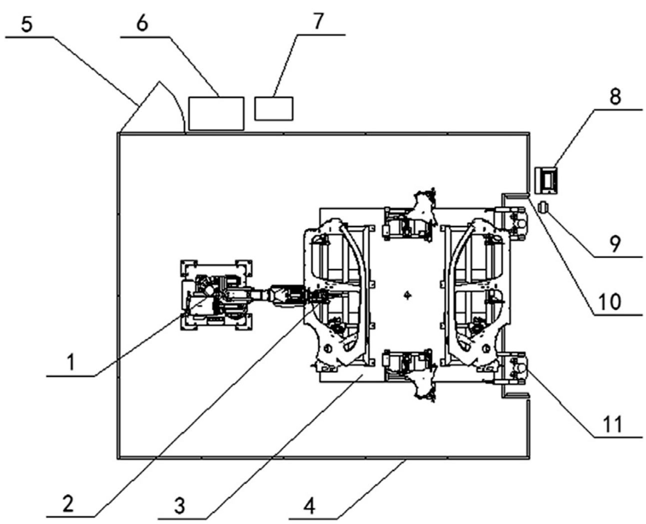

Fig. 2. Plane layout of the flexible punching workstation based on industrial robot 1. Robot 2. Punching pliers 3. Rotary table 4. Security fence 5. Safety door 6. PLC control cabinet 7. Robot control cabinet 8. Display screen 9. Button box 10. Safety grating 11. Workers.

generation method is proposed based on Siemens UG NX 10, according to the shape feature of punching plier.

2. Flexible punching system

2.1. General introduction of the flexible punching workstation

The flexible punching system using industrial robots for automotive panels is composed of industrial robot, punching pliers, high precision rotary table, protective device and control system (including PLC control cabinet, button box, and display screen). Plane and 3D layout are shown in Figs. 2 and 3. In the processing, two or four workpieces (automotive panels of compact cars and the SUV) can be fixed on the high precision rotary table with the pneumatic clamps, which can achieve the high repeat-positioning accuracy($\pm$0.02 mm) of the workbench with the help of the pneumatic locating pins. ABB IRB-6700 industrial robot is adopted.

Fig. 4 shows the diagram of control system. PLC control cabinet is the control core for the whole system. Mitsubishi PLC links to all the devices in different ways to open and close them as needed. The punching pliers, high precision rotary table, protective device and button box are linked to the digital input and output modules. Meanwhile, the display screen is linked to the PLC by RS232 bus. Good man-machine interface makes it convenient to set or display the parameters, which is based on the SIMATIC PANEL touch screen of SIEMENS Company, as shown in Fig. 5. We can set up the system running mode on the home page, as shown in Fig. 5(a), such as automatic operation, manual operation, single piece automatic mode and inching operation. Users can choose the different modes according to the actual situation and monitor the state of running system. For example, in the automatic mode, the screen can display the robot position, the real-time kind of workpiece being punched, rotary table real-time position and punching count, as shown in Fig. 5(b). It also can set counter of the waste collection box. When the counter reaches the limit, the waste collection box will be cleared. At the same time, the interface can also check system information, such as I/O information, alarm information, robot information and production statistics, in order to make the equipment maintenance and production planning easy. Users can view or modify the information, according to the different user permissions. PLC control cabinet communicates with the robot control cabinet by CC-LINK Field-bus in the system, which can save system wiring, and make maintenance and debugging easy.

2.2. The design of punching plier for industrial robot

It is easy to imagine that the punching plier should include four major parts: Stamping die, actuator, guideway and bracket. Actuator provides power to drive stamping die along the guideway. One option for actuator is to use servo-motor. It is gaining more attention in both industrial and household appliance manufactures because of its high efficiency, high power density, high torque, low inertia, less noise, compact form, salient operation and reliability [7]. But it need position feedback to control the punching position, otherwise, punching sooner or too late will contribute to the vibration of the punching plier, which may reduce the life of the stamping die, easily cause the overload of the motor and can't guarantee the processing quality. So position sensor should be integrated into this system. But adding position feedback will increase the cost and makes it more complex, which is not convenient for equipment maintenance. The other option for actuator is the pneumatic cylinder or the hydraulic cylinder. While, the former is convenient to get the power source and has a low cost, but it has a poor stability of the working speed because of the compressibility of the air, a bigger volume and a lower working pressure. The latter can achieve a high working pressure with a small volume and a high rigidity [8], but it has a high cost of the installation and maintenance and has the trouble of the rise of the oil's temperature, which may cause the leakage of hydraulic oil due to the thermal deformation of the seals. In this study, a gas-liquid actuator is adopted, which synthesizes advantages of both the pneumatic cylinder and the hydraulic cylinder, as shown in Fig. 6.

The gas-liquid pressure cylinder is an actuator which can change the smaller input pressure into the bigger output pressure. It uses the ratio of piston area to piston rod area, which is also the pressure ratio. The principle is that the pressure will rise with the pressure area decreasing when the pressure force is changeless. So it can realize the effect that the output pressure will increase the number of times. The simulation results using AMESim software showed that, the moving speed and the output force of the gas-liquid pressure cylinder can meet the requirement of die-punching press. [9]

Fast forward stroke and gas-liquid conversion function are added for this punching system and a three-punching-stroke system is designed instead of the traditional two-punching-stroke system. The working principle is shown in Fig. 7. In detail, it includes:

2.2.1. Fast forward stroke

The main control valve works and the air enters into the cavity B through the port P2. The hydraulic fluid flows into cavity C and the air exhausts from the port P1. Finally, working piston 2 pneumatically drives the terrace die to move fast and softly until approaching the surface of workpiece.