Design of Mechanical Structure of Punch Feeding Manipulator

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Abstract. In this paper an automatic feed manipulator for automobile stamping is introduced. It can achieve the process cycle for various cars parts manufactured such as automatic grab, loading and blanking, which is suitable for the large quantities and small mechanical parts material process. The primary purpose of this article is to present the manipulator structure and to design the virtual prototype of the manipulator. The calculation and optimization of stress and strain are carried out for the robot key moving parts by the analysis of the movement process and sport principle. Compared with the multi-joint robot, its manufacture, control requirements and the cost are low. The robot is suitable for large quantities and small parts process.

1. Introduction
In cars production, many different parts need to be sent to the machine tools and then to be offloaded after finishing processing. But it needs large working space, operating difficulties and poor security for some heavy and huge metal stamping parts. The robot cooperates with the machine tool on the numerical control machine tool replacing manual operation. Under the premise of balance control ability and function requirement, the design realizes all the process for small auto parts production like grabbing, loading and blanking. It also applies to the large quantities and small mechanical parts material process such as automobile transmission gear, brake disc, metal stamping parts etc, making for reducing enterprise investment cost and improve competitiveness.

2. Design of Feeding Manipulator
In order to increase the stability and fulfill the irregular auto parts requirement, the design added an axis on the four axis cylindrical coordinate robot. From the analysis of all the coordinates’ structure and the manipulator’s freedom analysis, the five axis cylindrical coordinate manipulator met the requirements of flexibility and simple controller. In general, three compartment car’s door sheet metal weight about 10kg. And according to the different shape and size, the brake disc weight about 6kg to 15kg. But ordinary, the car sheet metal weight about 25kg. According to the above date, the maximum load of the robot was set to 30kg in order to the cost savings of handling most parts. Its technical indicators are shown in table 1.
Table 1. Table of main technical parameters

| Project | Parameter |
|---------|-----------|
| J1 axis | Ball Screw+ Linear Guide, Travel of 400mm, Rated Running Speed of 0.7m/s |
| J2 axis | Servo Motor + Reducer, Rotating Range of ±135°, Rated Speed of 30r/min |
| J3 axis | Servo Motor + Linear Slide, Stroke of 800mm, Rated Speed of 0.7m/s |
| J4 axis | Belt Drive + Reducer, Rotating Range of ±135°, Rated Speed of 30r/min |
| J5 axis | Servo Motor + Reducer, Rotation Range of 360°, Rated Speed of 30r/min |
| Biggest negative heavy | 35kg |
| Repeat precision | ±0.2mm |

Figure 1 is Schematic diagram of the new economic type automatic feeding manipulator. Its include frame, lead screw, three servo motor, flange plate, speed reducing motor, gear synchronous belt transmission mechanism and PLC control device. Three servo motors were fixed on the machine frame to control the manipulator to horizontal movement and vertical movement by linear guide rail and straight line cross guide rail through screw driver and gear wheel driver.

![Figure 1: Schematic drawing of the feeding robot](image)

1-The first shaft motor; 2-Linear guide rail assembly of the first shaft; 3-The second shaft motor; 4-The second shaft reducer; 5-The third shaft motor; 6-The third shaft belt drive linear guide rail assembly; 7-The fourth shaft motor; 8-The fourth shaft belt drive assembly; 9-The fifth shaft motor; 10-The fifth shaft flange; 11-Hollow shaft

Figure 1. Schematic drawing of the feeding robot

Specific working principle is:

First, the manipulator puts up the work piece. Then, the first shaft motor drives the ball screw to rotate, so that the entire second shaft motor, the hollow shaft and the like are upward moving in other that the work piece is grabbed by a certain height.
The third shaft motor drives the third shaft belt drive linear guide rail assembly backward movement through synchronous belt wheel drives, so that the mechanical arm together with the work piece to shrink.

The second shaft motor drive the whole hollow shaft above the parts rotate to move the work piece. The fourth shaft motor can rotate the fifth shaft motor through the belt drive. And the fifth shaft motor can rotate to change the direction of mechanical arm. With the cooperation of the two motors, the robot can turn and rotate the work piece in order to achieve the desired attitude.

The second shaft stop after reaching a certain position, the third shaft manipulator arm out reached the desired position and the first shaft moves downwards in order that the work piece into the machine. Let it go and return to the starting point of work piece. This is finished the loading once. And follow this cycle to work. The principle of the blanking is also so analogy.

After mounting on a manipulator of vacuum adsorption, this design can be used for the smaller car sheet metal production. Such as white body door, roof cover, head cover sheet metal, etc. If mounted on a special fixture gripper, it can be used for other auto parts of the production line. Such as gear wheel, hub, friction disc, etc.

3. schematic drawing of the feeding robot
In order to make the structure more compact in the overall structure, the second shaft motor and the third shaft motor were installed in the center axis, the fourth shaft motor was installed in the opposite direction to drive the fourth shaft by belt drive. At the same time, the rotation shaft was set as second shaft. The robots just needed to drive the third shaft above the rotating component. To the robot have a better stability, it reduced the moment of inertia to the lowest when the mechanical arm is rotated and the fourth shaft motor balance out a small part of the radical force. The third shaft was set as motor controlling motion along a linear guide rail. It eliminated all kind of disadvantage about driving the third shaft by hydraulic cylinder. In the control line wiring of the moving parts, for the electrical control line did not wrap around the parts we adopted the tank belt type.

Firstly, we chose servo motor model 152G1 MHME high inertia three-phase permanent magnet synchronous AC servomotor as first shaft motor. Secondly we chose 5AZG1 MHME high inertia three-phase permanent magnet synchronous AC servomotor as the second and three-shaft motor. Thirdly we chose 022G MHMD servomotor as the fourth and five-axis motor. The selection of the main controller PLC Control Engineering Co. Ltd. produced DCCE network Dalian computerized programmable controller PEC6600. The selection of servo motor controller for the delta ASDA-B2 series was an open type servo driver. Power supply selected the PMT series tablet type industrial power supply as well as 220V power supply. Touch screen type selected Kunlun Beijing state automation software technology Co., Ltd. TPC7062 touch screen. Figure 2 is the manipulator’s virtual prototype.
1. The first shaft assembly; 2. The second shaft assembly; 3. The third shaft assembly; 4. The fourth shaft assembly; 5. The fifth shaft assembly; 6. Control cabinet

Figure 2. Virtual Prototype of Punch Feeding Manipulator

**4. Stress Analysis of Key Operating**

Third axis robot arm had huge force in the fulcrum, end of manipulator may appear relatively large deflection. It would appear unnecessarily shift and jitter when the grab lifted work piece and even leaded to the mechanical arms breaking off. Compared with 2018 aluminum alloy and Q390 low alloy high strength structural steel, the third axis mechanical arms had finite element analysis with the strain diagram shown in Figure 3. We made a tentative to use 2018 aluminum alloy for mechanical arm material and end of manipulator was under 350N pressure. By using finite element analysis with SIMULATION, the stress and strain for the mechanical arms could be obtained directly, such as the aluminum alloy’s mechanical arm of the stress diagram shown in Figure 4 and aluminum alloy’s mechanical arms of the strain diagram shown in Figure 3.

Using Mises equivalent stress to check was suitable basin than using the third strength theory. It followed the fourth strength theory of material mechanics (shape change theory).
Some conclusions can be drawn from analysis graph 3. End of manipulator’s maximum deflection by 2018 Aluminum Alloy was 4.498 mm. It was really detrimental for mechanical arms, due to excessive displacement caused the starting point positioning, there would be shaking problem. So the 2018 Aluminum Alloy did not meet the stiffness requirement of this manipulator.

After recalculating, used Q390 low-alloy structural steels as material of mechanical arms. Equivalent yield stress of the steel was larger than the aluminum alloy and satisfied the strength requirement.

Strain analysis was shown in figure 4 for structural steel mechanical arm strain diagram. As the figure shown, the maximum deflection was 1.58 mm, two times smaller than before in the acceptable range. So three axis mechanical arms decided to make from Q390 low-alloy structural steels.

![Figure 4. Strain diagram of structural steel manipulator](image)

By the finite element method, the manipulator and the slider strength of screw had been calibrated, the position of mechanical arm was fixed like Figure 5, and it was fixed with six screws. After installing screws, we got the stress diagram of bolt of manipulator in figure 6.

As shown in picture 6, inner six angle screw called M6 under the maximum stress was 117.581mpa,
the safety factor was 2 and the materials needed to use tensile strength greater than 235.16mpa. So we used No. 15 steel screw after normalizing, of which tensile strength was 355MPa and enough to connect piece as a mechanical arm. In light of this, the manipulator was fixed with six screws, the end of manipulator stress 350N pressure and the safety factor was 2 times. Using M6 six angle screws making from No.45 steel fixated could meet the requirements.

Figure 6 Stress Diagram of Screw Hole of Manipulator

5. Conclusion
According to analysis, the experimental results indicate that various parts of the five - axis automobile stamping machine tool for loading and blanking manipulator can meet the design requirements. It use PLC control system, move most of the lightweight car parts as well and the feed - in and feed - out materials precisely between material table and machine tool. At the same time, it’s allowed to adjust the form of parts as well as fulfilling all kinds of flip and rotation requirements in production.

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