Research on Design and Application of Automatic Production Line for Mechanical Components

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Abstract. In order to meet the requirements of automatic processing for mechanical components manufacturing enterprises, the paper describes a design method of automatic production line. Firstly, the paper made the overall design of the automatic production line, takt time is calculated according to the annual production demand, and the analysis of device configuration and position layout of the production line was carried out based on the annual production requirement. Secondly, the paper selects types of CNC machines and industrial robots, and design structural of the silo, the temporary storage platform, the conveyor belt, the fuel injection and water removal. 3D model of each component and space layout of the production line are drawn by Solidworks software. Thirdly, the process flow of automatic production line was designed, and the CNC intelligent management system was developed to meet the requirements, which can monitor the process information such as takt time. Test is carried out after establishment of automatic production line, the test run finally shows that the automatic production line works stably and can meet the requirements of enterprise.

1. Introduction
With the development of automation technology and the gradual growth of labor costs, more and more enterprises pay attention to the automation of production processes. In order to improve the efficiency and stability of production, shorten production cycle and reduce product cost, automatic production lines are under establishment. The automatic production line mainly includes CNC machine tools, industrial robots, fixtures, conveying equipment and so on. The PLC takes the general control to realize the automatic process of the entire production line. The paper gives the design and establishment of automatic production lines which take the actual processing needs of the company into consideration.

2. Design Method of automatic production line
The main works in designation of automatic production line include: the identification of takt time, the calculation of required work sites and equipment, the determination of the number of workers, the designation of the conveying method, the layout of production line, and the designation of production line process. After trial operation, make the comprehensive evaluation of the designed automatic production line [1].
First of all, the overall design scheme should be made, it is the most important part in designing and manufacturing process of the entire production line. The overall design scheme plays a decisive role in takt time, production efficiency, operational reliability, cost, designing and manufacturing cycle, which would determines whether the entire production line succeeds or not.
Secondly, select types of CNC machine tools and industrial robots, design the layout and PLC control systems of production lines. Based on the requirements of work site for robot, such as load, accuracy, working radius and speed, combine with the cost performance to select the type and model of the industrial robots.

Thirdly, the fixtures and various positioning devices are designed based on the structure and processing technology of products. The PLC control system designed to make the cooperation between the robot and other components smoothly to realize automatic production. Use the simulation software to measurement the effect of the entire automatic production line, and continuously optimize based on the results.

And then, put the assembly of all components through a test to complete the construction of the whole automatic production line.

There are some problems should be paid attention to in the designing process of the automatic line. For example, the related processes should be placed in a centralized manner to make the automatic production line run smoothly, the layout among all components should be put relatively compact to avoid crossovers in the process. To ensure takt time, the resource allocation and rate in the various processes of automatic production line should be controlled as balanced as possible, the layout should be also optimized to make full use of space, the future upgrade of the production line should be take into consideration, the interfaces needed to be reserved to make the production line flexible that can be suitable for many varieties production [2].

3. The overall design of the automatic production line

3.1 Analysis of automatic production line takt time

Takt time refers to the time that takes to produce one part on average from the automatic production line, we can optimize the production process and improve production efficiency by intergrating the automation line in the basis of desired takt time [3].

Production line takt time is calculated as

\[ R = \frac{T}{Q} \]  

(1)

In formula (1), R refers to the takt time, T refers to the planned effective working time, and Q refers to the planned product output.

\[ T = T_1 \times K \]  

(2)

In formula (2), \( T_1 \) refers to the planned working time, taking into account the impact of other factors on working hours, K is the working time utilization factor, and \( K \leq 1 \).

The takt time expected for the automation line can be calculated by the planned annual production and the effective working hours for enterprise, that means how much time one part takes would meet the annual output of the enterprise.

3.2 Overall configuration analysis

Based on the actual processing needs of enterprise, the automatic production line consists of two six-axis robots, four CNC machine tools, one set of three-in-one quality inspection stations, one set of two-in-one quality inspection stations, and one set of 32-position dot matrix fixed. The silo is composed of a conveying device and a dewatering equipment. Two industrial robots load and unload four CNC machine tools. Spot check every 10 parts processed, and the parts that are inspected are put into the sampling table by industrial robots. The silo is a pallet with a uniform structure to ensure the center position of the workpiece is consistent. The de-water injection equipment is equipped with a hot air system, which can quickly dry parts and is equipped with an automatic oil-passing system to make the workpiece covered with anti-rust oil. In addition, it is equipped with CNC intelligent management system, which can monitor the processing parameters of the production line. The screen can display the operating parameters of the equipment, processing capacity, such as basic data, equipment failure,
number of workpiece processing, pass rate, takt time, downtime, etc. It’s convenient for real-time monitoring and management.

4 Design of automatic production line components

4.1 Select the type of CNC and robot

The CNC machine tool is the machining center of automatic production line. When selecting the model, the factors such as comparison accuracy, spindle power and maximum spindle speed should be integrated. The practicality, economy, operability, stability and openness of the interface should also be considered. the vertical lathe was selected and the FANUC CNC operating system was adopted in the paper [4].

The industrial robot is an intelligent unit of automatic production line. It mainly undertakes functions such as loading and unloading, and its performance affects the processing quality of the workpiece and the takt time of the production line.

The maximum load, maximum working radius and degree of freedom of the robot are important factors to be considered in the selection of industrial robots. One industrial robot is loading and unloading for two CNC machine tools in this automatic production line, Selected 6-axis industrial robots based maximum rotation angle and working radius of each axis of the industrial robot., with a wrist load of 20KG and a forearm load of 10KG. The maximum rotation is shown in table 1 [5]. Figure 1 is the three-dimensional model of robot.

| Joint | Joint Speed | Joint Angle |
|-------|-------------|-------------|
| J1    | 170°/s      | ±165°       |
| J2    | 170°/s      | +155°~90°   |
| J3    | 152°/s      | +75°~200°   |
| J4    | 350°/s      | ±360°       |
| J5    | 333°/s      | ±120°       |
| J6    | 600°/s      | ±360°       |

Figure 1. Three-Dimensional model of robot

The movement of the industrial robot is controlled by the teach pendant, and the basic motion of the robot is realized by interpolation commands such as MOVJ/MOVL. The robot loading and unloading program instruction is used as a subroutine. In the paper, the working mode of the robot is divided into manual mode and automatic mode. The robot in the manual mode can only manually control the robot to execute each motion program through the teach pendant. The robot in the automatic mode is triggered by the PLC to trigger the robot main program to call the relevant motion subroutine to complete the automatic operation of the robot.

4.2 Design of peripheral parts

The silo is a split double-layer structure, which can be placed with two layers of processed parts. When the processing of one side of the tray is completed, the handle can be pulled to move the silo out
of the working range of the robot, and the material is manually loaded again, so as to ensure personal safety and convenient to fill material.

The silo contains an inductive switch, and the alarm is working when the material on the tray is empty.

There are two trays, 16 discs in a single disc, for a total of 64 workpieces.

When the robot changes the workpiece, four-station temporary storage station store the processed workpiece, wait for the mechanical hand material to be completed, and then pick up the processed workpiece for the next step.

The robotic gripper has a toothed adjustable structure for easy adjustment of specifications. The end of the robot is equipped with a laser detecting device. The detecting device is mounted on the hand to avoid contamination of the sensor by the cutting fluid of the machine. The sensor is placed outside of the machine during processing. The beating of the low-speed rotating blank on the machine tool is detected, the machine is closed when jump detection is OK, and the robot takes out the blank into the defective storage table when jump detection is NG. Figure 2 is three-dimensional structure model of robotic gripper.

Two-in-one storage station is used for store the defective products and sampling products, it contains a sensor switch. when the workpiece is full, the alarm will work to prevent the robot from colliding.

The conveyor line is transported in the form of a double speed chain to meet the workpiece caching function, and the water such as cutting fluid can be dropped to the water tank to ensure the parts quickly remove moisture. It includes pusher mechanism, sensing device, 180° turning mechanism and filter cleaning tank.

Dewatering mechanism is used for drying workpieces, the first process uses air knife to form air curtain, the second process uses high pressure gas, and the third process uses hot air drying and evaporation, to ensure that the parts have no water residue, and then spray. It includes upper and lower fuel injection mechanisms, which have the fuel nozzles on the upper and lower layers of each of the six circumferences to ensure that the surface of the parts are covered with oil film the air knife generator and the movable baffle and so on. The fuel injection mechanism is installed before and after to prevent the oil mist from drifting out. After the baffle is lowered, the fuel injection starts, the fuel injection ends to open the baffle. Dewatering mechanism model as can be seen in Figure 3.

Figure 2. Structure model of robotic gripper

Figure 3. Dewatering mechanism model
4.3 CNC intelligent management system

The paper developed a CNC intelligent management system. The daily business volume of system is 10000 times each day, and the maximum response time is less than 2 seconds, daily inquiry is less than 10 seconds, report inquiry is less than 15 seconds, batch inquiry is less than 30 seconds. The number of concurrent users is 50, and the maximum number of online users is 500. It can meet the actual needs of industrial site [6]. Table 2 is main functions of CNC management system.

Table 2. Main functions of management system

| NO. | Module                | Main Function Point                                                                 |
|-----|-----------------------|--------------------------------------------------------------------------------------|
| 1   | System management     | system login, user management, rights management, log management, maintenance of various prompt information |
| 2   | Basic data management | Production line data, personnel configuration data, shift data maintenance; production work order data, equipment status data, etc.; equipment alarm data, equipment parameter abnormal data, equipment process slice analysis data, etc. |
| 3   | Status monitoring management | Real-time monitoring of different states such as power-on, power-off, alarm, and standby. |
| 4   | Production statistics management | Provides the corresponding processing quantity data under different program number conditions of the equipment. |
| 5   | Parameter monitoring management | Device parameter abnormal statistics, status monitoring, device parameter critical settings |
| 6   | Equipment Efficiency Analysis | Equipment CT and Equipment Availability UT Monitoring |
| 7   | Production slice analysis | Equipment time composition analysis, including different state slices such as fault, wait, edit, run, etc. |
| 8   | Production quantity statistics | Equipment output is based on the number of program numbers, and provides interfaces and work orders for docking. |
| 9   | Equipment fault management | Equipment fault code collection and time statistical analysis |
| 10  | DNC management        | Device program preview, program upload, download, comparative analysis and other services |
| 11  | Interface             | Receives automatic scanning of device data, receives status of processing equipment, receives tool status result determination of processing equipment, equipment processing result/device information system reception, spindle load reception |

5. Processing technology of production line

The operator puts the blank material into the silo in turn, and the robot 1 grabs the billet from the silo and put into the CNC machine tool. The air gun on the robot blows the iron scrap on the tooling, then puts the blank material into the tooling, and the spindle rotates at a low speed to carry out runout detection, if runout detection is unqualified, the robot 1 moves the blank to the defective product temporary storage station, and re-takes the blank from the silo into the machine tooling. If the runout detection is qualified, it will be put into the machine tool 1 for processing, and the safety gate will be closed automatically by the PLC control, and CNC will start machining.

When the workpiece processed is finished, the safety door is opened automatically, the robot 1 takes out the workpiece, puts it into the cleaning pool 1 and shakes it cleanly, and the safety door closes automatically, the machine tool turret out of the chip cleaning tool, and then opens the safety door automatically.

1PC is sampled when 10PCS are processed, and the robot 1 moves the sampled product to the sampling station 1, and manually returns the transfer conveyor body after the inspection. When the workpiece is cleaned, the robot 1 puts it into the transfer conveyor line for transmission and automatically completes the flip.

And then the robot 2 picks up the workpiece from the transfer conveyor and puts into the machine tool. The workpiece is close to the air gun blown in the machine tool. The air gun on the robot first blows...
off the iron filings on the tooling, and then puts the blank into the tooling, forging and pressing, the machine tool starts processing. When the workpiece processed is finished, the safety door is opened automatically, the robot 2 takes out the workpiece, puts it into the cleaning pool 2, and cleans it. At the same time, the safety door is closed automatically, and the machine tool turret out of the chip cleaning tool, and then opens the safety door automatically.

1PC is sampled when 10PCS are processed, and the robot 2 moves the sampled product to the sampling station 2, and manually returns the water-injection device after the inspection. When the workpiece is cleaned, the robot 2 puts it into the water spray injection device. After the workpiece is sprayed, it automatically slides to the blanking position, and then manually checks the appearance of the finished product. The operator sequentially puts the finished product into the finished product frame if it’s no problem. Now the entire production processing process is completed.

6. Conclusion
Using Solidworks software to draw the structure of each part and layout of production line, coordinate the placement of four vertical lathes, two robots and conveyor lines within the working radius of the robot. Production line works well through solidworks simulation. The actual automatic production line is set up according to the design program. After a period of trial operation, the automatic production line works well and meets the requirements of enterprise. Provide a solution for the design of mechanical automatic production lines.

7. References
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