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Research on Automatic Detection Equipment for Pulling Force of Slender Metal Wire

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Abstract

The current process of detecting the pulling force of slender metal wires is time-consuming, labor-intensive, and inefficient. By exploring the design of automatic feeding modules, automatic posture adjustment modules, fixed distance fork separation modules, and multi wire automatic pulling modules, an automatic plastic pulling force testing equipment has been built, which has increased efficiency by more than 4 times and greatly reduced labor intensity.

Keywords

Thin and Long Foot Wire Pull-Out Force Testing Module Design, Automatic Testing to Improve Efficiency

1. Introduction

Plastic plugs are important components in the ignition assembly of electric detonators. The main function of plastic plugs is to transmit external current through wires to the bridge wire, triggering the combustion of gunpowder. Plastic plugs are mainly composed of metal wire (enameled copper wire) and cylindrical plastic. Its structure is shown in **Figure 1**. The wire and cylindrical plastic are connected by thermosetting plastic molding. In order to ensure the reliability of plastic plugs, it is necessary to check whether the wire (enameled copper wire) and cylindrical plastic are firmly connected. The detection method is to fix the cylindrical plastic and pull the foot wire with a certain amount of tension. By checking whether there is displacement between the foot wire on the end face of the cylindrical plastic and the cylindrical plastic, it is determined whether the product's pulling force detection is qualified [1]-[3].

The current process for testing the pulling force of plastic plug components is as follows: the operator separates the foot wires, places them into the testing fixture, clamps one of the foot wires with a pointed pliers, slowly pulls it with force to move it to the end of the groove, and repeats this action until each foot wire completes the pulling force testing. The testing fixture is connected to a 2 kg weight through a fixed pulley to achieve constant pulling force. The pulling force testing is shown in **Figure 2**.

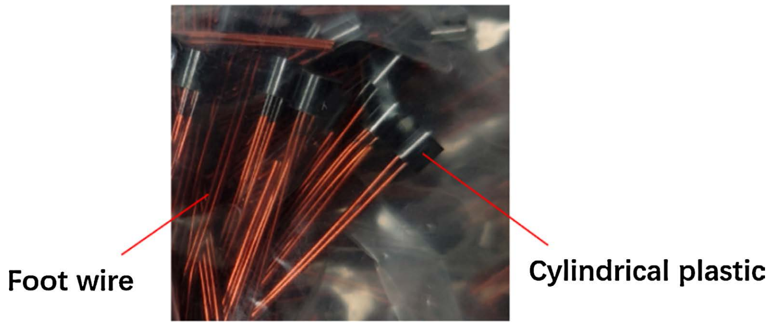


Figure 1. Schematic diagram of plastic plug.

Figure 2. Current pulling force test equipment diagram.

The current pull-out force detection mainly has the following shortcomings:

1) The distance between the foot wires is very close, and manual splitting of the foot wires is required, which is time-consuming and laborious.

Due to the fact that each plastic plug is composed of multiple wires, and the distance between the wires is close, it is difficult to directly conduct tensile testing. Therefore, before conducting tensile testing, the wires must be forked.

2) The large quantity of plastic plugs results in low efficiency of current testing fixtures, making it difficult to meet production needs.

There are a large number of products that require hundreds of thousands of pulling actions, and manual pulling is labor-intensive. Moreover, the current tooling is in disrepair and the usage is extremely difficult. The average testing time for each four legged wire plug is about 45 seconds, and the detection efficiency is low. When the task is urgent, overtime is often required to complete the task.

3) The drawing data is not recorded, and the traceability is poor.

The plastic plug components are tested by manual pulling force, and each plastic plug is not numbered and marked, making it impossible to record the test data. If there are missing detections or other situations that cannot be traced, there is a certain risk.

In response to the above issues, this article designs and develops an automatic detection device for plastic plug pull-out force by designing modules for automatic feeding, automatic posture adjustment, fixed distance fork separation, and multi foot wires automatic pull-out force detection of plastic plug wires. The device improves detection efficiency and reduces labor intensity.

2. Methods

2.1. Determination of Research Subjects

At present, the diameter of the cylindrical plastic end and the spacing between the foot wires are also different among various products in the factory. The diameter of the cylindrical plastic end is mainly divided into two types: φ 6.00 mm and φ 4.50 mm, and the spacing between the foot wires is mainly divided into two types: 1.50 mm and 1.20 mm. The number of foot wires is divided into two types: 2 and 4, as shown in Figure 3.

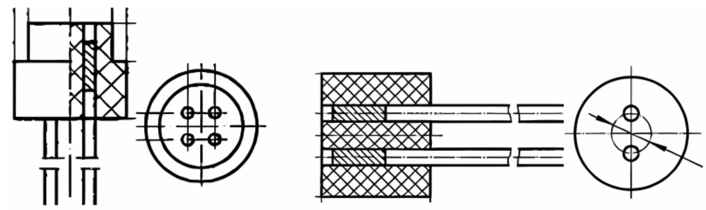


Figure 3. Schematic diagram of plastic plug mechanism.

Statistical analysis of typical products in the factory shows that the end diameters and foot spacing of various products are different, but their structures are consistent. The specific parameters are shown in Table 1.

Table 1. Parameters of four types of plastic plugs.

Serial Number	Product code	Foot wires spacing (mm)	End size (mm)	Weight (g)	Number of Foot Threads (Root)
1	A	1.50 + 0.15	φ6.00	0.75	4
2	B	1.50 + 0.15	φ6.00	0.68	2
3	C	1.50 + 0.04	φ4.50	0.50	2
4	D	1.20 + 0.15	φ4.50	0.54	4

2.2. Composition of Modules

Based on the current process of testing the pull-out force of plastic plugs, it is known that in order to achieve automation of the pull-out force testing process, it is necessary to implement functions such as automatic feeding of plastic plugs, automatic fork separation of foot wires, automatic pull-out of foot wires, and automatic recording of test data. With this goal in mind, modular design has been carried out for each functional part, and the design of each module is as follows.

2.2.1. Design of Automatic Feeding Module

1) Requirement sorting

The incoming status of plastic plugs is batch packaging in plastic pockets, with an overall chaotic sorting, as shown in Figure 4. In order to achieve automation of the plastic plug pull-out force testing process, it is necessary to turn the disordered incoming materials into neatly arranged ones.

Figure 4. Schematic diagram of incoming plastic plugs.

2) Module composition

Through analysis of various types of plastic plug mechanisms, it was found that the four types of plastic plugs have the same structure and their weight is concentrated at the cylindrical plastic end. Therefore, plastic plugs are suitable for automatic feeding using vibrating material trays. Based on this, an automatic feeding module was designed. The automatic feeding module mainly consists of vibrating material tray, plug positioning seat, fiber optic sensor, vibration controller, guide groove, etc. The structure is shown in Figure 5.

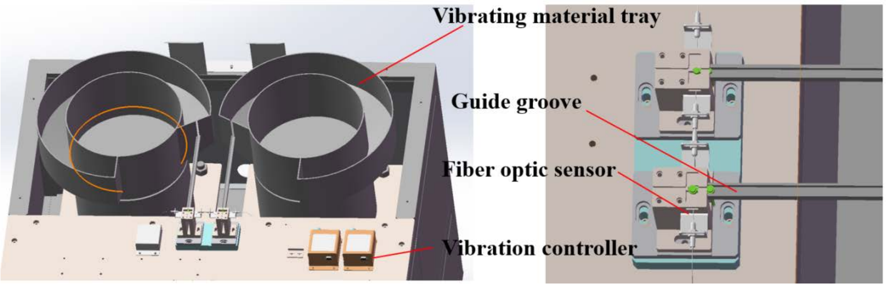


Figure 5. Schematic diagram of automatic sorting structure of vibration disc.

3) Working principle

The operator places the plastic plugs packaged in batches into the vibrating tray, which vibrates at high frequency. The plugs are arranged in an orderly manner into the guide groove, which is inclined at a certain angle to the plug positioning seat. After reaching the end of the guide groove, the plastic plugs can smoothly slide into the plug positioning seat. The fiber optic sensor can detect whether there is a product on the plug positioning seat for subsequent clamping of the gripper.

2.2.2. Foot Wires Automatic Posture Adjustment Module

1) Requirement sorting

Due to the cylindrical shape and multiple foot wires of the plastic plug, in order to ensure consistent feeding status of the plastic plug, in addition to ensuring consistent position of the cylindrical plastic end, it is also necessary to ensure consistent angle of the foot wires. The vibrating material tray can only achieve consistent position of the cylindrical plastic end, but cannot guarantee consistent angle of the foot wires. Therefore, it is necessary to design a foot wire automatic adjustment module to adjust the position of the foot wires.

2) Module composition

There are two ways to identify the position of the foot wires: one is side recognition, and the other is top-down recognition. However, due to the black paint layer at the root of the foot wires and the consistent color of the plastic end, as well as the random bending of the foot wires in its natural state, it is difficult to accurately identify the position of the foot wires through side recognition. On the other hand, the top end face of the plug is polished to make the position of the foot wires clear, and the color difference between the foot wires and the plug end is obvious. Therefore, top-down recognition is adopted, as shown in **Figure 6** [4] [5].

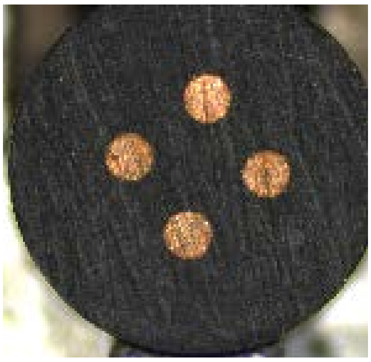


Figure 6. Top view schematic diagram of plastic plug.

From the above analysis, it can be concluded that the process of automatic adjustment of the foot wires should include two processes: visual recognition of the foot wires position and automatic adjustment of the foot wires posture. Based on this, a foot wires automatic adjustment module is designed. The automatic posture adjustment module for the foot wires mainly consists of a cross module, a rotating gripper, and a visual camera, as shown in **Figure 7**.

3) Working principle

The cross module adjusts the position of the visual camera to the top of the plug positioning seat, and the visual camera performs image acquisition to determine the position of the foot wires in the current state. The coordinates of the foot wires are calculated, and the deviation angle is determined by comparing the current coordinates with the target coordinates, thereby calculating the rotation angle of the rotating gripper and achieving automatic posture adjustment of the foot wires.

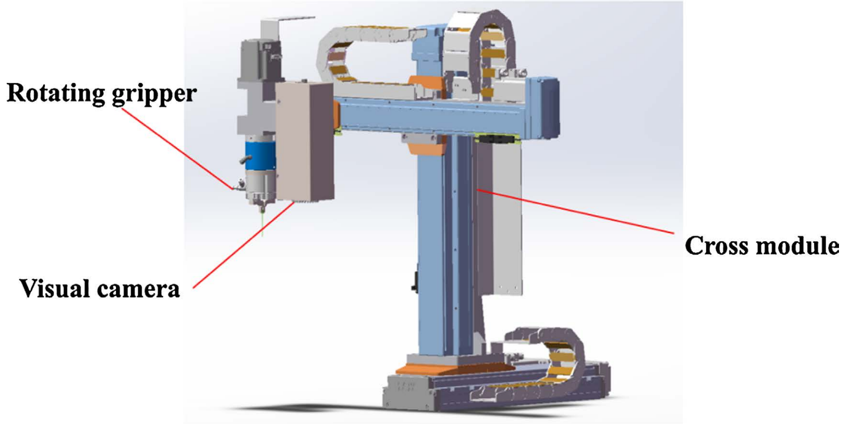


Figure 7. Schematic diagram of the structure of the foot wires automatic posture adjustment module.

2.2.3. Foot Wires Spacing Fork Module

1) Requirement sorting

Before conducting the pull-out force test, it is necessary to fork the adjusted foot wires to better clamp them. At the same time, in order to achieve automated pull-out testing, it is necessary to ensure that the fork separation distance of the foot wires is basically consistent.

2) Module composition

Due to the very close distance between the wires, custom pins are inserted between the two wires to achieve automatic foot wires splitting. The pins are designed with a conical shape, with the tip of the needle positioned and the conical part for pin splitting. The needle tip of the pin needs to be smaller than the distance between the wires, while the conical part should be larger than the distance between the wires. At the same time, analysis shows that the distance of foot wires splitting is mainly related to the downward pressure distance of the foot wires. Therefore, by controlling the downward pressure position of the plug, the distance between the wires is ensured to be consistent. The foot wires spacing fork module is mainly composed of the components of the plug, plug socket, base, and cylinder are shown in **Figure 8**.

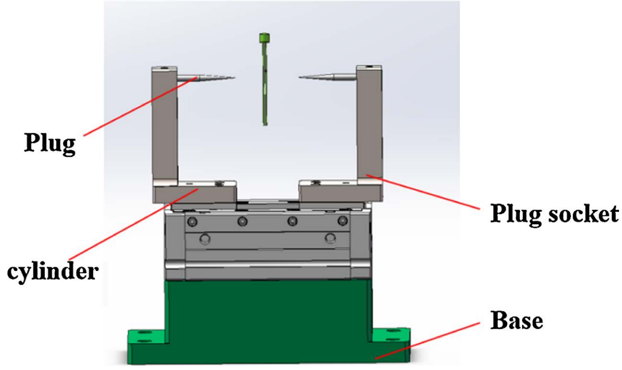


Figure 8. Schematic diagram of the structure of the fixed distance fork module for the foot wires line.

3) Workflow

The rotating gripper moves the adjusted plastic plug to the upper part of the pin, and the cylinder moves to insert the fork between the foot wires, achieving preliminary fork separation of the foot wires. The horizontal module moves horizontally along the tapered part of the pin, gradually fork separation of the plug foot wires. Finally, the vertical module adjusts the downward pressure distance of the plug, achieving fixed distance fork separation of the foot wires. The specific process is shown in Figure 9.

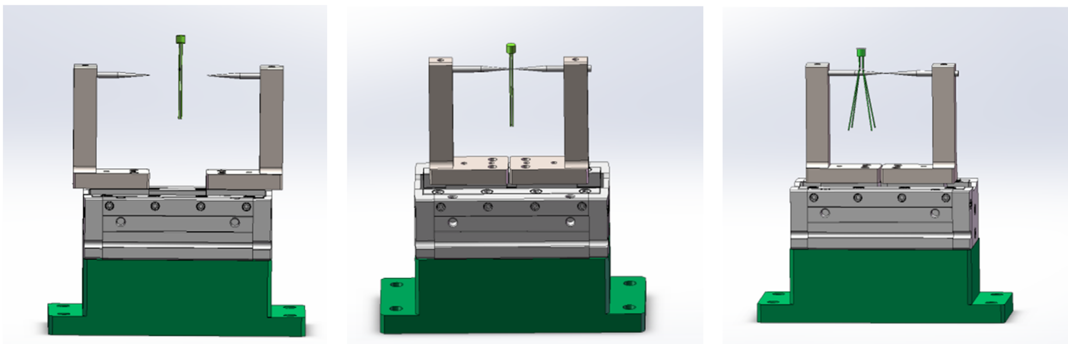


Figure 9. Schematic diagram of the process of dividing the foot wires with a fixed distance.

2.2.4. Multi Foot Wires Automatic Pulling Force Detection Module

1) Requirement sorting

After the fixed distance fork separation of the foot wires, it is necessary to perform a pulling force detection. Currently, manual pulling of each foot wire is time-consuming, laborious, and inefficient. Therefore, it is necessary to design a multi foot wire automatic pulling module to achieve automatic pulling of multiple foot wires, improve pulling efficiency, and reduce labor intensity.

2) Module composition

The current workshop adopts the method of connecting weights with fixed pulleys to achieve constant pulling force testing. In order to ensure that the process status does not change, a multi foot wire automatic pulling module has been designed based on the current testing method. The module is mainly composed of cylinders, screw guides, plug limit fixtures, mobile slides, weights, and position sensors, as shown in Figure 10. The cylinder is connected to the moving rail, and the four moving rails are independent of each other. The moving rail block is connected to the weight, and each rail is equipped with a separate position sensor to detect slipping and other phenomena. The linear module is connected to the plug limit fixture.

3) Workflow

The operator places the four forked wires into the guide holes (with the center to center distance of the guide holes matching the distance between the forked wires), and the plastic end is clamped on the plug limit fixture. The equipment is started, and four independent cylinders clamp it. The screw guide moves to drive the plug limit seat, which in turn drives the plastic plug to move, and then pulls the weight to achieve multi legged wire pulling force testing.

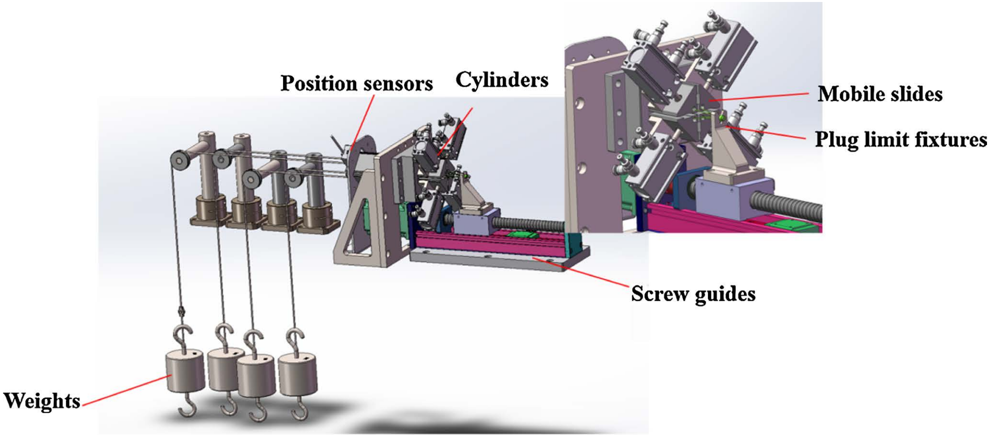


Figure 10. Schematic diagram of the structure of the automatic multi legged wire drawing equipment.

3. Results

3.1. Design of Automatic Detection Device for Pulling Force of Plastic Insertion Puller

3.1.1. Overall Design of the Device

Based on the design of each module in the previous text, an automatic detection device for the pulling force of plastic insertion and extraction was constructed as shown in Figure 11.

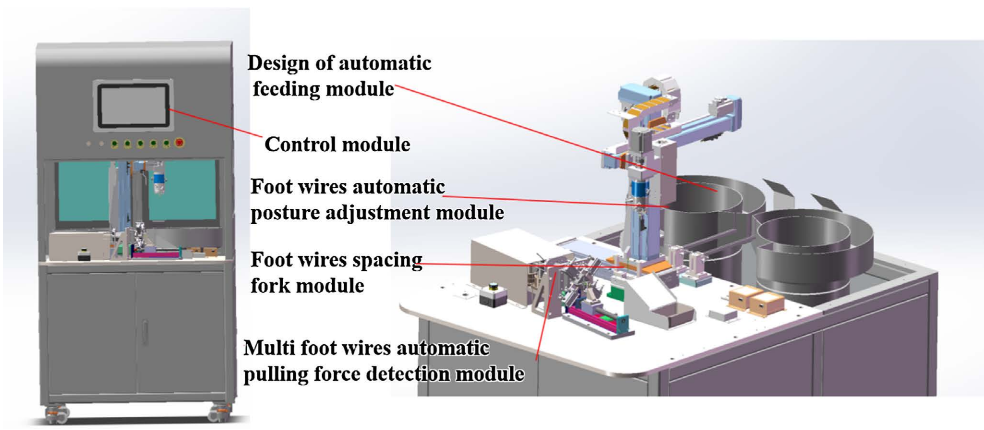


Figure 11. Schematic diagram of the overall structure of the device.

3.1.2. Design of Device Control System

The entire control system adopts PLC for logic control. In order to improve efficiency, the multi foot wires pulling force automatic detection module adopts independent control. The operator can automatically load and fork the test plug in advance. When performing the wire pulling force detection, only the forked plugs need to be checked one by one, greatly improving the detection efficiency. The overall process is shown in Figure 12.

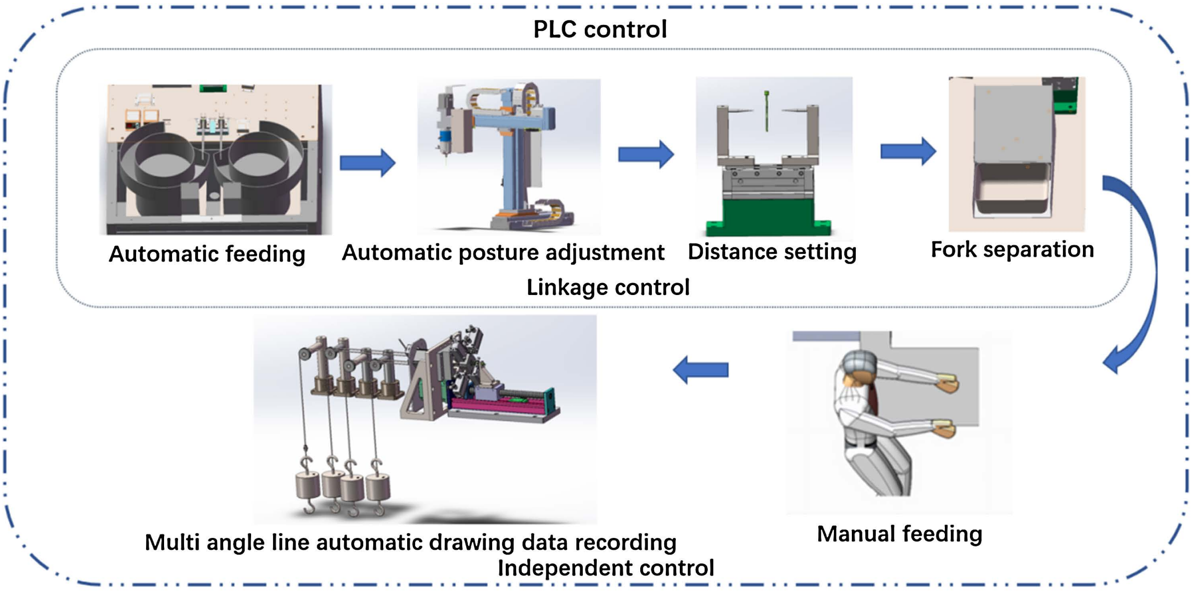


Figure 12. Schematic diagram of overall control flow.

The forked plugs are placed in the collection box, and the equipment is equipped with a counting function. The operator can set the number of plugs to be placed in one box. When the number reaches the limit, the operator will be reminded to replace the collection box. At the same time, the equipment is equipped with an abnormal alarm function. In case of abnormal situations such as plug jamming during the loading process, slipping during the multi foot wires pulling process, or missing measurement of some pins, the equipment can alarm and stop the machine, and prompt the operator.

3.1.3. Design of Automatic Recording of Detection Data

The plastic plug component adopts manual pulling force detection, and each plastic plug has no numbered mark, making it impossible to record the detection data. If there are missing detections or other situations that cannot be traced, there is a certain risk. In order to achieve data traceability and ensure no missing detections, it is necessary to achieve automatic data recording. Due to the simultaneous pulling of the four foot wires, it is necessary to ensure that each foot wire has undergone tension detection. Therefore, it is necessary to record the force situation of each foot wire. Since it is not possible to install tension sensors on the foot wire, it is necessary to confirm the tension situation from the side. Through analysis of the pulling force detection process, during the pulling force detection process, the foot wire moves with weights on the slide rail. If there is slippage or missing pulling, the slide rail and weights will not move with the foot wire. Therefore, by detecting the displacement of the slide rail or weight, it is possible to detect whether there is slippage or leakage. As the position of the slide rail is relatively fixed, position sensors are installed behind the four slide rails to detect the slide rail displacement in real time, as shown in **Figure 13**. If the slide rail does not move (clamping is unsuccessful or slips) during the tension detection process, the displacement sensor will trigger an alarm to remind the operator to perform the pulling force detection again. If successful, corresponding data will be recorded, as shown in Figure 14. This detection mainly records whether there is leakage or slippage during the pulling force testing process. After detection, whether there is displacement between the foot wire and the plastic plug needs to be manually detected with the naked eye.

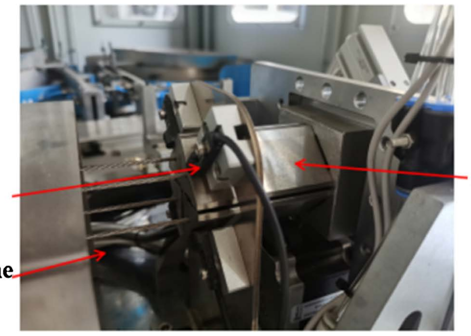
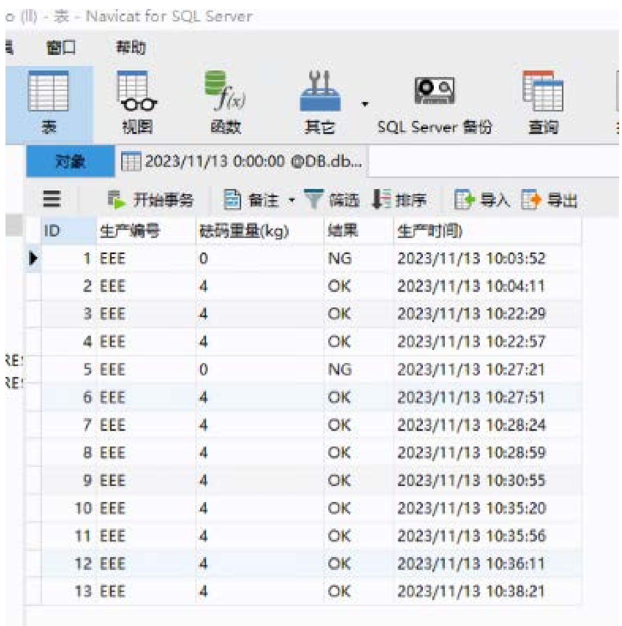


Figure 13. Schematic diagram of slider displacement detection.



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3	EEE	4	OK	2023/11/13 10:22:29
4	EEE	4	OK	2023/11/13 10:22:57
5	EEE	0	NG	2023/11/13 10:27:21
6	EEE	4	OK	2023/11/13 10:27:51
7	EEE	4	OK	2023/11/13 10:28:24
8	EEE	4	OK	2023/11/13 10:28:59
9	EEE	4	OK	2023/11/13 10:30:55
10	EEE	4	OK	2023/11/13 10:35:20
11	EEE	4	OK	2023/11/13 10:35:56
12	EEE	4	OK	2023/11/13 10:36:11
13	EEE	4	OK	2023/11/13 10:38:21

Figure 14. Schematic diagram of data recording.

3.1.4. Physical Device

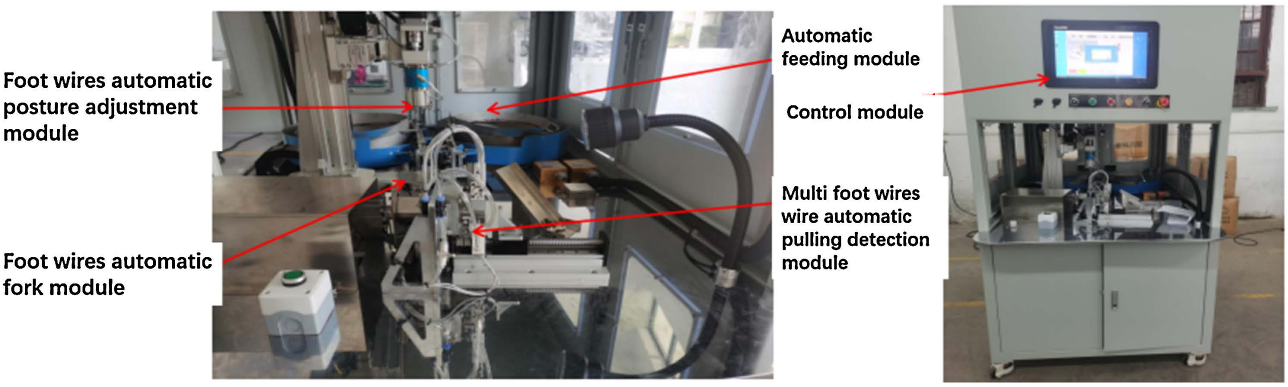
According to the device design plan, an automatic detection device for the pulling force of plastic plug components has been developed. The overall mechanism and various modules are shown in Figure 15.

The working principle of the equipment is:

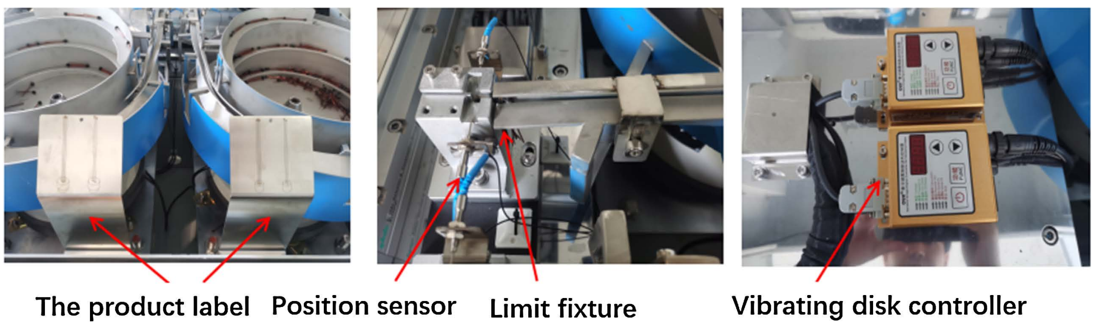
1) The operator places the plastic plug to be tested into the corresponding vibrating tray, which arranges the plastic plug components neatly at the feeding port through high-frequency vibration. The visual camera recognizes the current position of the plastic plug pin, calculates the angle difference between the current

pin position and the target pin position, and outputs a control signal to control the rotation of the rotating gripper until it reaches the target position.

2) After adjusting the posture, the plastic plug undergoes initial positioning, fork separation, fixed distance fork separation, 90˚ rotation, fork separation, fixed



(a)



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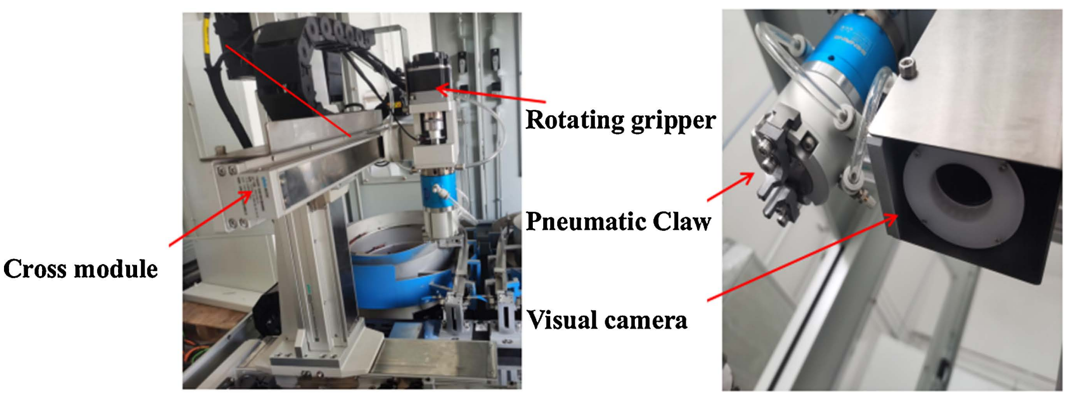
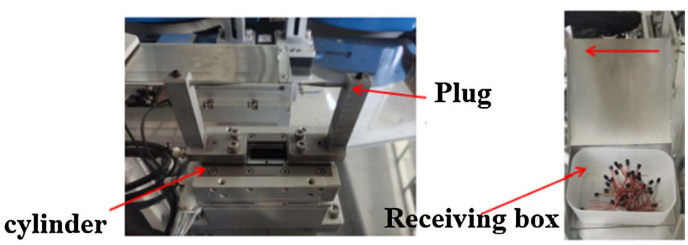


(c)



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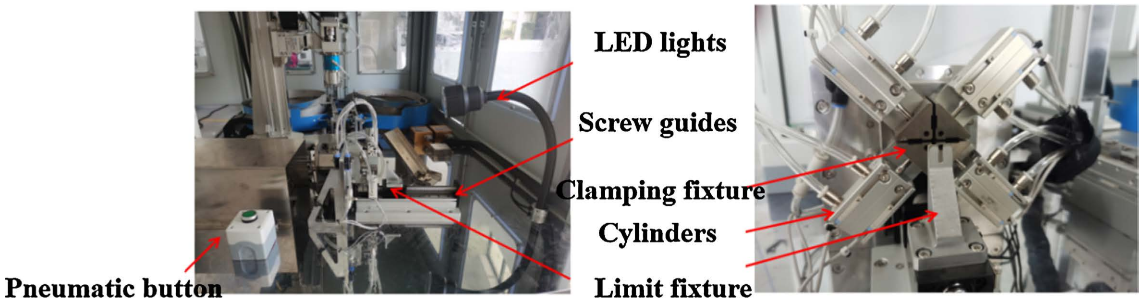


(e)

Figure 15. Physical picture of the overall structure of the device. (a) Overall schematic diagram of automatic testing equipment for pulling force of plastic plug components; (b) Schematic diagram of the structure of the automatic feeding module; (c) Schematic diagram of the structure of automatic posture adjustment; (d) Schematic diagram of automatic fork splitting structure; (e) Schematic diagram of automatic detection structure for multi foot wire pulling force.

distance fork separation, and unloading to achieve fixed distance fork separation. The fork separated plug is placed in the collection box, and the fixed distance fork separation process is shown in Figure 16.

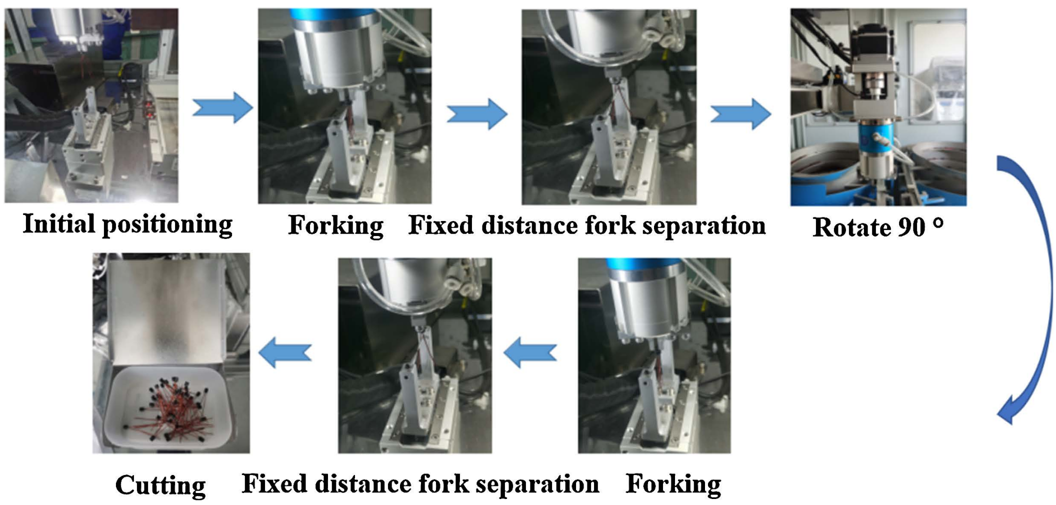


Figure 16. Schematic diagram of automatic fork splitting process for foot wires.

3) The operator inserts the four leg wires (two foot wires) of the plastic plug that has been divided into forks into the corresponding four (two) circular holes on the foot wire clamping fixture. As the distance between the circular holes is the same as the distance between the leg wires after the fixed distance fork is divided, and the circular holes have rounded corners, the leg wires can be quickly inserted into the clamping fixture. The four leg wires correspond to the four clamping fixtures, which are independent of each other. The clamping fixture is connected to a fixed pulley with weights. After the leg wires are inserted into the clamping fixture, the plastic end displacement is limited by the plug limit fixture. The plug limit fixture is connected to the screw guide rail, and the plug limit fixture is driven to move by the screw guide rail. Drive the clamping fixture and the fixed pulley to achieve the detection of pulling force.

3.2. Functional Verification

3.2.1. Automatic Feeding Verification

In order to verify that the two legged and four legged wire plugs can achieve automatic feeding, and to locate and grab the plastic plugs, four typical plugs A, B, C, and D were selected and placed in a vibrating tray for automatic feeding test. Each product had 200 plugs, with a vibration frequency of 50 HZ and a vibration amplitude of 1mm. The test results showed that products with the same plastic end diameter could be loaded onto the same vibrating tray. The four products correspond to two vibrating trays, and the feeding results are shown in Figure 17, which meets the technical specifications.

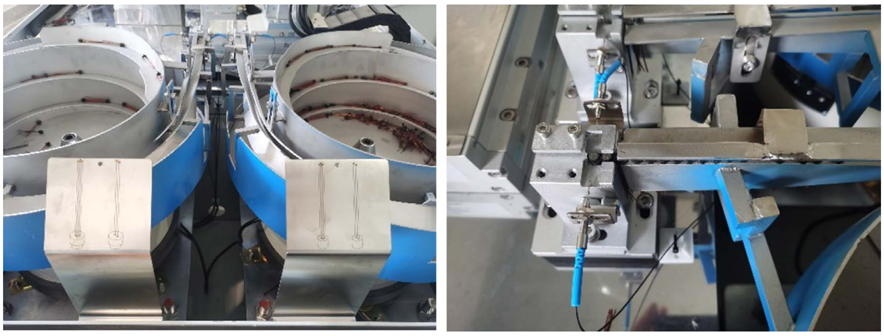


Figure 17. Schematic diagram of automatic feeding test results.

3.2.2. Fixed Distance Cross Validation

The main purpose of this experiment is to verify that the two foot wires and four foot wires plugs of the equipment can achieve fixed distance fork separation. Four typical plugs, A, B, C, and D, with 100 each, were used for fixed distance fork separation testing. The test results show that various products can perform automatic fixed distance fork separation, and the distance between the pins after fork separation is basically the same, meeting the technical requirements. The test verification results are shown in Figure 18.

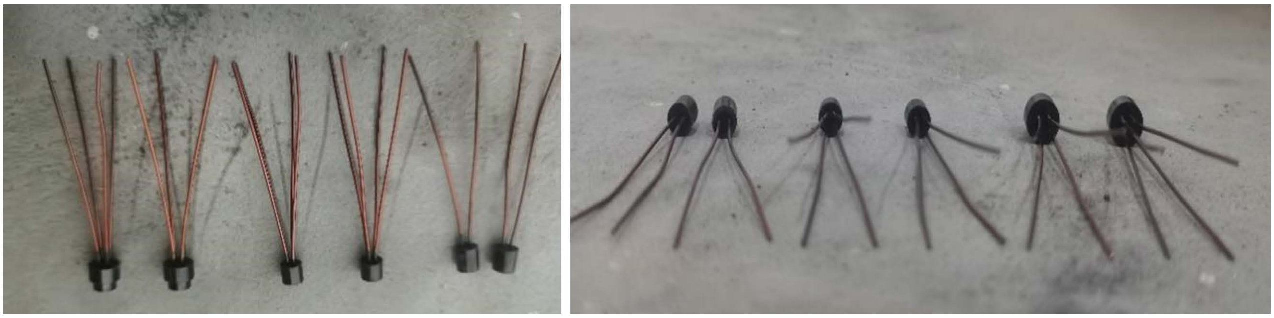


Figure 18. Schematic diagram of the results of the fixed distance fork test.

3.2.3. Multi Foot Wires Automatic Drawing Verification

The main purpose of this experiment is to verify that the equipment can achieve automatic drawing of multi wire. The experiment uses 100 typical plugs of A, B, C, and D for automatic drawing of multi wire. The weight of the weight is 2 kg (determined by the product type), the air pressure is 0.6 MPa, and the drawing detection speed is 10 mm/s. The test results show that the equipment can simultaneously perform automatic drawing of four wire pins. After drawing, the plastic plugs meet the technical requirements. The test results are shown in **Figure 19**.

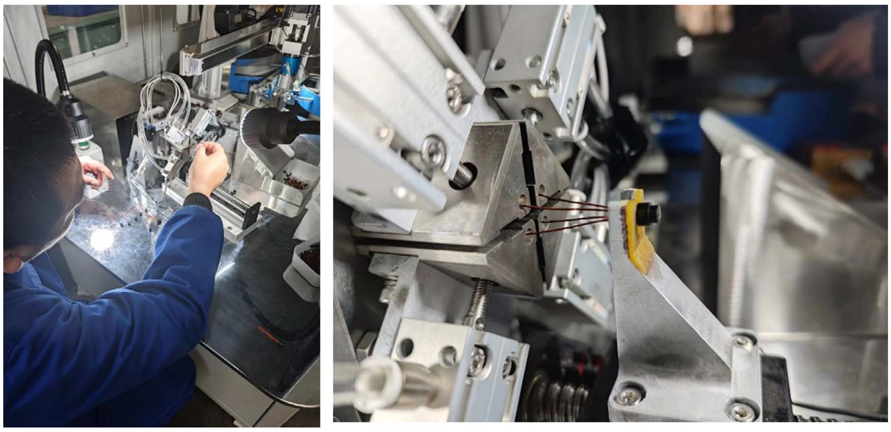


Figure 19. Schematic diagram of automatic drawing verification for multi foot wires.

3.2.4. Verification of Pulling Force Testing Efficiency

The main purpose of this experiment is to verify the efficiency of single pull force detection for various types of plugs. The experiment used 100 typical plugs of A, B, C, and D that have been forked for testing. The test results are shown in **Table 2**.

Table 2. Efficiency of pulling force detection for each insertion puller.

Product code	Number of Foot Threads (Root)	Number of detections (pieces)	Total testing time (S)	Single average detection time (S)
A	4	100	984	9.84
B	2	100	867	8.67
C	2	100	912	9.12
D	4	100	1080	10.8

Based on the above detection data, it can be seen that the average detection time for the plugs of the two foot wires and four foot wires is about 10 seconds, which has increased efficiency by more than 4 times and meets the technical specifications.

3.2.5. Appearance Verification after Inspection

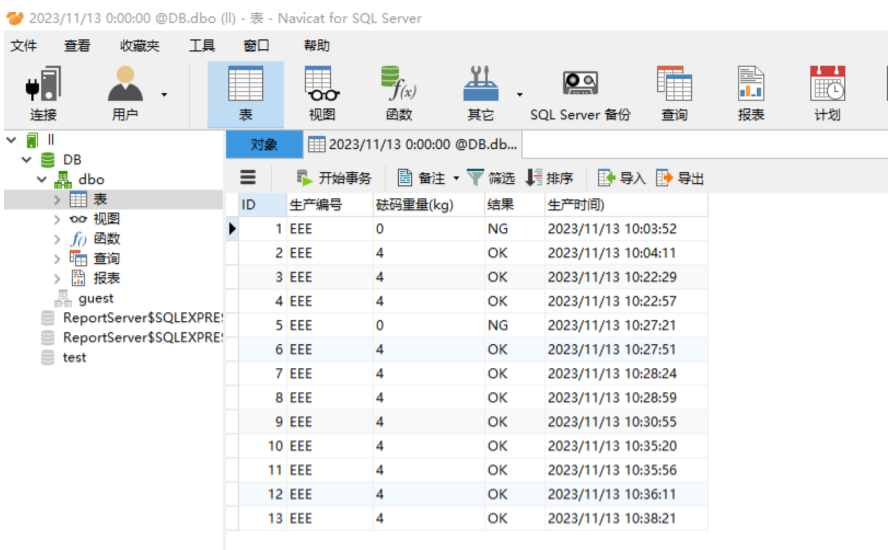
The main purpose of this experiment is to verify that there are no scratches on the appearance of plastic plugs during automatic feeding, wire splitting process, and multi wire automatic pulling process, and that the paint layer on the surface of the wire is not damaged. The experiment uses the four typical plugs A, B, C, and D tested one by one according to the requirements of the operator. The test results show that the appearance of the plastic plug and the paint layer on the surface of the wire are not damaged, meeting the technical requirements. The test results are shown in Figure 20.

(a) (b)

Figure 20. Schematic diagram of appearance damage detection after inspection. (a) Diagram of plug insertion after pull-out testing; (b) Schematic diagram of operator testing one by one.

3.2.6. Data Record Verification

After the above verification test is completed, open the backend test record to verify whether the test results are recorded and can be extracted at any time. Through the backend record, it can be seen that the data records various data such as test batches, test quantities, and test results, achieving traceability of test results and meeting technical requirements. The data record is shown in Figure 21.



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12	EEE	4	OK	2023/11/13 10:36:11
13	EEE	4	OK	2023/11/13 10:38:21

Figure 21. Schematic diagram of detection data recording.

3.3. Small Batch Verification

Based on the automatic detection equipment for pull-out force of plastic plug components, four typical plugs A, B, C, and D were selected as objects, and functional verification was used as the basis for small-scale experimental verification. 100 plugs of each of the four types were selected for testing, and the testing process is shown in Figure 22.

The experimental results are shown in Table 3:

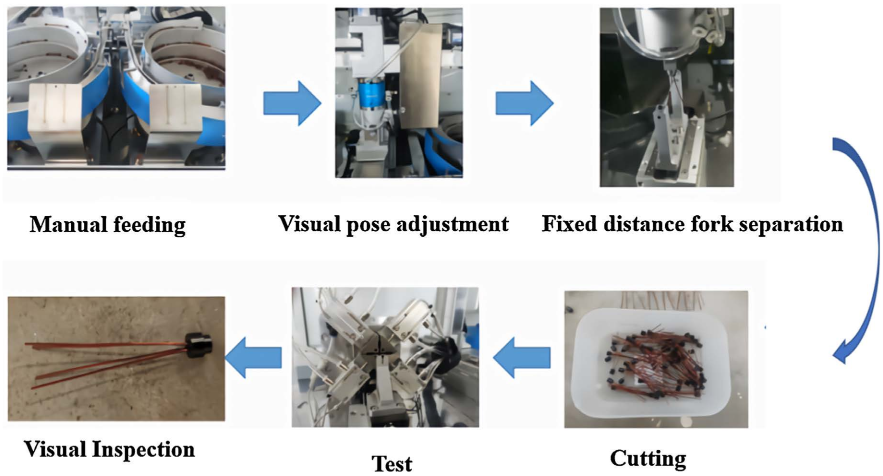

Figure 22. Flow chart of small batch detection.

Table 3. Statistical table of experimental results.

Verify category	validating	Verification Conclusion
Automatic feeding	Can achieve automatic feeding of four typical plugs	Meet requirements
Visual pose adjustment	Can accurately achieve automatic posture adjustment	Meet requirements
Automatic fork splitting	Can achieve fixed distance fork separation	Meet requirements
Multi foot wire automatic drawing	Can simultaneously achieve automatic pulling of two legged and four legged wires	Meet requirements
Detection efficiency	The average testing time for each product is about 10 seconds, which increases efficiency by more than 4 times	Meet the requirement of increasing efficiency by 30% and ensuring that the pulling force detection time for each socket does not exceed 30 seconds
Visual Inspection	The appearance has not been scratched or damaged	Meet the technical requirements of automatic feeding of plastic plugs, no scratches on the appearance during the process of wire fork separation, and no damage to the surface paint layer of the wire
Data record	Automatic recording of data implementation	Meet the requirements of recording and storing detection data to achieve traceability of technical indicators during the drawing and testing process

4. Conclusion

This article designs and develops an automatic detection device for the pulling force of plastic plug components, effectively solving the problems of outdated equipment, low detection efficiency, and unrecorded detection data in the process of plastic plug pulling force detection. The average detection time for each product is about 10 seconds, which increases efficiency by more than 4 times and greatly reduces the labor intensity of operators.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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