Design of an Airtightness Detection Device for Infusion Connector with Automatic Loading/Unloading Function

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Abstract: Based on the production and detection procedures of a medical infusion connector, the original detection device was innovatively designed, and an airtightness detection device with automatic loading/unloading function was developed, in an effort to improve the loading/unloading efficiency and airtightness detection efficiency of the infusion connector and complete the automatic detection task at rate of 20-30 ones per min. The basic device composition of this infusion connector was introduced, and the basic structural features and working principles of each device were analyzed. The importance was attached to the calculation methods for key dimensions that influenced the detection quality and material loading, and in this way, while the batch material loading was realized, the difficulties in the airtightness detection and automatic sorting of finished products were solved. The original manual material loading was converted into automatic material loading and the frequency of simultaneous airtightness detection was increased, which reduced the amount of labor used, improved the overall production efficiency and lowered the production cost.

1. Introduction
As a needle-free closed infusion series product, the needle-free airtight infusion connector can connect the injector, infusion apparatus and blood transfusion apparatus by virtue of its unique design, and it is especially applicable to venous transfusion [1-2]. In order to prevent the bacterial invasive infection during the infusion, very strict requirement has been proposed for the airtightness of infusion connectors, so during the mass production of infusion connectors, the airtightness detection will certainly become a crucial step in the technological process. According to relevant investigations, many enterprises have carried out the airtightness detection of infusion connectors with some specifications as shown in Figure 1. The traditional manual operation is used under most circumstances, namely, the infusion connector is firstly manually placed in the airtightness detection device, the downward compression contact of air cylinder is then detected, followed by the air inflation detection. After the detection is completed, the detection products are manually sorted out, so the whole process detection is time-consuming, with large labor intensity and high production output. Therefore, in order to ensure that the efficiency of airtightness detection product meets the overall requirement for production efficiency, enterprises have increased the quantity of laborers to improve the detection efficiency. The whole detection procedure needs at least 20 workers. Enterprizes are urgent to develop an automatic detection device to rapidly respond to the market needs, improve the production efficiency and lower the labor cost [3-6]. An airtightness detection device with automatic loading/unloading function was explored in this study to mainly complete the automatic loading, automatic detection and automatic unloading functions of to-
be-detected products, and this device could realize the automatic airtightness detection at the rate of 20-30 ones per min. The whole airtightness detection device could save at least 10 laborers, where only one device monitoring personnel was needed, thus saving the labor cost, greatly reducing the labor intensity, ensuring the laborers’ working safety, and improving the overall operating efficiency of the production line.

![Product of One Specification](image1)
![3D Schematic Diagram of the Product](image2)

Figure 1 Product of Certain Specifications

2. Basic composition of airtightness detection device with automatic loading/unloading function

The airtightness detection device with automatic loading function developed in this paper mainly included five parts: underframe, loading mechanism on the underframe, unloading mechanism at front side of loading mechanism, transverse traveling mechanism realizing the accurate movement of loading mechanism and airtightness detection device. The general assembly drawing of this device is shown in Figure 2.

![General Assembly Drawing of Airtightness Detection Device with Automatic Loading/Unloading Function](image3)

Figure 2 General Assembly Drawing of Airtightness Detection Device with Automatic Loading/Unloading Function

Workflow: With the arranged material loading device, the drive mechanism of lead screw pair drives the vibration disk to load materials into all jacks along the guiding direction of the transverse guidance mechanism. After the material loading is completed, the airtightness detection mechanism will automatically detect the airtightness of infusion connector and feedback the detection result to the receiving air cylinder. If any inferior-quality product is found, the inferior-quality product recycling mechanism will move beneath the detection position, the piston rod of receiving air cylinder corresponding to the inferior-quality product is retracted, so the product falls into the recycling mechanism, which is then reset, in the end, the piston rod of receiving air cylinder corresponding to the qualified product is retracted, and the qualified product slips into the transit case via the qualified product guide disk, thus automatically completing the classified recycling of finished products, avoiding the manual selection and classification errors and further elevating the automated production level.
3. Working Principles of Main Devices

3.1. Operation analysis of automatic loading device

The loading device was composed of transverse movement-type loading mechanism and lifting mechanism used to adjust the transverse movement-type loading mechanism to a proper height. The Transverse movement-type loading mechanism included rest block, transverse guidance mechanism on the rest block, drive mechanism of lead screw pair, and vibrating loading disk on the transverse guidance mechanism. The assembly drawing of this automatic loading device is shown in Figure 3.

![Assembly Drawing of Automatic Loading Device](image1)

Figure 3 Assembly Drawing of Automatic Loading Device

1. Lifting mechanism; 2. Transverse movement-type loading mechanism

![Lifting Mechanism](image2)

Figure 3 (a): Lifting Mechanism
1. Vertical guidance mechanism, 2. Ejector sleeve, 3. Rotary shaft section, 4. Guide pillar, 5. Adjusting screw, 6. Mounting rack

1) The lifting mechanism consisted of two symmetric vertical guidance mechanisms arranged at two ends of the rest block, mounting rack beneath the rest block, ejector sleeve used to drive the upward and downward movement of the transverse movement-type loading mechanism, and regulating mechanism used to regulate the distance from top to bottom of loading mechanism. The adjusting screw included the rotary shaft section and screw section, a supporting block having threaded connection to the adjusting screw was placed on the mounting rack, and the rotary shaft section of adjusting screw was connected to the rest block via linear bearing. The vertical guidance mechanism included the erection column vertically set on the underframe and guide rail fixed on the erection column, a sliding block could be set on the guide rail and connected to one end of the ejector sleeve via L-shaped bracket, so the two ends of ejector sleeve were effectively supported and its stationarity was improved, thus reducing the vibration of vibrating disk and affecting the transmission precision and material loading effect of drive mechanism of lead screw pair.

![Transverse Movement-Type Loading Mechanism](image3)

Figure 3 (b): Transverse Movement-Type Loading Mechanism

1. Drive mechanism of lead screw pair; 2. Transverse guidance mechanism
2) The transverse movement mechanism was composed of drive mechanism of lead screw pair and transverse guidance mechanism as shown in Figure 3 (b). The drive mechanism of lead screw pair included the servo motor on the ejector sleeve, spiral lead screw and lead screw nut nested on the lead screw, and the output end of drive motor was connected to lead screw drive via a coupler. The lead screw nut was fixed at the bottom of loading vibrating disk, and the transverse movement of loading disk was realized through the screw drive of lead screw and nut; the transverse guidance mechanism consisted of two parallel guide rails and sliding blocks on the guide rails, and the two sliding blocks were respectively fixed at the bottom of vibrating disk.

3.2. Operation analysis of automatic sorting and unloading device

The sorting and unloading device consisted of material receiving and sorting mechanism and qualified and inferior-quality product recycling mechanism (Figure 4), where the former mainly took charge of feeding materials onto the vibrating loading disk and recycling the nonconforming products detected; the qualified product recycling mechanism, which was located at a fixed position, was used to recycle qualified products, while the inferior-quality recycling mechanism would selectively push out, retract and receive nonconforming products via the air cylinder.

Figure 4 Assembly Drawing and Partial Enlarged Drawing of Sorting and Unloading Device

1. Qualified and inferior-quality product recycling mechanism; 2. Material receiving and sorting mechanism; ① Inferior-quality product recovery tank drives the air cylinder; ② Inferior-quality product recovery tank; ③ Qualified product sliding guide disk; ④ Air cylinder 2; ⑤ Scraping plate; ⑥ Positioning plate; ⑦ Semi-circular arc-shaped slot

The material receiving and sorting mechanism consisted of multiple air cylinders and scraping plates, positioning plate with an arc-shaped end, and semi-circular arc-shaped slot connected by cylinder heads as shown in the enlarged drawing of mechanism 2 and partial enlarged drawing in Figure 4. There
were multiple infusion connectors to load materials in the vibrating disk, the output end of vibrating disk moved above the jacks, the piston rods of all material receiving air cylinders were stretched out from the end parts, so the positioning plate formed a jack (namely, detection position) in combination with the semi-circular arc-shaped slot. The transverse movement-type loading mechanism was adjusted to a proper height via the lifting mechanism, ensuring that an infusion connector could slide into the jack by means of vibration in the vibrating disk. As the diameter of top section of infusion connector was larger than the jack diameter, the lower end face at the top of infusion connector was compressed on the upper end face of jack. Each time the material loading was finished in one jack, the drive mechanism of lead screw pair drove the output end of vibrating disk to move above the next jack for the follow-up material loading:

(2) After the material loading was completed in all jacks, the vibrating disk would stop working, and its output end moved out of the working area of positioning plate. At the time, the infusion connector would be detected by the detection device. When any inferior-quality product was detected out, the inferior-quality product recycling mechanism moved beneath the infusion connector via the air cylinder, the piston rod of material receiving air cylinder corresponding to the inferior-quality product was retracted, so the inferior-quality product, losing the support, fell into the inferior-quality product recycling mechanism. The scraping plate aimed to prevent resetting of inferior-quality product recycling mechanism carrying materials when the material receiving air cylinder was retracted, the piston rod of material receiving air cylinder corresponding to the final qualified product was retracted, so the qualified product fell onto the qualified product guide disk, facilitating the classified recycling of qualified products. When no inferior-quality product was found, the inferior-quality product mechanism would not be started, the piston rods of all material receiving air cylinders were retracted, and the qualified products fell onto the qualified product guide disk.

3.3. Operation analysis of airtightness detection device
The core content of the device developed in this paper lied in rapidly and accurately detecting the airtightness of infusion connector, which was also a key technical index in the device design. The device was innovatively transformed by reference to the existing device design methods. The structure was mainly composed of air cylinder, airtight connector and support frame (Figure 5).

As for the structural design of this airtightness detection device, two parallel and vertically mounted pillars were firstly arranged, where the two pillars were connected through the mounting plate. Multiple location holes were opened on the mounting plate, each location hole corresponded to the jack on the material receiving and sorting mechanism, a detection air cylinder was set at each location hole, and the end part of piston rod of detection air cylinder presented threaded connection with one airtight connector after passing through the location hole. The airtight connector was located above and faced the jack, and an inlet hole was set on its side wall. The working principle was described as follows: The airtight connector was connected to the inlet hole and vacuum leak detection device, where the latter was
electrically connected to the PLC and fed back the detection results to the LC, thus controlling the motion of material receiving air cylinder. After the material loading was completed at all detection positions, the bottom of airtight connector was compressed on the top of infusion connector for sealing, the airtight connector implemented vacuum testing of the infusion connector and fed back the detection results to the PLC, so the unloading device could recycle the products separately, and the piston rod of detection air cylinder was finally retracted.

4. Analysis of Main Technical Parameters

4.1. Dimensions of positioning plate and positioning hole of receiving and sorting mechanism

The width design of location plate should consider the requirements for the position dimension of vibrating loading disk, size of unloading disk, and size and stiffness of inferior-quality product recycling disk as shown in Figure 6. Empirical values were used in this study. It was already known that the diameter of top section of infusion connector was 12-20 mm, and the difference value from the secondary diameter size (jack) was 0.75 mm at one edge. Therefore, the length of location plate is calculated as follows:

\[ M_1 = n \times M_2 + 2 \times R + 2 \times M_3 \]

Where: \( M_3 = (8-12) \text{ mm} \)

Take the maximum diameter (12 mm) of infusion connector for example, and assume that totally eight products (to be determined according to concrete production requirement) are detected each time, and the length of location plate is calculated as below:

\[ M_1 = 7 \times 30 + 2 \times 6 + 2 \times (8 \sim 12) \text{ mm} \]

Width of location plate:

\[ M_4 = M_5 + R = (2 \sim 4) \text{ mm} = 74 + 6 + (2 \sim 4) = (82 \sim 84) \text{ mm} \]

The material receiving jack consisted of location plate and semi-circular arc-shaped slot, and the determination principles of the location arc size at one side of location plate were as follows: no sharp edge was allowed; the arc size should be greater than the secondary maximum diameter and smaller than the maximum diameter (namely, 12 mm) in order to prevent the infusion connector from falling, and the radius of circular arc is:

\[ R_1 = R - 0.6 \text{ mm} \]

Through the further calculation, \( R_1 = 6 - 0.6 = 5.4 \text{ mm} \)

The fillet at the arc edge can increase the bearing weight of circular arc and avoid scratching the products.

Figure 6 Structural Diagram of Material Receiving and Sorting Mechanism and Plan Sketch of a Product of Certain Specifications
4.2. Transverse movement distance of loading disk

The loading disk can load materials into infusion connectors of multiple dimensions and certain specifications, and they mainly differ in diameter and height. The device designed in this paper could complete the detection of infusion connectors of at least three different dimensions, so the size of location arc, namely, the location jack, also varied with the location plate. It was assumed that the same production efficiency was required, namely the detection frequency each time was the same, the location plate of M1 with the corresponding dimensions should be replaced. Moreover, the transverse movement distance of loading disk also varied with the size of location plate as shown in Figure 7. In order not to interfere with the operation of airtightness detection device when the loading disk was under to-load-material status at two sides of the location plate, the transverse movement distance, according to practical experience, can satisfy the following equation:

\[ L = M1 + 2 \times (10 \sim 20) \text{mm} \]

(4)

![Figure 7 Structural Assembly Drawing of Material Receiving and Sorting Mechanism](image)

5. Conclusion

As an innovative transformation design of the existing traditional detection device, the airtightness detection device with automatic loading/unloading function designed in this study can reach the technical indexes of automatic material supply to infusion connector, automatic detection, automatic sorting, automatic unloading and production efficiency of 20-30 ones per min. Meanwhile, it can satisfy the automatic detection and sorting of products with different dimensions and certain specifications, so it is worth certain practical application and popularization value [6].

Except being able to complete the abovementioned technical indexes, the new-type automatic airtightness detection device also shows the following characteristics and advantages during the production process:

1) The past manual material loading, receiving and sorting mode is changed. The whole device can realize the automatic production via the PCL control program and save the labor cost. Only one worker is needed in the whole production process of this device to operate the device and monitor its operating state;

2) Each mechanism, reasonably designed in the device, can guarantee the steady and reliable operation of this device, and ensure the labor safety and reduce the labor intensity while improving the production efficiency;

3) The whole set of this device is of simple assembly, simple operation and maintenance and long continuous operation cycle, with greatly lengthened maintenance cycle, thus lowering the equipment maintenance cost of enterprise.

The low-carbon environmentally friendly operation is advocated, the action actuator of each device is completed using air cylinders, the accurate position movement is realized via the servo drive system,
and with the simple and mature control technology, this device can reach the optimal operating state and realize zero-emission production.

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