Design of wearable squat booster for automobile assembler based on ergonomics

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Abstract. Aiming at the problem that automobile assembler need to squat for a long time, a wearable squatting assistance system with low cost, simple control and easy to squat and walk is designed. Based on ergonomics and finite element theory, UG was used to draw a three-dimensional solid model of the wearable squatting power system for automobile assemblers. With the help of ANSYS software, the statics analysis of key components is carried out to check their strength and stiffness. It is concluded that the wearable squatting power assist device for automotive fitters based on ergonomics has reached the design requirements in terms of function use and strength and stiffness.

1. Introduction

There are a large number of occupations similar to automobile assemblers in actual production operations, which require long-term squat operations at an indefinite point, and long-term operations are extremely likely to cause adverse joint effects such as strain on the staff and protrusion of the lumbar intervertebral disc [1-3]. In order to improve the working conditions of these labor groups, this paper aims to design a low-cost, simple wearable squat assist mechanism. This structure can be worn by people of different body types, help leg muscles and joints support the human body during squats, and reduce fatigue and soreness during long-term squats [4-6]. This design needs to fully integrate ergonomics and use ergonomic knowledge to design the overall structure of the system, so that the agency should also protect the waist and leg joints of the automobile assembly workers as much as possible under the function of assisting [7]. The parts are easy to be injured or worn at work, so that the system can provide timely assistance when the worker squats, and does not affect the normal walking of the workers when they do not need to squat.

2. Analysis of human lower limb movement characteristics

2.1 Establishment of simplified model of human lower limbs

According to ergonomics, the lower limb movement of the human body is mainly composed of the coordinated movement of the ankle, knee and hip joints. From a unilateral perspective, the lower limb movement mainly includes 7 degrees of freedom, and the hip joint includes 3 degrees of freedom of
movement. The ankle joint mainly includes 3 degrees of freedom of movement, and the knee joint mainly includes 1 degree of freedom of movement[2]. It is possible to directly select and set key test points on the lower limbs of the human body, and then measure the angle transformation status and angle transformation range of each joint of the lower limbs of the human body during the movement by the key test points.

![Figure 1. Changes in flexion and extension angles of right leg joints during walking](image)

When the human body is in a standing state, the angle is defined as 0°. Taking the right leg as an example, Figure 1 is a schematic diagram of the flexion and extension angle of each joint continuously changing with the change of gait, in which the angle increases when bending and the angle extends. Figure 2 is a schematic diagram of the change of the abduction angle of each joint with gait, where a decrease in angle indicates restraint and an increase in angle indicates abduction. It can be seen that the changes of the left leg and the right leg are exactly the same, and the phase is opposite[2].

![Figure 2. Changes in the Angle of abduction of the right leg during walking](image)

It is not difficult to find that the angle change of each joint's introverted abduction angle in Figure 2 is extremely small in the angle of internal rotation/external rotation, and the main stepping motion of the lower limbs of the human body is completed by flexion/extension during walking. Therefore, the internal and external rotation angle can be regarded as approximately 0°, and the lower limb model of the human body can be simplified into the 7-bar model shown in Figure 3.

![Figure 3. Human lower limb model](image)
2.2 Dimensional data measurement and analysis

The research object of this paper is the wearable squat assist system for automobile assembly workers. Therefore, the human body parameters of the automobile assembly workers were measured according to the human body size of the adult sitting position provided in the national standard GB/T 1000-1988. The selected measurement items are: height, thigh length, calf length, hand function, thigh thickness during assembly work, knee height in sitting posture, sitting depth during assembly work, lower limb length, hip width, hip circumference[3].

The man-machine measurement obtains the pre-estimated data, and the allowable data variation range is obtained through the variance calculation, and the range value of the basic adjustment size is obtained. The effective values are shown in Table 1.

| Measured items            | Size (mm)          | Measured items            | Size (mm)          |
|---------------------------|--------------------|---------------------------|--------------------|
| Height                    | 1695±100           | Thigh thickness           | 143±20             |
|                           |                    | when sitting in assembly  |                    |
| Thigh length              | 474±20             | Knee height               | 499±20             |
|                           |                    | when sitting in assembly  |                    |
| Calf length               | 377±20             | Hip circumference         | 900±60             |
|                           |                    | when sitting in assembly  |                    |
| Arm length                | 751±20             | Lower limb length         | 1000±20            |
|                           |                    | when sitting in assembly  |                    |
| Sitting depth when sitting in assembly | 468±18 | Hip width when sitting in assembly | 325±20 |

The above anthropometric data can provide a reference for the size of the wearable squat assist system for automobile assemblers, and also help to determine the basic adjustment range of mechanical equipment.

3. Mechanical design

3.1 Joint design

Figure 4. Cardan connection
The structure of the universal joint used in this paper is a bit like the joints on the limbs of the human body. It allows the angle between the connected parts to change within a certain range. The universal shaft can usually transmit large torque, so adding it to the mechanism can achieve the effect of bearing the gravity of the human body. After analysis and comparison, the thigh rod and the calf rod are connected by a universal shaft, and the knee is connected by a universal joint, as shown in Figure 4.

3.2 Design of telescopic rod cooperating locking device

Different workers have different leg lengths, so the calf rod needs a telescopic rod to adjust the length. As shown in Figure 5, the locking method of the telescopic rod adopts a wrench-type locking and fixing method, and its structure is mainly composed of a wrench, a friction block and a locking bolt. The calf rod and the friction block are in a transitional cooperation relationship, and at the same time, the friction block and the inner wall of the housing of the locking device are in a transitional relationship. When the wrench is opened, the entire device is in an unclamped state, and the length of the calf rod expansion and contraction can be adjusted at this time. When the wrench is gradually compressed, due to the structure of the wrench itself, the distance between the contact point of the wrench and the housing from the rotation center of the wrench gradually becomes larger, so the entire locking device is compressed.

3.3 Foot protection and wearing convenience design

To avoid accidental injuries to the feet due to heavy objects falling, rolling, throwing or being hit by accidental workpieces. As shown in Figure 6, the safety toe cap is used to provide anti-smash protection for the instep and toes of workers in the industrial operating environment. The entire safety toe cap is made of a large size 13 steel toe cap. After the impact hammer 23KG is dropped and impacted at a height of 900mm, the gap in the shoe is not less than 15mm and after static pressure of 15KN, the gap in the shoe is not less than 15mm. This device can be used instead of safety shoes. When workers use this device, there is no need to replace safety shoes. When designing, the toe cap should be at least 45 yards in size, which can satisfy workers of different body types and feet as much as possible, so that the whole organization can be used by most ordinary workers. In addition, a 40mm wide elastic band is used to help fix the squat booster mechanism and the worker's feet, while also increasing the comfort as much as possible to avoid the pain of prolonged use.
3.4 Auxiliary structure design
As shown in FIGURE 8, two holes need to be drilled on each thigh rod, and the thigh rod and the elastic sponge pad are connected by bolts. The existence of the sponge pad is beneficial to protect the buttocks and thighs of automobile assembly workers, and the device is worn for a long time. It will not cause pain and increase comfort. The lower leg rod and the iron-head labor protection shoe accessories are connected by a U-shaped rubber connecting ring, and the U-shaped rubber connection ring and the iron-head labor protection shoe accessories are directly connected by a rotating pair. Due to the limitation of the length of the rod, when the worker walks upright, the whole device will be lifted up, the calf support rod will be separated from the ground, and the whole device will cling to the rear side of the leg of the automobile assembly worker, which will not prevent the worker from walking normally. When the worker has a tendency to squat down, the support rod behind the ground is in contact with the ground for support. On the basis of completing the three-dimensional modeling, in order to facilitate processing and assembly, a two-dimensional drawing of the wearable squat booster device of the automobile assembler based on ergonomics was completed.

![Figure 7. Chematic diagram of squatting booster device](image)

1- Elastic sponge pad 2- Universal shaft 3- Crus rod 4- Locking mechanism 5- Support telescopic rod 6- U-shaped elastic joint ring 7- Schematic diagram of labor insurance 8- Elastic 9- Thigh rod

4. Finite element analysis

![Figure 8. Contour of Deformation](image)

This paper uses ANSYS Workbench to perform finite element analysis on the structure and check the strength and stiffness. The purpose is to check whether the system structure is reasonable and can be used normally. The materials involved in assigning material properties are Aluminum Alloy, Elastomer Sample, Silicon Anisotropic, and Structural Steel. The thigh bar and calf bar are Aluminum Alloy, the telescopic clamping mechanism is Silicon Anisotropic, and the pad and elastic U-shaped connecting
ring are Elastomer Sample, the universal shaft mechanism is Structural Steel. In an ideal state, when an automobile assembly worker sits squat stably, the vertical force is transmitted from the thigh to the joint of the universal joint through the thigh rod, then from the universal joint to the calf support rod, and finally to the ground. The lower limbs of the wearable sitting squat assist system are now moved to the state of the human body in a static squat state and the typical working conditions when the thigh and calf rods are in a vertical state are subjected to force analysis. When the worker weighs about 100 kg, the A fixed constraint is applied to the sole of the iron toe and the bottom of the calf support rod, and a vertical downward force of 50 kg is applied to the underside of the thigh rod pad. From the analysis results, it can be seen that there is maximum deformation on the right side of the thigh rod of the entire system. As shown in Figure 8, the maximum deformation displacement is 2.4154 mm. Set the allowable deflection to \( \gamma = 3.5 \text{mm} \), from (1), it can be seen that the stiffness of the device meets the requirements.

\[
\gamma_{\text{max}} < [\gamma]
\]

(1)

Figure 9. Contour of equivalent stress

At the same time, the equivalent stress of the system is solved. As shown in Figure 9, the equivalent stress cloud diagram shows that the maximum equivalent stress experienced by the mechanism is at the end of the contact part between the pad and the thigh bar. As shown in Figure 10, at the end near the universal axis. The maximum equivalent stress on the thigh bar is 209.84MPa. For the 6061 aluminum alloy, its yield limit \( \sigma_s = 280 \text{MPa} \), taking the safety factor \( n = 1.1 \), the allowable stress \([\sigma] = 254.5 \text{MPa}\) can be obtained according to (2).

\[
[\sigma] = \frac{\sigma}{n}
\]

(2)

Known \( \sigma_{\text{max}} = 209.84 \text{MPa} \), according to (3)

\[
\sigma_{\text{max}} < [\sigma]
\]

(3)

It can be calculated that the maximum stress value is less than the allowable stress value. From this, it can be seen that the maximum displacement and stress of the wearable squat assist system of the automobile assembler fully meet the work requirements.
5. Conclusion

The use of a universal shaft as a joint connection in the overall structure is an innovative point of the design of this paper. The use of a retractable rod and a locking device increases the versatility and adaptability of the squat booster device. The combined use further embodies the humanity of the device and protects the worker's physical safety.

Through the finite element analysis of the wearable squat power assist mechanism of the automobile assembler, the overall force deformation and stress distribution of the designed device are preliminarily grasped. The strength and rigidity meet the actual needs, and have good reliability and rationality.

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