Auxiliary sit-up device with adjustable motion trajectory based on conversion movement of sitting and standing

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Abstract. The device takes the elderly as a service object, and proposes a device for assisting the elderly to get up and down. The device realizes a series of processes for the elderly from lying on the bed to sitting up, and then from sitting to standing. And can provide some assistance through the reverse operation of the device when the elderly need to lie down. The overall operation process of the device is simple, and it solves the problem of getting up and getting out of bed due to insufficient waist and arm strength of the elderly at present.

1. Introduction
With the continuous development and progress of the society and the improvement of people's living standards, the average life expectancy of our country has gradually increased, and the problem of aging population has become increasingly prominent [1]. It is expected that by 2040, the proportion of the elderly population aged 65 and over in the total population will exceed 20%. The proportion of the elderly in the total population has increased year by year. According to publicly available information, the proportion of elderly people with empty nests is nearly half. Data show that by 2020, the number of this type of elderly is expected to increase to 118 million, and by 2050, the number of elderly living alone will reach 250 million. Many elderly people have no children or babysitters, caregivers to accompany and take care of them, and there are some problems in their lives. In the context of increasing ageing issues, it is necessary to address them.

2. Project overall introduction
As shown in the figure, in order to consider its functional requirements [2]. The device is mainly composed of a backrest module, a leg flexion module, and a bed lift assist standing module.

Figure 1. Overall device diagram
2.1. Back module
The lifting module is mainly composed of a push rod at the bottom, a rod connected by the push rod, a slider, and a backrest plate. As shown in Figure 2, ① is the backrest of the bed, ② is the slider installed on the bottom of the backrest, and ③ is the link connecting the slider and the push rod, ④ an electric push rod for pushing the backrest board to rotate upward.

![Figure 2. Sketch of the back module mechanism.](image)

The putter at the bottom is an electric putter with a stroke of 150mm. It is an electric drive device that converts the rotary motion of the motor into a linear reciprocating motion of the putter. The bottom putter pushes the rod under the drive of the motor. The connection of the rod is fixed, and the connection of the slider and the connecting rod is fixed. Both the connecting rod and the electric push rod have a hinge at one end, which can rotate around the hinge. There is a slide rail on the backrest board to limit the slider, so that it can only perform linear motion on the slide rail. The rotation angle of the backrest board is 0° to 70°. Taking into account the human nature of the design, let the elderly control autonomously [3].

2.2. Leg bent module
The module consists of a thigh plate, a calf plate, a slider, a putter 1 and a putter 2. As shown in Figure 3, ① is a thigh plate with a length of 570mm. ② is the slider, ③ is the calf plate, the length is 510mm, ④ is the putter 1, and ⑤ is the putter 2. Among them, the electric push rod 1 is fixed, perpendicular to the ground, at 90°, without hinges, and can only be directionally retracted. One end of the push rod 1 is connected to the slider, and there is a slide rail under the thigh plate to limit the slider, which can only move linearly up and down the slide rail. One end of the push rod 2 is connected to a hinge fixed on the thigh plate, so that it can move with the thigh plate and move within a certain angle around the hinge. The other end is connected to the lower leg plate by a connecting rod. The connection between the connecting rod and the push rod 2 is movable, but the connection with the lower leg plate is fixed, so that the connecting rod and the lower leg plate are always 90°. The curved leg module completes the process of lowering and lifting the leg from 0 to 90° [4].

![Figure 3. Schematic diagram of auxiliary lifting module mechanism.](image)
During operation, the motor first drives the push rod 1 to extend, so that the top slider increases a certain height in the vertical direction. At the same time, the slider moves linearly in the chute at the bottom of the thigh plate away from the thigh plate rotation axis, so that the thighs The board can be rotated up and down by 15° around the shaft to lift up, so that the thigh board and the backrest board form an angle, so that the human body is slightly caught in the included angle, and the human body is fixed to avoid accidents during the lifting process of the bed. At the same time, the push rod 1 contracts, the lower leg plate falls down under its action, and the elderly person's lower leg is lowered by turning 75°, and the angle of the push plates of the two legs is fixed.

2.3. Assisted lifting module
As shown in Figure 4, the device is mainly composed of ① large gear, ② bed board, ③ bedside armrest, ④ pinion gear, and ⑤ electric push rod.

![Figure 4. Schematic diagram of auxiliary lifting module mechanism.](image)

When it is necessary to assist the elderly to stand, the electric pusher rotates forward, and the pusher can be extended to lift the bed board at an angle from 0° to 25°, which can ensure that the elderly can get the help of the bed board when they get up. The size of the bed board is designed to be 200mm in length, 120mm in width, and 50mm in height. When the bed board is lifted, the handrails at the bed are also raised simultaneously, and you can use the handrails next to you to support them when they are assisted while standing. The length of the bedside armrest is 660mm, which can make people get the maximum assistance when using the bedside armrest. The bedside armrest and the bed board are connected by a pair of large and small gears. The pinion gear is connected to the bedside armrest, so that the pinion gear controls the rotation of the bedside armrest, while the bedplate is controlled by the big gear. The rotation of the big gear determines the rotation angle of the bed board, and the large and small gears mesh normally to drive the handrail Rotate to support the elderly to get up. The design of the bedside armrest is actually giving emotional care to the elderly [5].

3. Strength check analysis
This section calculates and checks the data of the gears and other aspects of the device.

3.1. Selection of gear type, accuracy class, material, heat treatment
According to the transmission scheme, a straight-toothe cylindrical gear is selected, and the accuracy level is selected to 7. In order to ensure the gear has sufficient strength and minimize the size, the gear should be a hard-tooth surface gear. Since the two gears have a transmission ratio of 1, the size is basically the same Therefore, both gears are carburized and quenched with 20CrMnTi steel with a hardness of 56 ~ 62HRC. Check the table to get the bending fatigue limit stress $\sigma_{F_{\text{lim}}} = 430MPa$ and contact fatigue limit stress $\sigma_{H_{\text{lim}}} = 1500MPa$.

3.2. Gear Strength Calculation
Designed according to the tooth bending fatigue strength, the calculation formula is
\[ m = 12.6 \sqrt[3]{\frac{KT Y_{FS} Y_{e}}{\psi_d z_i^2 \sigma_{FP}}} \]  

(1)

3.3. Determining Allowable Bending Force \(\sigma_{FP}\)

According to formula

\[ \sigma_{FP} = \frac{\sigma_{F lim} Y_{ST} Y_{N}}{S_{F lim}} \]  

(2)

Because the calculation given by the national standard is adopted, the stress correction factor of the test gear \( Y_{ST} = 2 \); Taking into account that the speed of the gear is not high, the life coefficient of fatigue bending strength calculation \( Y_{N} = 1 \) Minimum safety factor for bending strength \( S_{F lim} = 1.6 \), then

\[ \sigma_{FP} = \frac{\sigma_{F lim} Y_{ST} Y_{N}}{S_{F lim}} = \frac{430 \times 2 \times 1}{1.6} = 537.5 \text{MPa} \]

3.4. Calculating the nominal torque of the gear \(T_1\)

According to the foregoing calculation, the pair of gears transmits power to the central shaft, and the torque of the central shaft is the torque of the pair of gears, then \(T_1 = 24340 \text{Nm}\).

3.5. Selecting the load factor

Since the prime mover is an electric motor, the rotation speed of the device is small, the movement is relatively stable, and the accuracy level is 7, so the load factor can be selected to be smaller, taking \(K = 1.3\).

3.6. Preliminary selection of gear parameters

Considering that the torque transmitted by this pair of gears is large, the number of teeth also needs to take a larger value, taking \(Z_1 = 80, Z_2 = Z_1 i = 32\), and tooth width coefficient.

3.7. Determining Compound Coefficients \(Y_{FS}\)

Because the material and heat treatment are the same for the two rounds, so \(\sigma_{FP}\) is the same. Check the table, \(Y_{FS} = 3.93\).

Bringing the above parameters into the calculation formula can be obtained

\[ m = 12.6 \sqrt[3]{\frac{KT Y_{FS} Y_{e}}{\psi_d z_i^2 \sigma_{FP}}} = \frac{13 \times 24340 \times 3.93 \times 1}{0.6 \times 80^2 \times 537.5 \times 10^6} = 4.94 \text{mm} \]

Look up the table and take the standard modulus \(m = 50 \text{mm}\), then the centre distance

\[ a_1 = \frac{m(Z_1 + Z_2)}{2} = 400 \text{mm} \]

3.8. Calculating Geometry

\[ d_1 = d_2 = mz_1 = 400 \text{mm} \]

\[ b_1 = \psi_d d_1 = 240 \text{mm} \]

\[ b_2 = b_1 + (5 \sim 10) \text{mm} = 250 \text{mm} \]
3.9. Checking tooth contact strength

The calculation formula is

$$\sigma_{H} = 112Z_{E} \frac{KT_{u}(u \pm 1)}{bd_{u}} \leq \sigma_{HP}$$  \hspace{1cm} (3)

The pair of gears are steel gears, and the elastic coefficient can be taken as $Z_{E} = 189.8 \sqrt{MPa}$, then

$$\sigma_{H} = 112Z_{E} \frac{KT_{u}(u \pm 1)}{bd_{u}^{2}u} = 112 \times 189.8 \times \sqrt{\frac{1.3 \times 24340 \times (1+1)}{2400 \times 4000^{2} \times 1}} = 273 MPa$$

The allowable contact stress calculation formula of the tooth surface is

$$\sigma_{HP} = \frac{\sigma_{H \lim}}{S_{H \lim}} Z_{N} Z_{w}$$  \hspace{1cm} (4)

The minimum safety factor is taken as $S_{H \lim} = 1.5$, the life factor calculated from contact fatigue strength $Z_{N} = 1$, and the work hardening factor $Z_{w} = 1$, then

$$\sigma_{HP} = \frac{\sigma_{H \lim}}{S_{H \lim}} Z_{N} Z_{w} = \frac{1500}{1.5} \times 1 \times 1 = 1000 MPa$$

Because of the $\sigma_{H} \leq \sigma_{HP}$, the contact fatigue strength is also sufficient.

4. Conclusion

In this paper, a device for assisting the elderly to get up and down is introduced. Compared with the existing device for assisting the elderly to get up and down, the device has the following advantages: the use of electric push rods, gear trains, etc., to achieve the elderly's up and down, bent legs and assisted standing functions to achieve the integration of functions it can effectively reduce the back pressure of the elderly. When the elderly need to get up and down, it can provide assistance and greatly help the elderly. The device adopts the matching design of the link mechanism and the gear mechanism, and meets all the needs of the elderly when they get up and down with a simple mechanism. Compared with some professional and cumbersome bed and bed machinery nowadays, it has fewer workers, higher efficiency, and the device conforms to the nursing mode of technology-based retirement [6], it will have a good application prospect.

References

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