Design and Analysis of Learning Case based on Knee Rehabilitation Training Device

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Abstract: With the aging of population, the increase of physical diseases such as stroke and transportation, the number of patients with limb dyskinesia, especially knee dyskinesia, increases sharply. This paper introduces the structural design and analysis of knee joint rehabilitation training device, which can maximize the recovery of patients' motor function, provide the basis for rehabilitation doctors to evaluate the effect of rehabilitation training and formulate rehabilitation plan, reduce the labor intensity of rehabilitation doctors, and improve the rehabilitation efficiency. Through the case design and analysis of knee rehabilitation training device, students' mechanical design calculation ability can be cultivated, and students' understanding and application of basic knowledge can be enhanced.

1 INTRODUCTION

In order to change the situation of relying solely on rehabilitation physicians to assist patients with knee joint to carry out rehabilitation training, further improve the efficiency of rehabilitation training, and improve the rehabilitation effect, the rehabilitation robot technology combining robotics and rehabilitation medicine has increasingly become a research hotspot of scholars at home and abroad (Wang, Chang, Zhu 2019). So far, many scholars at home and abroad have done a lot of research work on the rehabilitation robot, especially the lower limb knee joint rehabilitation robot, and have made many achievements (Weber-Spickschen, Colcuc, Hanke, et al. 2017, Mavroidis, Bonato 2007, Koller-Hodac, Leonardo, Walpen, et al. 2011, Koller-Hodac, Leonardo, Walpen, et al. 2010, Smart portable rehabilitation devices 2005, Adnan, Karamat, Kamal, et al. 2014).

According to the rehabilitation training posture of patients, lower limb rehabilitation institutions can be divided into two categories: horizontal CPM machine and vertical lower limb auxiliary rehabilitation device (Hu 2009). At present, the most commonly used lower limb rehabilitation device is the horizontal CPM machine, and the lower limb fit adopts the lap type. Patients can use the lying position after operation, and put the lower limb directly on the CPM mechanism for training. The concept of CPM was put forward by Salter, a Canadian Orthopaedic expert, after a lot of experiments in the 1970s. It is the use of special equipment by mechanical or electronic devices to drive or maintain part of the limb movement, so that the joint for a long time of slow passive movement, so that the combination of treatment and rehabilitation, can relieve pain, improve joint range of motion, prevent joint contracture and adhesion. It can promote the regeneration and repair of intra-articular cartilage, and is conducive to the recovery of limb function (Li, Li 2007). CPM machine training is a mature method for postoperative limb continuous exercise training (Morris 1995). The development of CPM has gone through three historical stages. Salter first put forward the concept of CPM in 1975 after trial and clinical research. In 1982, Coutts et al. Applied CPM device to human rehabilitation training. In 1992, McInnes et al. Started a prospective study to explore the application effect of CPM in different situations (Ning, Xu, Li 2007). At present, CPM technology has been widely accepted in orthopedic rehabilitation field in China, and its application scope is becoming wider and wider.

This device can be worn on the lower limbs of patients, and can fit closely with the legs. The parts of the mechanism that fit the lower limbs are generally made of light and soft materials, which are

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closely combined with the legs, so it can achieve more accurate angle control. The wearable structure makes the training flexible, and rehabilitation training can be carried out in standing, sitting and lying positions. In this kind of research, pneumatic artificial muscle and cylinder are more selected as actuators, which can provide certain flexibility and relatively high safety. However, due to the short stroke of pneumatic artificial muscle and cylinder, the rehabilitation angle of this kind of rehabilitation mechanism is relatively small, which can not meet the requirements of large angle rehabilitation, so it is often used in gait training and disability assistance. This kind of device is complicated and inconvenient to wear. Because the vertical lower limb auxiliary rehabilitation mechanism is mostly wearable, it fits closely with the human body, and the bending angle of the mechanism is equal to the bending angle of the human joint, which can achieve accurate control. Moreover, it uses pneumatic artificial muscle or air cylinder as the driver, which has good flexibility and can meet the safety when contacting with people. Due to the limitation of rehabilitation posture, the vertical lower limb auxiliary rehabilitation mechanism can not be used for postoperative rehabilitation, and the rehabilitation angle is very small, so it is mostly used for auxiliary rehabilitation training. But the wearable mechanism is generally more complex, and to distinguish between the left and right legs, wearing trouble, not very practical. Through such analysis and data searching, students can understand the cutting-edge technology, master the specific application and implementation process of mechanical design, design the corresponding design scheme, reasonably analyze the design calculation, and cooperate with the team to complete the design and rationality analysis. In this process, design calculation will be checked repeatedly, which can cultivate one's design calculation ability and craftsmanship spirit.

Mechanical structure design is the basis of rehabilitation training for rehabilitation robot. This paper mainly analyzes the structure design of knee rehabilitation robot, and designs a reasonable structure of rehabilitation robot. Through the introduction of this case, students' craftsmanship spirit can be cultivated in the process of design and calculation.

2 DESIGN AND CALCULATION OF KNEE REHABILITATION TRAINING DEVICE

2.1 Weight and Height Data

The relationship between weight and height is as follows

Normal weight

$$W_2 = H - 110(kg) \tag{1}$$

Ideal weight

$$W_L = H - 100(kg) \tag{2}$$

If a person's weight is often lower than or higher than 10% of the normal weight, it is an abnormal state.

2.2 Calculation of Body Volume and Surface Area

When the body weight is 50-100kg, the body volume and surface area can be calculated according to the following formula.

Calculation of human body volume

$$V = 1.015W - 4.937 \tag{3}$$

Where V is the volume of human body (m^3); W is the body weight (kg).

Through the design and calculation of human body data, students' learning ability and application ability of interdisciplinary knowledge can be cultivated.

2.3 Weight and Height Data

According to ergonomics, the knee joint is rotated to achieve the effect of rehabilitation treatment. The weight of the human body accounts for about 35% of the total weight of the human body. The average person's weight is generally between 50kg-100kg, and the m_{leg} is 17.5kg-35kg. The rotation times of knee rehabilitation treatment cycle is n_2 = 6 r/min, the transmission ratio is I = 3. The stepping motor with rated voltage of 220 V and rated power of 20 W is selected.

2.4 Structural Design of Belt Drive

（1）Determination of calculated power P_{ca}

$$P_{ca} = Ka \cdot P = 1.0 \text{ X } 20W = 20W \tag{4}$$

Among them, the rehabilitation robot works 4-6 hours a day, so the working condition coefficient Ka = 1.0.

（2）Determination of V-belt pattern

Check the mechanical engineering manual and select a-belt by P_{ca} and n_2.

（3）Determine the reference diameter of the pulley and check the belt speed

The datum diameter d_{d1} of the primary pulley is 75mm.

Check the belt speed according to the formula:

$$V = \frac{\pi d_{d1} n_1}{60 \times 1000} = \frac{\pi \times 75 \times 18}{60 \times 1000} \text{m/s} = 0.07\text{m/s}$$

Where n_1 = I = 18r / min.

Because the belt wheel speed is required to be suitable for human knee rehabilitation treatment, the belt speed of 0.07m/s can ensure human safety and the stability of the machine.

Calculate the reference diameter of large pulley

$$d_{d2} = i \cdot d_{d1} \tag{5}$$

Select standard diameter d_{d2}= 150 mm.

2.5 Determine the Center Sistance and Reference Length of V-pulley

(1) Primary selection with formula a_0

$$0.7（d_{d2}-d_{d1}）\leq a_0 \leq 2（d_{d1}+d_{d2}） \tag{6}$$

Therefore, primary a_0= 400mm.

(2) Calculate the required base length of the tape

$$a \approx 2 a_0 + \frac{\pi}{2} \times (d_{d1} + d_{d2}) + \frac{(d_{d2}-d_{d1})^2}{4a_0} \tag{7}$$

$$a = [2 \times 400 + 2\pi \times (75+150) + \times \frac{1100-1156}{2}]\text{mm}$$

$$\approx 1156\text{mm}$$

Look up the table and select the datum diameter 1100mm.

(3) Checking the wrap angle on the small pulley

$$\alpha_1 \approx 180° - （d_{d2}-d_{d1}）\frac{57.3°}{a} = 180° -（150-75）\times \frac{57.3°}{372} \approx 168° > 120°$$

(4) The number Z of design bands

A single V-belt is used, and the number of V-belts is 1.

From d_{d1} = 75mm, n_1 = 18r / min, P_0 = 0.26kw is obtained. According to n_1 = 18r / min, I = 2, ΔP_0 = 0.05kw is obtained. Look up the table to get K α= 0.98，K_l=0.91。

The initial tension F of a single belt is obtained from the formula

$$F_0 = 500 \frac{(2.5-K_\alpha) P_{ca}}{K_\alpha z v} + qv^2 = 67\text{N}$$

According to the table, the mass per unit length of type a belt q = 0.105kg/m.

(5) Calculate the axial force F_P

$$F_P = 2zF_0 \sin\frac{\alpha_1}{2} = 2 \times 1 \times 67 \times \sin\frac{168°}{2} = 134\text{N}$$

(6) Design conclusion

The common V-belt of type A is selected, the datum length of the selected belt is 1100mm, the datum diameter of the pulley d_{d1} = 75mm, d_{d2}= 150mm, the center distance is controlled at about a = 400mm, and the initial tension of a single belt F_0 = 134 N. The final CATIA design is shown in Fig.1.

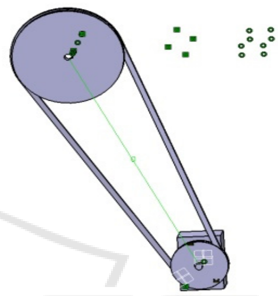

Figure 1: Belt drive structure.

3 DESIGN AND CALCULATION OF KNEE REHABILITATION TRAINING DEVICE

3.1 Design and Calculation of Thigh Bar

The average thigh width of healthy adult men is 150 mm-170 mm, and the calf width is 100 mm-120 mm. Therefore, according to the ergonomic structure design, the modeling sketch in CATIA software is shown in Fig.2.

Model design of main parts of lower limb rehabilitation robot.

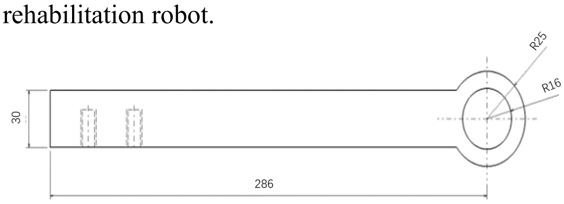

Figure 2: Thigh bar.

3.2 Design and Calculation of Spindle

The function of the main shaft is to connect the pulley and the leg bar. Under the support of the leg bar and the bearing, the main shaft can rotate and transmit the motion of the motor to the leg bar, so as to drive the rotation of the leg bar and realize the purpose of circular rotation. The sketch of the spindle is shown in Fig.3.

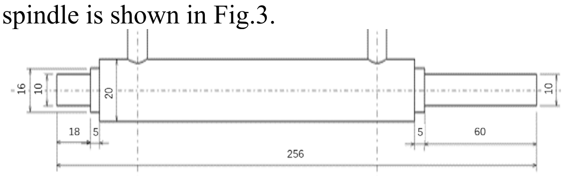

Figure 3: The spindle.

Bearing, end cover and large pulley are installed at 60mm part of left end. In order to save materials and simplify the design, the shank part is directly welded to the spindle part to achieve better human-computer interaction.

3.3 Design and the Design of Leg Bar of Spindle

The shank rod is connected with the main shaft by welding, so that it can be better stressed and manufactured. According to the weight and size of the human body, the shank rod adopts a cylinder with a diameter of 10 mm and can be made of aluminum alloy with a length of 400 mm. The back end is connected by plate and welded, so that the human body can step on or tie on the leg during training. The leg bar is shown in Fig.4.

Figure 4: The design of leg bar.

3.4 Design of Bearing End Cover

The function of the bearing end cover is to prevent the axial movement of the bearing, so the end cover is used for axial positioning. Bearing end cover is divided into two kinds, front cover and rear cover, so it needs to be designed and processed separately. According to the maximum outer diameter 40mm and inner diameter 32mm of the thigh bar, the design is carried out. The two end caps are shown in Fig.5.

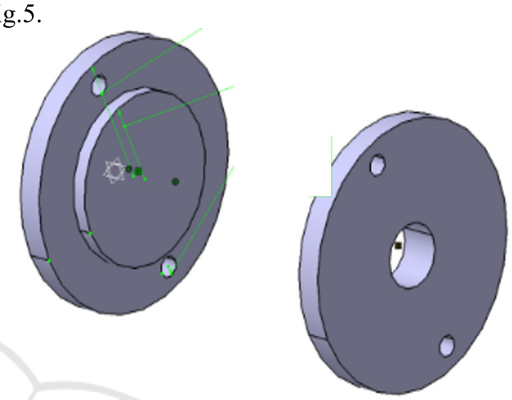

Figure 5: Bearing end cover.

3.5 Selection of Bearings

The above analysis shows that the axial force F = 134N, the pressure exerted by human legs is about F = 116N, through the working state of the bearing, the radial force F_r = 250N, the axial force F_a = 60N. And use deep groove ball bearing.

(1) To find the ratio of F_a and F_r, there is a formula:

$$\frac{F_a}{F_r} = \frac{60}{250} = 0.24$$

According to the bearing manual, when e = 0.24, X= 0.56, Y= 1.8.

(2) Preliminary calculation of the equivalent dynamic load P, where the working factor f_d = 1.0

$$P= f_d（XF_r +YF_a）=1.0×（0.56×250+1.8×60）N =248N$$

(3) According to the formula, the basic rated dynamic load of the bearing is calculated

$$C=P\sqrt[\varepsilon]{\frac{60nLh}{10^6}} = 248 \times \sqrt[3]{\frac{60\times 18\times 4000}{10^6}}\,\mathrm{N} = 870\mathrm{N}$$

It is assumed that the use time of the lower limb rehabilitation robot is 4000 hours. According to the bearing manual, 6200 bearing is used. Deep groove ball bearing with inner diameter d = 10 mm, outer diameter D = 32 mm and width B = 10 mm.

3.6 Force Analysis

According to the analysis of the operation of the lower limb rehabilitation machine, the motor applies torque on the small pulley, and the small pulley drives the belt to rotate, so as to drive the large pulley to rotate. The movement and force are transmitted through the key and act on the main shaft to realize the rotation of the main shaft. Therefore, the rigid constraint is set through the part connected by the key, and is applied to the face corresponding to the key. There are many ways of modal extraction, and block Lanczos method is used in this paper.

The natural frequency of the assembly body is determined by its structure. After modal analysis, the vibration of the shaft is mainly concentrated in the middle, which will swing left and right. The maximum frequency of the sixth mode is 73.442Hz. The vibration mainly includes the rotation of the spindle, left and right swing, and the swing of the spindle base along the Z axis. The minimum frequency is 25.111Hz. The mechanism can work normally.

4 CONCLUSIONS

When introducing these ideological and political breakthroughs, try not to express the teachers' own views directly, and use more cases, facts and phenomena to inspire students to think, the effect will be better. After practice, students are easy to accept the actual case and video. Through practice, it is found that in the process of design, calculation and analysis of knee joint rehabilitation training device, students have cultivated the ability of independent thinking, analysis, problem-solving and interdisciplinary learning, and cultivated their craftsmanship spirit. Therefore, the actual design and calculation of cases to explain knowledge points can better help students understand and apply knowledge.

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