

# Experimental Study On Wearable Ankle Rehabilitation Device

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**Abstract**—In this paper, the experimental platform of wearable ankle rehabilitation device is built, and the mechanical performance of the wearable ankle rehabilitation device is tested on the experimental platform. Four kinds of experiments were carried out: trajectory tracking test, step response test of moment, position frequency response test and isokinetic muscle force test. Because the traditional rehabilitation training process of ankle injury is mainly to carry out the rehabilitation training of ankle dorsiflexion/plantar flexion freedom, the experiment in this paper is mainly aimed at the dorsiflexion/toe flexion freedom of ankle rehabilitation device.

**Keywords**—experimental study; rehabilitation robotics; elasticity; ankle orthosis

## I. INTRODUCTION

In order to change the traditional treatment methods and improve the efficiency and effect of rehabilitation training, a series of robotic automation devices were developed to assist or replace physiotherapists to complete joint rehabilitation training. The wearable ankle orthosis was shown in Figure I. In this paper, the experimental study of ankle rehabilitation equipment is carried out. Through the isokinetic muscle force experiment of ankle dorsiflexion/toe flexion degree of freedom at different speeds for two healthy trainees, the torque value of ankle dorsiflexion/toe flexion degree of freedom is measured by torsion spring, and the designed torsion spring and ankle rehabilitation device are verified. Feasibility[1-3].

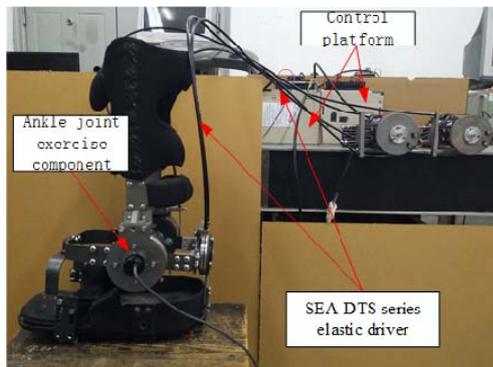


FIGURE I. THE WEARABLE ANKLE ORTHOSIS

This paper will build the experimental platform and conduct experimental research on the mechanical properties of the wearable ankle rehabilitation device on the experimental

platform [4-11]. The experimental platform built is shown in Figure II, in which the ankle joint motion executing component is fixed on the auxiliary support frame. Because the traditional ankle joint injury rehabilitation training process, mainly for the rehabilitation of the ankle joint dorsiflexion, so the experiment is mainly for the ankle joint rehabilitation device dorsiflexion degree of freedom.

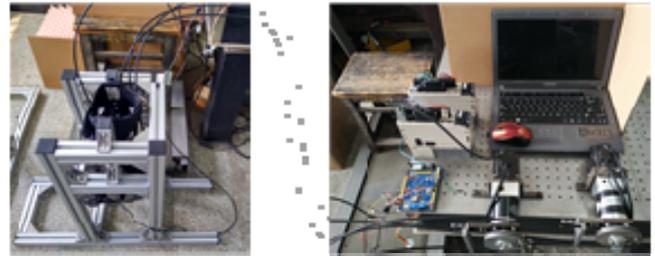


FIGURE II. THE EXPERIMENTAL PLATFORM OF THE WEARABLE ANKLE ORTHOSIS

## II. TRAJECTORY TRACKING TEST

To enable the wearable ankle rehabilitation device to achieve accurate passive rehabilitation training in the passive training mode, the active training mode quickly tracks the limb movement of the patient without hindering the ankle joint of the patient. The tracking performance of the wearable ankle rehabilitation device on the desired trajectory under no-load conditions is its basic indicator. In this paper, the normal human ankle joint dorsiflexion angle curve [12,13] is taken as the desired trajectory. The designed PD controller adopts the speed closed loop as the inner loop, and the position closed loop as the outer loop. The control block diagram is shown in Figure III. The specific parameters of the PD controller are shown in Table I. The speed inner ring is ensured by the servo motor's driver through its encoder to collect the servo motor speed. The position outer ring collects the current ankle joint dorsiflexion degree of freedom motion feedback through the encoder two on the wearable ankle joint rehabilitation device; In this way, the position loop is achieved. The results of the trajectory tracking of ankle joint dorsiflexion at three kinds of asynchronous speeds are shown in Figure IV. It can be seen from Figure IV (a) that the trajectory tracking error is maintained within the range of  $-2^\circ$  to  $2^\circ$ , and the absolute error for most of the time is within  $1^\circ$ . It can be seen from Figure IV (b) that the trajectory tracking error is maintained between  $-2^\circ$

and 3°, and the absolute error for most of the time approaches 0°. It can be seen from Figure IV(c) that the trajectory tracking error is maintained in the range of -2.5° to 4°, and the absolute error of most of the time approaches 1°.

TABLE I. PROPERTIES OF THE PD CONTROLLER

Gain parameter	Value
$k_P$	2.2
$k_D$	0.9

As the pace increases, the error of the trajectory tracking will increase accordingly. The trend of the actual tracking trajectory is consistent with the expected trajectory, indicating that the ankle joint rehabilitation device has good trajectory tracking performance. However, due to the transmission characteristics of the double lasso transmission mechanism and the presence of the torsion spring, there is a certain position error and phase lag between the actual tracking trajectory and the desired trajectory, and the maximum error is 3.56°.

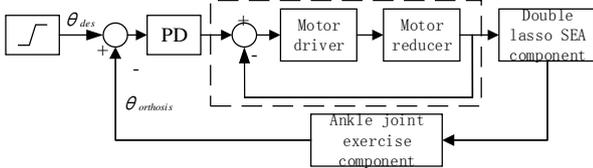


FIGURE III. THE BLOCK DIAGRAM OF THE PD CONTROLLER

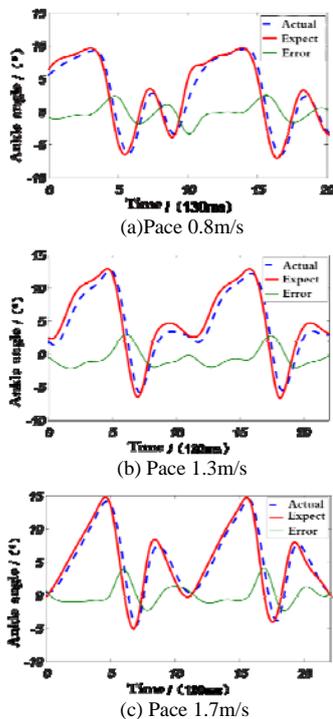


FIGURE IV. RESULTS OF THE TRAJECTORY TRACKING EXPERIMENTS

The new SEA-DTS series elastic actuator designed in this paper has a certain buffer shock absorption function. However, in the actual control, the ankle joint rehabilitation device needs to have a fast response characteristic, and can quickly and accurately track the desired torque according to the control requirement, so it is necessary to perform a torque step response experiment. Referring to Robinson's method, the sole plate of the ankle joint rehabilitation device is fixed on the auxiliary support frame, and the torque step response test is performed under the two torques of 3.0 N.m and 6.0 N.m respectively, and the change of the ankle joint torque is detected by the torsion spring. The control block diagram of the torque step response is shown in Figure V.

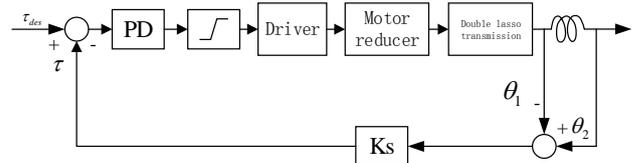


FIGURE V. THE BLOCK DIAGRAM OF THE MOMENT STEP RESPONSE EXPERIMENTS

The experimental results are shown in Figure VI. As can be seen from the figure, the ankle rehabilitation device can achieve fast and accurate torque tracking. When the torque is 3.0 N.m, the overshoot is 10%, and the adjustment time Ts1 is about 40 ms. When the torque is 6.0 N.m, the overshoot is 16%, and the adjustment time Ts2 is approximately 30 ms.

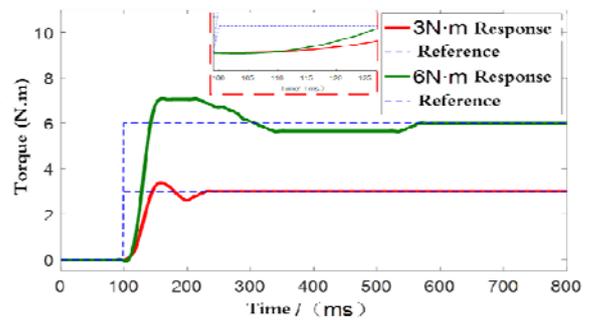


FIGURE VI. RESULTS OF THE MOMENT STEP RESPONSE EXPERIMENTS RESULTS OF THE TRAJECTORY TRACKING EXPERIMENTS

### III. POSITION FREQUENCY RESPONSE EXPERIMENT

Visually analyzes system stability and other motion characteristics based on position frequency response experiments. In this paper, the position frequency response experiment of the ankle joint rehabilitation device is carried out. The sinusoidal curve with the frequency from 0.1 to 8 Hz is used as the input signal to measure the amplitude and phase difference between the input and the steady-state output at each frequency. The experimental results are shown in Figure VII. It can be seen from Figure VII (a) that in the process from low frequency to high frequency, the following curve is gradually attenuated, and the frequency corresponding to the 3dB drop in frequency response is 5.5 Hz, that is, the bandwidth of the

ankle joint rehabilitation device is 5.5 Hz. It can be seen from Figure VII (b) that the phase difference of this experiment ranges from 0° to 103, and the trend of the entire phase-frequency characteristic curve is consistent with the trend of the amplitude-frequency characteristic curve.

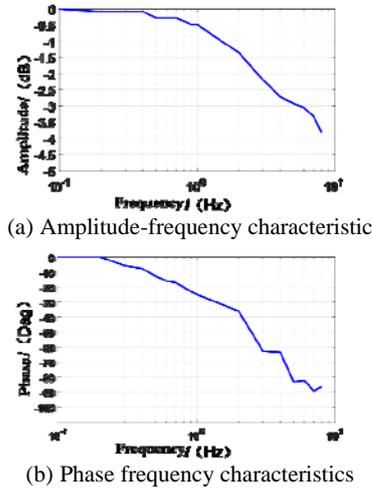


FIGURE VII. RESULTS OF THE POSITION FREQUENCY RESPONSE EXPERIMENTS

The nonlinearity of the lasso transmission itself and the presence of torsion springs result in a large phase difference in the phase-frequency characteristic curve, but it is within the control range of the ankle joint rehabilitation device, and the rehabilitation training speed is slow in practical applications. Therefore, to meet the practical application requirements.

#### IV. ISOKINETIC MUSCLE TEST

The first three experiments were mainly to study the mechanical properties of the ankle joint rehabilitation device and verified the rationality and feasibility of the mechanism. This section is the practical application of ankle rehabilitation training: isokinetic muscle strength experiment. This paper invites two healthy wearers (A: Male, height 1.82m, weight 78Kg; B: male, height 1.7m, weight 62Kg) to perform isokinetic muscle strength test of ankle joint dorsiflexion under different ankle joint speeds.

Two different experiments were performed in the two joints at 3 degrees/s, 4 degrees/s, and 6 degrees/s. The experimental results are shown in Figures VIII and IX. From the wearer's experimental data, it can be seen that in the three experiments of the wearer A, the maximum moment values of the ankle dorsiflexion degrees were 14.2 N.m, 12.6 N.m, and 11.3 N.m, respectively. In the three experiments of wearer B, the maximum moment values of ankle dorsiflexion degrees were 12.4 N.m, 11.3 N.m, and 11.1 N.m, respectively. The experimental data of the two groups further verified the feasibility of the torsion spring and the ankle joint rehabilitation device designed in this paper. At the same time, it can be seen from the experimental data that as the ankle joint movement speed increases, the maximum moment that the ankle joint can produce decreases correspondingly.

Analysis of the actual trajectory of the two sets of experimental data shows that the actual trajectory of the ankle joint motion component and the expected trajectory have slight changes. There are two main sources of error: one is due to the tensile deformation of the rope during the transmission of the power; the other is because the torsion spring needs to return to the initial state when the SEA-DTS changes the direction of operation.

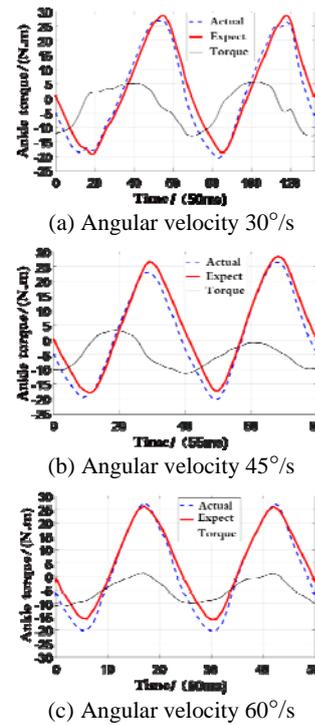
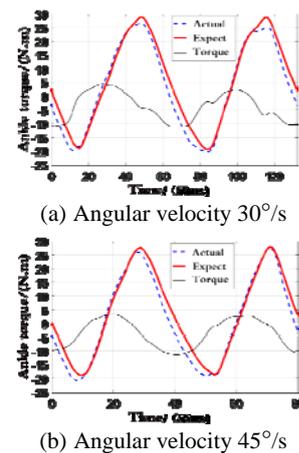
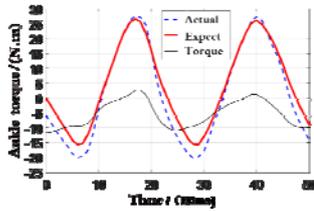


FIGURE VIII. RESULTS OF THE ISOKINETIC DYNAMOMETER EXPERIMENTS OF HUMAN A





(c) Angular velocity 60°/s

FIGURE IX. RESULTS OF THE ISOKINETIC DYNAMOMETER EXPERIMENTS OF HUMAN B

## V. CONCLUSION

The trajectory tracking experiment proves that the ankle rehabilitation device has good trajectory tracking performance. The moment step response experiment shows that the ankle rehabilitation device can achieve fast and accurate moment tracking. The trend of the phase-frequency characteristic curve is consistent with that of the amplitude-frequency characteristic curve. The isokinetic muscle force experiment verifies the feasibility of the torsion spring and ankle rehabilitation device designed in this paper.

## ACKNOWLEDGMENT

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