Design and Current Tracking Control of Leg Press Training Device with Clutch

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Abstract. Aimed at the characteristics of the existing stretch leg rehabilitation products with single function and complicated structure, a leg stretching training device with multiple training modes is proposed. At the same time, a controller strategy based on fuzzy slip film algorithm is proposed for the constant velocity resistance training mode. The automatic control of the magnetic powder clutch in constant velocity resistance training is studied. The clutch based on BP neural PID algorithm is designed. Current tracking control strategy and simulation. Finally, the feasibility of the designed current tracking control strategy is verified by simulation and experiment, which will guide the subsequent in-depth research.

Keywords: Leg-press device, FSMC, Current tracking.

1. Introduction

With the increasing aging of the society, the functional degeneration of the knee directly affects the healthy life of patients [1,2]. Preventing the elderly from falling down and ensuring the ability of walking and climbing ladders are important to improve the happiness index of the elderly in their later years. In the training to restore the movement function of the thigh, calf and knee joints, Continuous Passive Motion (CPM) rehabilitation training has obvious rehabilitation effects on the muscle groups involved in knee flexion and extension [3, 4]. Active Resistance Motion (ARM) training as a medium-to-high-intensity training model has proven its health benefits [5,6].

At present, there are three types of products in the field of stretching and fitness in the market. The first category is traditional CPM machines, such as Italy's Fisiotek 2000 [7], the US CPM lower limb continuous passive training instrument [8], ZEPU's ZEPU-K2000 [9]. These products focus on CPM training and are simple and single-function portable rehabilitation equipment; The second category is the common counterweight kick trainer, such as the ELEMENT series of the Italian Technogym company [10], the Pure Strength series kick trainer [11], Simonson [12], etc. It is only used for high-intensity constant impedance resistance training, which is cumbersome, expensive, and not suitable for ordinary patients; The third category is pneumatic rehabilitation training equipment, such as the HUR produced by the Finnish company [13,14], the More-Gait lower limb rehabilitation device in Germany [15], the main and lower limb rehabilitation device of Okayama University in Japan [16]. Various forms of resistance training, but their price is high and lack of power source, unable to achieve active and passive training.

In view of the defects of the above products, this paper designs a leg stretching training device, which can realize various training modes such as active and passive training and resistance training in isobaric/equal speed form. At the same time, a new drive scheme combining motor and magnetic powder clutch is proposed. The related dynamics analysis and the related design of the anti-resistance synovial membrane control algorithm are designed. The clutch current tracking control strategy is designed. The feasibility of the control algorithm is verified by simulation and experimental results.

2. Design of the Mechanical and Electrical System

2.1 Mechanical Structure Design

The leg stretching device is mainly composed of a patient area, a training area and a power area, as shown in Fig. 1. The backrest elevation and height of the patient area seat are adjustable to suit the needs of different patients. The training area consists of a linear slide, an upper limb push-pull assembly and an ankle assembly, and a support wheel and a connecting frame are provided to facilitate the disassembly and transportation of the seat and the training device body. The power area is composed of a power box, which provides corresponding driving force in different training modes. At the same time, the encoder can adjust the training speed of the training area in real time to ensure the safety and scientificity of the training process.

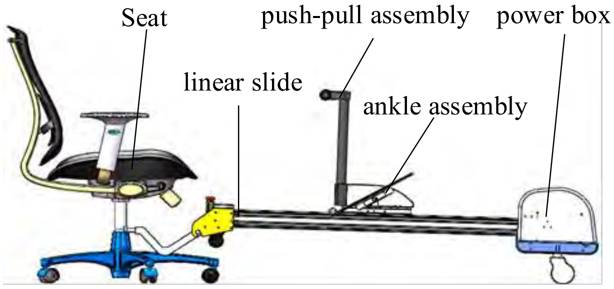


Fig. 1 The leg stretching device

The magnetic powder clutch is automatically clutched by the force difference between the two ends without additional signal control, and the transmission torque is controllable and easy to control, which is very suitable for rehabilitation robots [17]. The driving scheme of the leg stretching training device is driven by a combination of a motor and a magnetic powder clutch. The schematic diagram of the transmission scheme is shown in Fig. 2. Compared with the single motor torque drive, the response speed is fast, the noise is small, the return speed is controllable and stable, and the motor and the clutch perform their duties and have higher safety. Through the different combination control measures of the motor speed and the magnetic powder clutch transmission torque, a plurality of training modes of a single device can be realized, and the use efficiency of the training device is improved.

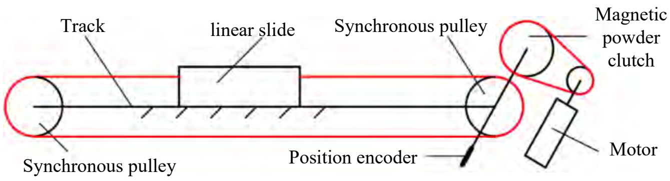


Fig. 2 Transmission schematic

2.2 Electrical System Design

Fig. 3 shows the electrical system block diagram of the elderly lower limb flexion and extension training device. The system includes a main control unit, a remote control unit, a motor controller unit, a magnetic powder clutch controller unit, and a pressure sensing unit.

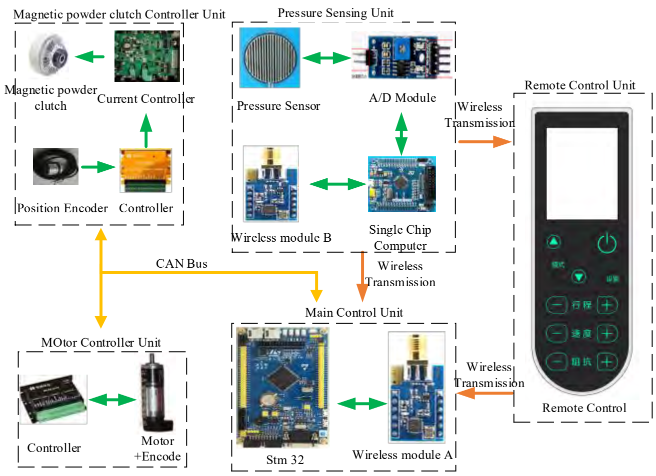


Fig. 3 Block diagram of the electrical system of the elderly lower limb flexion and extension training device

The overall electrical system is housed in the power box and ankle assembly as required by the unit. The part installed in the power box is the main control system, and the part installed in the pedal assembly is the auxiliary control system.

Fig. 4 shows a schematic diagram of the overall control system for impedance training. The external input of the system is mainly a signal from a human brain and a signal from an anti-resistance trainer. The controllable input is the control objective function of the resistance training device decision, and the purpose is to periodically complete the constant velocity resistance training. During the training process, on the one hand, the exerciser consciously and periodically generates the consciousness of stretching the leg, and converts it into a kind of tonic stimulation signal and sends it to the quadriceps muscle to generate motion, and receives feedback signals of various sensing organs in the process; On the other hand, the resistance training controller receives the pedal speed and acceleration information fed back by the pedal position sensor, and performs a difference with the controller control target, and then calculates the magnetic powder clutch excitation current increment, and adjusts the magnetic powder clutch braking torque, which makes the leg extension speed and muscle contraction rate as expected.

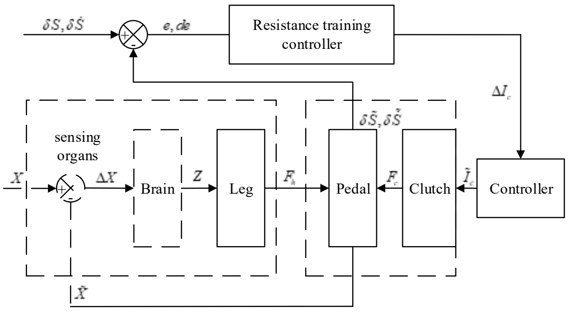


Fig. 4 Schematic diagram of constant velocity resistance training control system

3. Design of Clutch Current Tracking Control

In this paper, PWM is used as a way to reduce the clutch pressure, and the bidirectional chopper circuit is used as the main driving circuit of magnetic powder clutch， as shown in Fig. 5. In the picture, magnetic particle clutch (under normal working condition) can be regarded as resistance load R. Forward excitation circuit is a chopper circuit composed of 2 MOSFET of Q1, Q3. The reverse demagnetization circuit is a chopper circuit composed of 2 MOSFET of Q2, Q4. The forward excitation circuit transfers different sizes of current to the clutch, in order to form different strong and weak magnetic fields in the coil, the reverse demagnetization circuit outputs constant current. And to solve the residual magnetism phenomenon of magnetic powder clutch [18].

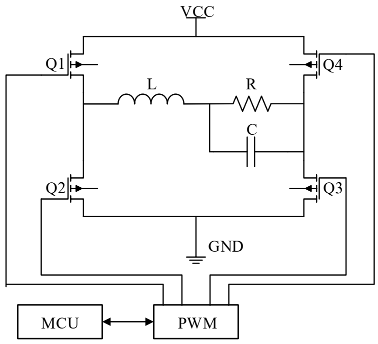


Fig. 5 Clutch power drive circuit

The state space description of the excitation current circuit system is obtained:

$$\begin{cases} \dot{\boldsymbol{X}} = \begin{bmatrix} 0 & -\dfrac{1}{L} \\ \dfrac{1}{C} & -\dfrac{1}{RC} \end{bmatrix} \boldsymbol{X} + \begin{bmatrix} \dfrac{D}{L} \\ 0 \end{bmatrix} \boldsymbol{U} \\ y = \begin{bmatrix} 0 & \dfrac{1}{R} \end{bmatrix} \boldsymbol{X} \end{cases} \tag{1}$$

The driving circuit is a non-linear system. The equivalent resistance of clutch is not a fixed value. It varies according to the load and speed. Besides, the difference between the actual drive circuit and the ideal circuit and the external disturbance in the training process all directly or indirectly affect the current tracking effect [19]. In this paper, BP neural network is used to tune PID parameters to optimize the control effect.

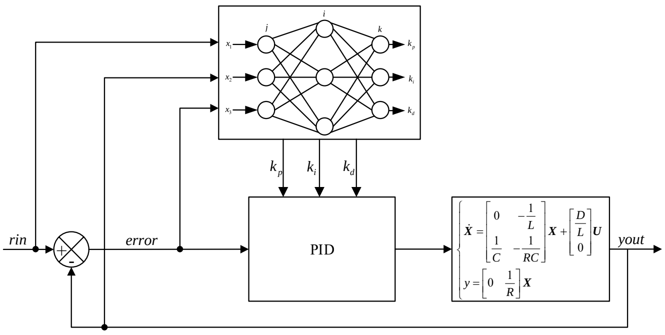


Fig. 6 PID controller based on BP neural network

Fig. 6 shows the structure of PID controller based on BP neural network parameter tuning. Among them, the BP network adopts three layers, three inputs and three outputs. The control algorithms are summarized as follows:

(1) $k=1$. The weights are initialized and the appropriate learning rate and inertia coefficient are selected.

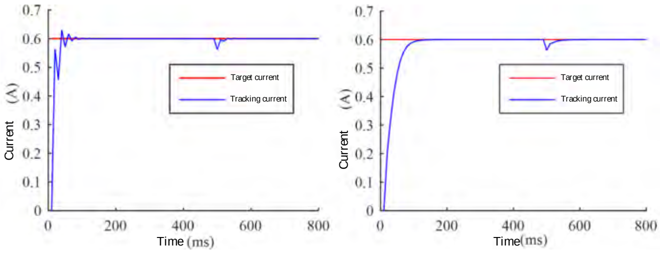
(2) Sampling to get target $rin(k)$ and actual output $yout(k)$. And calculate the time error $error(k)$.

(3) According to k_p, k_i, k_d, Calculate output $u(k)$.

(4) The output layer weight increment $\Delta w_{ij}^{1}(k)$ and hidden layer weight increment $\Delta w_{li}^{2}(k)$ are determined sequentially. Adjust the weight.

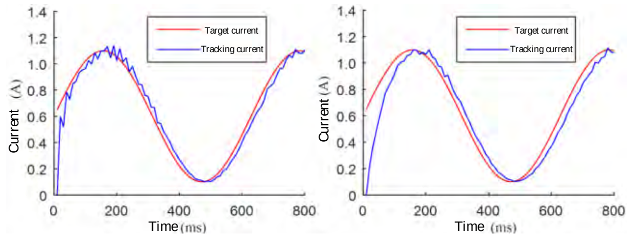
(5) $k=k+1$. Return to (1).

The basic parameters of the driving circuit are as follows: The equivalent resistance (static no-load) of the magnetic powder clutch is 15.3Ω and the input voltage is 24V and the switching frequency is 28.8 KHz and the capacitance is $C=660\mu\text{F}$ and the inductance is $L=0.4\text{mH}$. Set the target current value to 0.6A and add a clutch resistance mutation interference at 0.5 seconds and its size is +1Ω. Fig. 7 (a) and (b) show the simulation results of current step response of digital PID control and BP neural PID control respectively. Fig. 8 a and b show the simulation results of current sinusoidal tracking response of digital PID control and BP neural PID control with resistance disturbance respectively.



(a) (b)

Fig. 7 PID current step response simulation curve



(a) (b)

Fig. 8 PID Current Sinusoidal Tracking Response Simulation Curve

4. Prototype Production and Experiment

4.1 Bottom Current Tracking Control Experiment

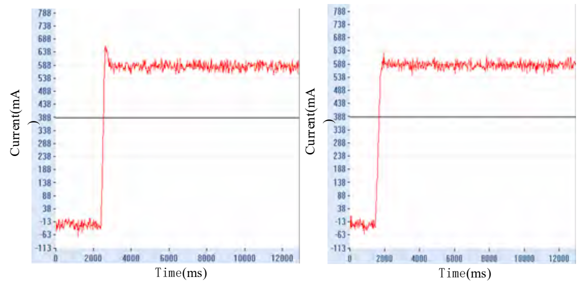
The controller of the magnetic powder clutch is shown in Fig.9. The chip bottom is built with digital PID and BPPID control algorithm, and the upper layer adopts fuzzy sliding mode control algorithm. The magnetic powder clutch is controlled with a nominal torque of 12N. M and a rated current of 1A. The experimental platform is shown in Fig. 10.

Fig. 9 Clutch driver template

Fig. 10 current tracking experiment platform

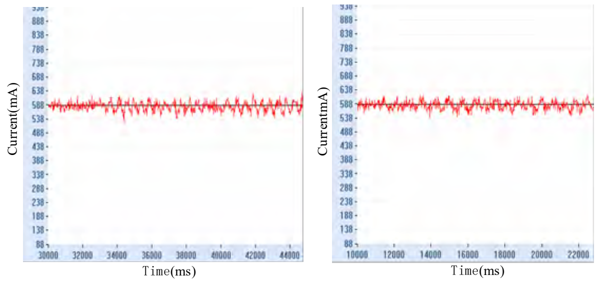
Fig. 12 (a) and (b) are the results of current step response of digital PID control and BP neural PID control respectively. The comparison shows that the digital PID control can respond quickly but has a few overshoots, and the current tracking of the neural PID control can respond quickly without overshoots.

Fig. 13 (a) and (b) are the current anti disturbance experiment results of digital PID control and BP neural PID control respectively. Under the condition of continuous external interference, the tracking current has obvious fluctuation in digital PID control, and fluctuates between 538mA and 621mA



(a) (b)

Fig. 11 Experimental curve of PID current step response



(a) (b)

Fig. 12 Experimental curve of PID current anti jamming

Compared with the simulation results in this section, the actual circuit has more interference, and there are more factors affecting the tracking results. The actual control effect is worse than the simulation results. But whether from the simulation results or experimental results can be seen, the experimental results using neural PID control compared with digital PID control has a significant improvement.

5. Conclusion

In summary, we propose a multi-training mode leg extension training device and a new drive scheme of magnetic powder clutch + motor. BP neural PID control is used to track the current of the most important clutch in the model, and the feasibility and stability of the control method are verified by simulation and experiment, which is of guiding significance for further study.

Acknowledgments

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References

[1]. He Yao.The Strategy of Population Ageing and Healthy Ageing in China[J]. Chinese Journal of Prevention and Control of Chronic Diseases, 2012, 20 (05): 507-509.

[2]. Walsh G S. Effect of static and dynamic muscle stretching as part of warm up procedures on knee joint proprioception and strength[J]. Human Movement Science, 2017, 55:189.

[3]. Taguchi T, Yanagisawa K, Nitta O, et al. The Effect of Isokinetic Leg-press Exercise on the Strength of Lower Extremity Muscles[J]. Bulletin of Saitama Prefectural University, 2002, 4:53-58.

[4]. Wu Chunli, Chen Xiaoqing.Effect of isokinetic muscle strength training of knee flexors and extensors on improving gait in patients with knee osteoarthritis[J]. Orthopaedic Biomechanics Materials and Clinical Study, 2017, 14 (1): 39-42.

[5]. Candow D G, Chilibeck P D, Facci M, et al. Protein supplementation before and after resistance training in older men. Eur. J. Appl. Physiol. 97, 548-556[J]. Arbeitsphysiologie, 2006, 97(5):548-556.

[6]. Bu Fanjun,Yang Ning. Research on the Benefits of Resistance Training for the Elderlt [J]. Journal of Hubei Adult Education Institute,2017,23(04): 88-90.

[7]. Nodehimoghaddam A, Khaki N, Kharazmi A S. Comparison of Shoulder Proprioception between Female Volleyball Players and Non-Athlete Females[J]. Journal of Rehabilitation, 2009, 332(1):45-49.

[8]. Saringer J H. Apparatus for Imparting Continuous Passive Motion to a Lower Limb: US, US4930497 A[P]. 1990-08-13.

[9]. Chen C S, Chiou J H, Tsai S H. Intelligent Nonsingular Terminal Sliding Mode Control for Single-Degree-of-Freedom Knee Rehabilitation System[C]//Taiwan: International Conference on Advanced Robotics and Intelligent Systems. IEEE, 2013:104-109.

[10]. Capodaglio P, Edda M C, Facioli M, et al. Long-Term Strength Training for Community-Dwelling People over 75: Impact on Muscle Function, Functional Ability and Life Style[J]. European Journal of Applied Physiology, 2007, 100(5):535-542.

[11]. Xie Y. Pull Training Device: US, US20150258361[P]. 2015-09-17.

[12]. Simonson R. Method and apparatus for leg press exercise with counterbalance: US, US 5616107 A[P]. 1997-04-01.

[13]. Mcdaid A, Kora K, Xie S, et al. Human-Inspired Robotic Exoskeleton (HuREx) for Lower Limb Rehabilitation[C]//Takamatsu: IEEE International Conference on Mechatronics and Automation. IEEE, 2013:19-24.

[14]. Kora K, Lu C Z, Mcdaid A J. Automatic Tuning with Feedforward Compensation of the HuREx Rehabilitation System[C]//Besacon: International Conference on Advanced Intelligent Mechatronics. IEEE, 2014:1504-1509.

[15]. Rupp R, Schließmann D, Schuld C, et al. MoreGait – Studienergebnisse eines von inkomplett Querschnittgelähmten zu Hause durchgeführten robotischen Lokomotionstrainings[J]. Physikalische Medizin Rehabilitationsmedizin Kurortmedizin, 2016, 26(4).

[16]. Sasaki D, Noritsugu T, Takaiwa M. 2G1-3 Development of Wearable Master-Slave Training Device for a Lower Limb constructed with Pneumatic Artificial Muscles[J]. 2009, 2009:179.

[17]. Liu Jianjian, Chen Zhuping. Magnetic particle clutch and its application [J]. Mechanical & Electrical Technology, 2010, 33 (4): 63-65.

[18]. Li Chufeng, Wang Xudong, Zhou Kai.Excitation and demagnetization system of magnetic powder clutch[J]. China New Technologies and Products, 2010, 2010 (7): 3.

[19]. Zhou Kai, Yang Jisen.Excitation control technique of magnetic powder clutch based on self-turning fuzzy PID [J]. Electric Machines and Control, 2017,21(2): 87-93.