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The control system of high acceleration loading device for football heading training

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ABSTRACT:
Heading training for a football game requires highly on the neck muscle force, according to the change of athletes' head and neck's acceleration in the process of heading. Based on the linear motor's characteristic which can realize large thrust, fast speed and high control precision in a short period of time, high power linear motor is used as power element of the high acceleration load heading training device. Two stepper motors are used to construct a pose adjustment platform to imitate the scene of soccer players heading the ball in different directions and angles. In order to achieve accurate control and data visualization, the upper computer control software is written in C# language, which can set the loading training parameters and display the changes of data in the loading process in real time. Finally, a dummy experiment was carried out to verify the feasibility of the scheme.
Key words: football heading, neck muscle training, linear motor, acceleration loading device

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In the scenes of football player's heading, racing driver's turning, carrier-based aircraft pilot's ejection takeoff, arresting landing and so on, special attention is paid to the strengthening training of neck muscles of participants.

Football heading is using the head to directly contact the ball, often to advance the ball down the field or score. It is a skill fundamental to the game, yet it has come under scrutiny. Repeated subclinical effects of heading may compound over time, resulting in neurologic deficits [1]. Greater head accelerations are linked to brain injury [2]. Developing an understanding of how the neck muscles help stabilize and reduce head acceleration during impact may help prevent brain injury.

The neck muscles actively pull the chest and back muscles for work, so that the body can exert its maximum function and achieve ideal movement. Neck muscle strength is strong, can make the head position get timely adjustment, so that the action is completed more quickly and accurately.

Strength training can enhance the stability and resistance ability of neck exercise, and is an effective method to prevent or slow down neck injuries [3]. According to the purpose, strength training can be divided into maximum muscle strength training, muscle endurance training and explosive force training. According to the purpose of developing muscle quality, training programs are not the same, but all of them have the demand of strengthening head and neck muscle training. A device that can train the strength and reaction ability of head and neck muscles and calibrate the strength of neck muscles is of great significance [4].

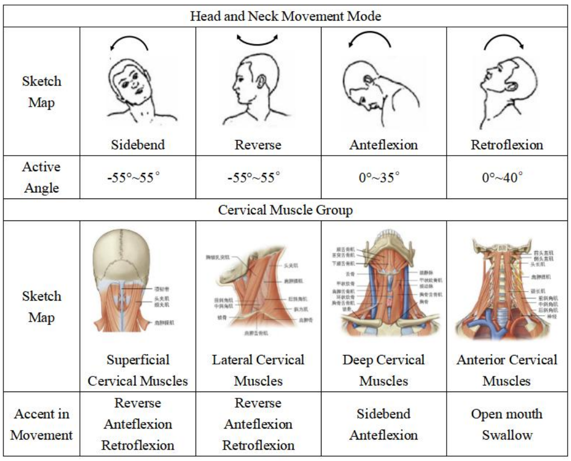
Aiming at the problem of the neck response of football players at the instant of heading the ball, by analyzing the different acceleration magnitude, different acceleration direction and different acceleration growth rate of cervical spine loading, the influence of each factor on neck injury was studied, and the way to strengthen the training of neck muscles was further obtained. With the change of acceleration, the head and neck movement is different, and the force trend of vertebrae, intervertebral disc and muscle tissue is different, leading to different neck injuries. In the past, the dynamic response of the neck was analyzed by high-G load experiment of a large manned centrifuge accelerator. However, due to the large volume, high cost and inconvenient operation, the dynamic response of the neck was analyzed by a series of problems. Therefore, it is of great significance to develop a safe, reliable, accurate, body-adaptive, low-cost, and adjustable neck transient following load simulation platform.

Aiming at the needs of neck muscle stability and resistance ability training, as well as the needs of football players for maximum muscle strength training, muscle endurance and explosive force training [5], a human-machine integration device for neck muscle rehabilitation nursing and intensive training was proposed.

1 Expected Function and Motion Planning

1.1 Overview of the state of each muscle in head and neck exercise.

Movement of the head and neck relative to the trunk usually occurs in one of four modes: lateral bending, twisting, forward bending, and backward extension [8]. Neck movement must be completed with the help of muscles. According to the position and attachment points of neck muscles, neck muscles are divided into superficial neck muscles, lateral neck muscles, anterior neck muscles and deep neck muscles. Table 2.1 shows the movement patterns [9][10] of head and neck and neck muscles.



Head and Neck Movement Mode				
Sketch Map	Sidebend	Reverse	Anteflexion	Retroflexion
Active Angle	-55°~55°	-55°~55°	0°~35°	0°~40°
Cervical Muscle Group				
Sketch Map	Superficial Cervical Muscles	Lateral Cervical Muscles	Deep Cervical Muscles	Anterior Cervical Muscles
Accent in Movement	Reverse Anteflexion Retroflexion	Reverse Anteflexion Retroflexion	Sidebend Anteflexion	Open mouth Swallow

Figure1 Head movement patterns and neck muscle groups

Players were served soccer balls by hand at a mean velocity of 4.29 m/s (±0.74 m/s). Players returned the ball to the server using a heading maneuver at a mean velocity of 5.48 m/s (±1.18 m/s) as shown in Fig2. Mean neck strength difference was positively correlated with angular head acceleration, with a trend toward significance for linear head acceleration [2].

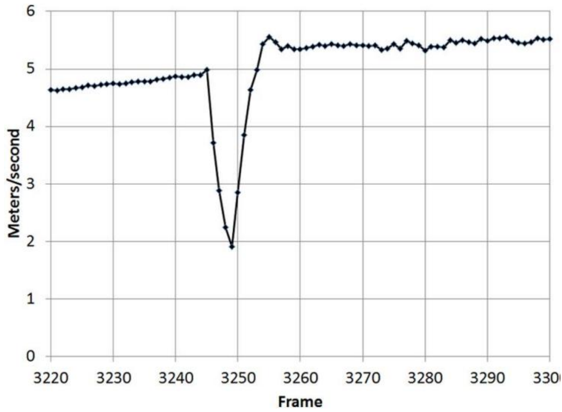


Figure2a Ball velocity change versus time during a 0.22-second window before and after impact with the subject's head.

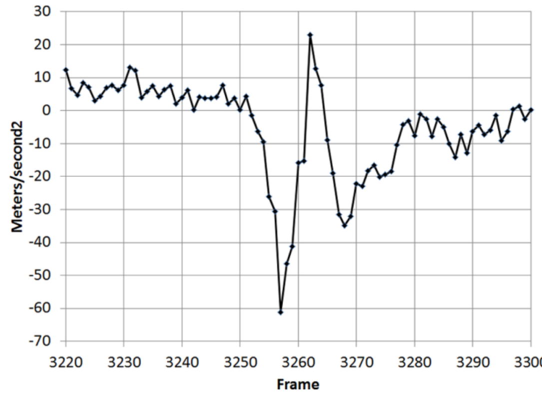


Figure 2b Head linear acceleration change versus time during 0.22-second before and after a heading impact with the ball

1.2 Demand Analysis

(1) The size of head and neck varies between individuals, which requires high height adjustability and wide applicability of the device;

(2) The instantaneous 6G acceleration requires the energy storage mechanism to release energy quickly and stably;

(3) The body posture can be rotated up and down, up and down 100mm; After the body is rotated ±90°, the head and neck are aligned by coarse rotation and fine adjustment of the chair back.

(4) After the body rotates ±90°, the head and neck alignment are ensured by the coarse adjustment of the rotation and the fine adjustment of the chair back;

1.3 High acceleration motion planning for short range of head and neck

From the perspective of safety, the moving range of the human neck is 100mm. To achieve high acceleration movement in a small stroke, the sum of the displacement of the acceleration section, the displacement of the uniform section and the displacement of the deceleration section of the linear motor should be within the movable range of the human neck, and the stable acceleration movement time should be maintained at 25ms，as shown in Fig3.

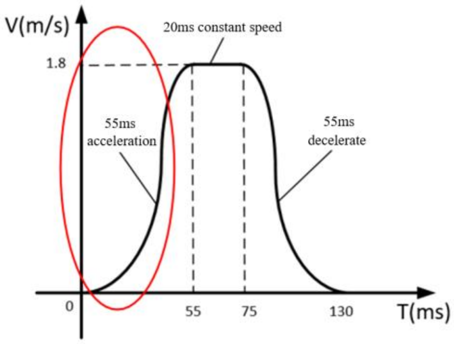


Fig3 Velocity planning curve

1.4 The proposal of the novel football heading training device

Aiming at the needs of neck muscle stability and resistance ability training, as well as the needs of football players for maximum muscle strength training, muscle endurance and explosive force training, a human-machine integration device for neck muscle rehabilitation nursing and intensive training was proposed.

The device uses a high-thrust linear motor to generate high acceleration. The athlete sits on a rotating and lifting seat, and the neck and the linear motor contact through the head gripping device to drive the neck to achieve high acceleration movement.

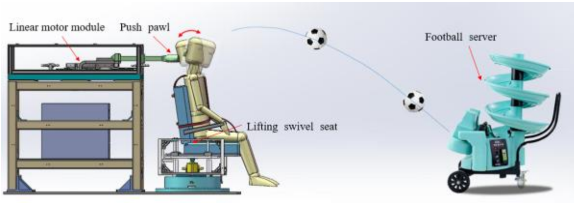


Figure5 Head movement training principle diagram

The high acceleration simulation part of the neck transient load loading training platform acts on the head of the dummy with a total height of 1341mm and a push claw height of 1207mm. The flatness of the base of the linear motor is 0.05, which ensures smooth operation, no impact, no abnormal vibration and noise during operation. Neck transient load body posture adjustment part minimum height 314mm, can carry 150KG and ensure stability.

The pose adjustment part is to adapt to the loading training of the neck muscles with different heights and different directions, which can lift, rotate and lock the position, and ensure the stability of the seat in the acceleration loading training.

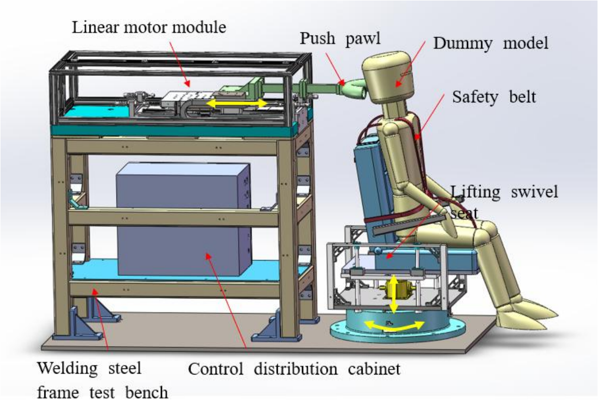


Figure4 Training device 3D model diagram

2 Designing of Control Flow Chart and Component of the High Acceleration Loading Device

Linear motor module: Selecting Hiwin LMSA34 type linear motor with high thrust core, which can be matched with Hiwin E1 driver for motion control. The instantaneous current used is small, the response time is fast, and the driver can be driven stably, as shown in Figure 6.

The continuous thrust of the silver LMSA34 motor is 1166N; Under this thrust, the continuous driving current is 8.0A, the instantaneous current is 24.0A, and the driving current can last for 1s. Limit current 40A; Limit thrust is 4314N, sustainable 0.5s, motor stator attraction is 5777N; The electrical time constant was 4.9ms, and the kinetor weight was 7.6KG. Bearing plate size 470 x 280 x 35, weight 12KG; As shown in Figure 5.4 and 5.5.

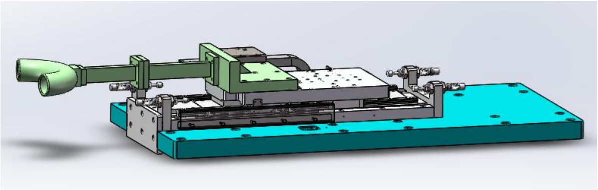


Figure6 Structure diagram of linear motor

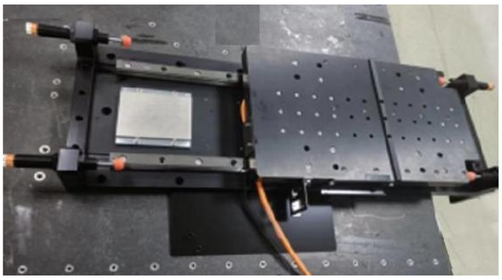


Figure7 Prototype drawing of linear motor

Linear motor power formula are as follows：

$$P_{dq}=\frac{3}{2}(u_d i_d+u_q i_q)$$
$$=\frac{3}{2}\left[(i_d^2R_s+i_q^2R_s)+(i_d\frac{\partial\psi_d}{\partial t}+i_q\frac{\partial\psi_q}{\partial t})+\frac{\pi v}{\tau}(\psi_d i_q-\psi_q i_d)\right] \quad (1)$$

The first term is the loss of the motor, the second term is the reactive power of the motor, and the third term is the electromagnetic thrust of the motor. That is, the horizontal thrust of high acceleration motor is expressed as:

$$F_e=\frac{3}{2}\frac{\pi}{\tau}\left[\psi_f i_q+(L_d-L_q)i_d i_q\right] \quad (2)$$

Reynisau grating sensor: A position feedback measuring device with an assembly accuracy of 1 micron is adopted. Readings in the head and feet as the instructions of the grating lattice spacing, and the reading head itself has the LED light source, when reading head moving relative to the grating ruler, LED light after the focusing lens, exposure to the grating ruler, and then light through the slit grating, diffraction to the end of the reading of the photoelectric detector, thus in the detector plane, the alternate sinusoidal interference fringes of light and shade [11]. As shown in Figure 8 and 9.

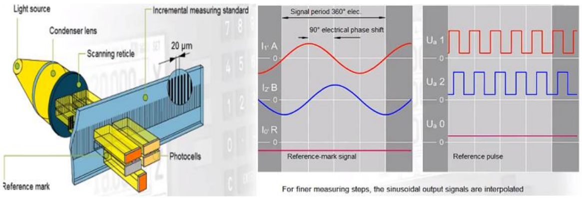


Figure8 grating sensor functional diagram

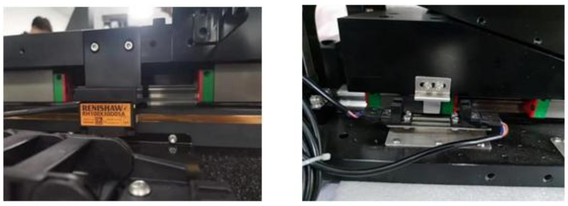


Figure9 Installation position of grating sensor

Figure9 Physical picture of training device

3 Hardware Composition of the control System and System Block Diagram of Heading Training Device

The electrical control part of the high acceleration loading device for football heading training is mainly integrated in the control cabinet. It includes 24V switching power supply, Siemens S7-1200PLC, 5KW E1 linear motor driver of Shanghai Silver Company, 57 stepper motor driver for rotary adjustment, 60 stepper motor driver for lifting adjustment, contactor, relay, circuit breaker, connector, button, indicator light and travel switch, photoelectric switch and other components [6][7].

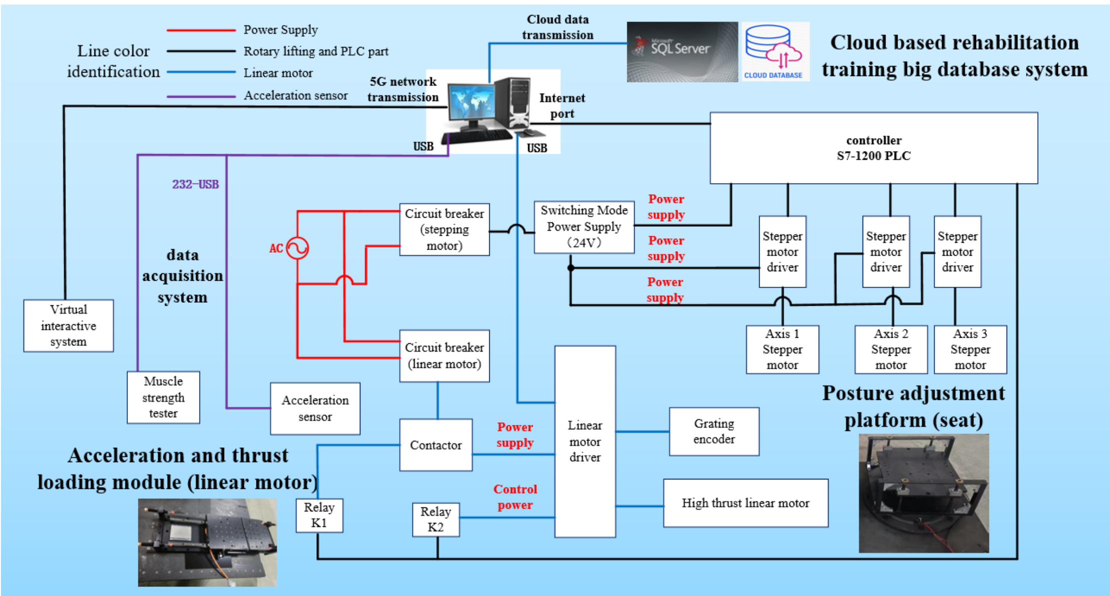


Figure9 Control schematic diagram

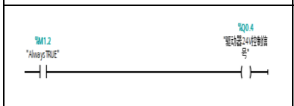
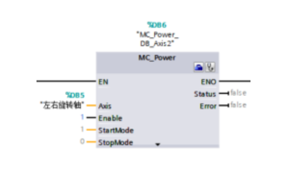
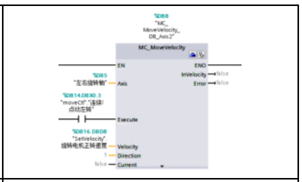
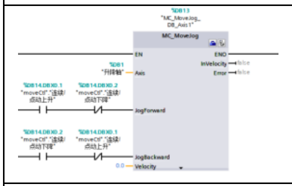
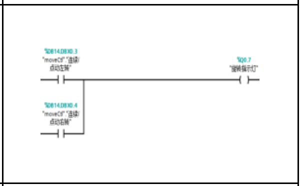
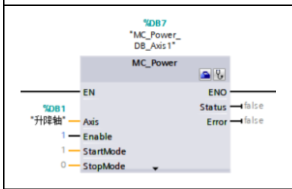
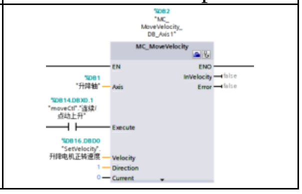
The high acceleration loading device for football heading training is mainly divided into two parts: linear motor impact module and chair rotating lifting platform; The linear motor module is connected to the PC through the USB universal serial bus interface, the rotating lifting platform is connected to the PC through the RJ45 network port, and the acceleration sensor is transferred to the PC through the 232-USB module, as shown in Figure9.

Figure9 Control cabinet

2.1 **PLC Controller based Pose Adjustment Platform**

The rotary and lifting platform includes the lifting motor and the rotating motor and its corresponding driver, the stepper motor driver power supply voltage is 24V, the stepper motor through the lower machine Siemens S7-1200PLC control, can be written by C# Windows application side speed and direction Settings, And S7-1200 is connected with a limited bit photoelectric switch, when the rotation or lifting motor movement to a limited position can send pulse signal to the PLC signal input end, PLC signal output end starts the corresponding pulse signal to stop the motor rotation;

Table1 :Main control program of lower computer controller

Switch on the control power of E1 driver of linear motor	Delay the connection of three-phase power supply of linear motor E1 driver
	
Enable/disable the seat rotation axis	Rotate the seat rotation axis at the set positive transmission speed
	
Inching rotation of seat rotation axis	Rotating indicator light
	
Enable/disable the seat lifter shaft	Rotate the seat lifting shaft at the set positive transmission speed
	

2.2 **DSP Core Driver Based Linear motor Control System.**

Linear motor module mainly includes the contactor and relay control circuit, the output power is divided into 24 v power supply and the control of three-phase 380 v power supply, when and only when the control power supply and power supply switched on when the linear motor can exercise at the same time, the linear motor based on MPI library Windows software developed by C # the upper machine control, acceleration time can be, The setting of the maximum speed, deceleration time, motion stroke, etc.

Before each loading training, the straight point needs to be returned to zero to ensure the effective stroke of neck movement during loading training. In addition, the position of zero can be set by the host computer to conveniently meet different training requirements.

4 **C-Sharp .NET Framework Upper computer Control Software**

C# language is used to write the PC desktop control software of neck simulation loading platform. The interface can be divided into parameter setting area, operation area and data display area, aspect operation setting and data visualization.

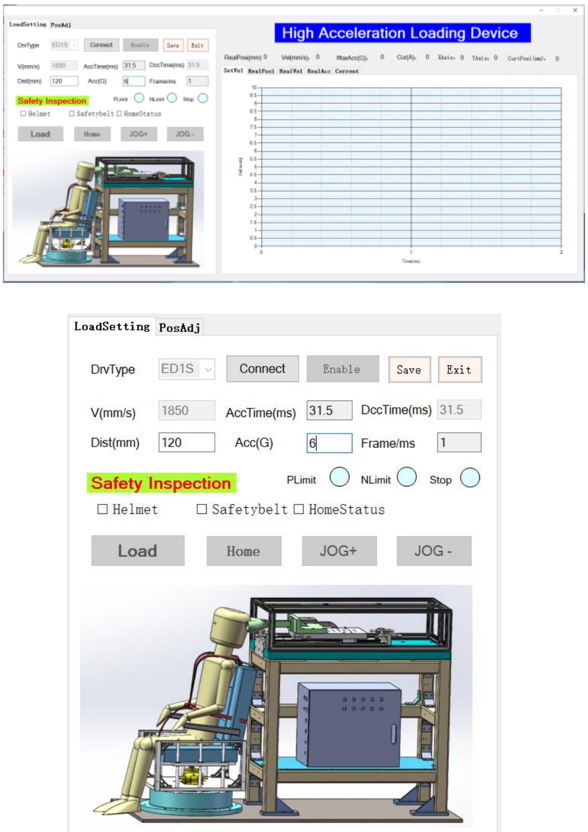


FIG.10 Software interface

Operation Procedure Description

1.Operation mode selection

Click " LoadSetting PosAdj " on the top menu bar to switch the control mode. Specifically, click the left interface of seat setting to switch to the "seat lifting rotation adjustment area", which can adjust the height and Angle of the seat to conveniently meet different test requirements. You can also input the speed, height or Angle for quick adjustment.

2. Drive connection and servo enable

If the user selects the " LoadSetting " test bench button, click "Connect to Drive" in sequence "B" and then click "Servo Enable on". The "Servo Enable" button is unavailable by default when the drive is not connected. Click C to exit the system.

3. Loading parameter setting (parameters to be input, only distance value and acceleration value)

In the parameter setting area, acceleration and running distance can be set;

" Dist(mm) 120 Acc(G) 3 ".

The maximum speed, acceleration time and deceleration time are automatically calculated according to the input acceleration and distance;

" V(mm/s) 1608 AccTime(ms) 54.7 DccTime(ms) 54.7 "

4. Safety check and testing start

Safety check is required before the test. If the helmet has been worn and the safety belt is fastened, and the motor has returned to the initial position, test " ☐ Helmet ☐ Safetybelt ☐ HomeStatus " can be carried out after checking the following selection box. Click Start test " Load " to accelerate the motor for training;

5 Data visualization

On the right side of the control window, real-time data and data waveform diagram can be observed, such as real-time position and velocity, acceleration and current " RealPosi(mm) 0 Vel(mm/s): 0 MaxAcc(G): 0 ";

On the top of the data waveform diagram, click the corresponding button to switch the display object of the data curve. " SetVel RealPosi RealVel RealAcc Cerrent ".

5 Experimental Verification

The actual running test of the neck muscle loading training device for heading ball shows that the acceleration output curve is consistent with the expectation.

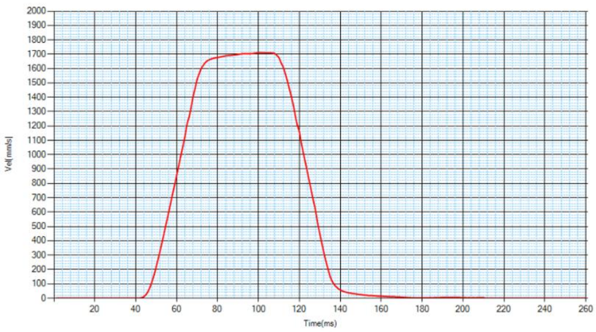


FIG.11 Velocity curve

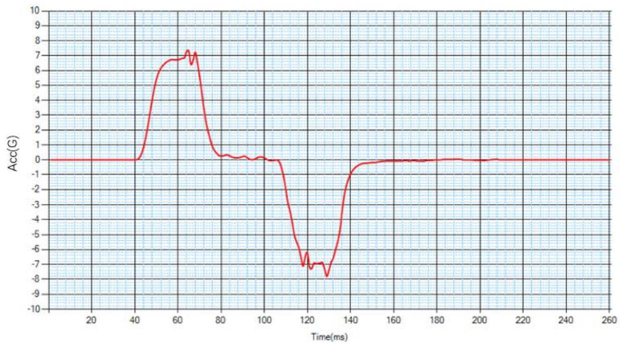


FIG.12 Acceleration curve

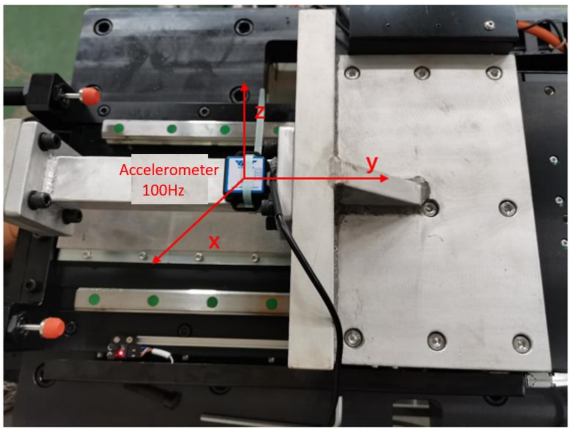


FIG.12 Accelerometer measurement

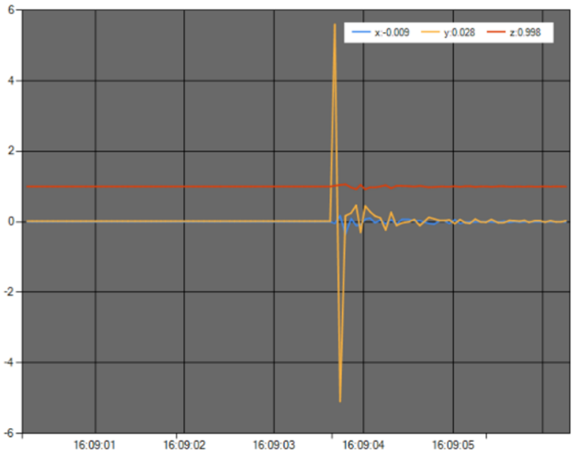


FIG.12 Curve of accelerometer

6 Conclusion

The specific innovations are as follows:

(1) Considering the characteristics of the traditional large centrifuge acceleration simulation loading device which occupies space and consumes high energy, a miniaturized acceleration loading training device for neck muscles is constructed creatively.

(2) Using linear motor as the power component, it can achieve large thrust in a short time (110ms) and within short distance (120mm), and thus achieve the purpose of 6G acceleration loading training, and the transient loading training characteristics of the device make less energy consumption

(3) In order to simulate the requirements of neck muscle training in different scenarios, the upper computer control software is programmed using C#, which can set and feedback the loading training parameters in real time and in high accuracy. Also the origin position can be set conveniently on the interface of the upper computer software to meet the loading requirements of different stroke.

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