Perspective Of Different Actuators of Hand Rehabilitation Robot and Wearing Safety

Mengqi Liu

College of Information Science and Engineering, China University of Petroleum-Beijing, Beijing 102249, China

* Corresponding Author Email: 2020010522@student.cup.edu.cn

Abstract. Stroke is a common acute cerebrovascular disease in middle-aged and aged people over 40 years old. With the development of science and technology, more and more patients with stroke related diseases are using hand rehabilitation robots for hand rehabilitation treatment. The body of middle-aged and aged people is weak and easy to be injured, so the safety of hand rehabilitation robot is very important. In this review, the selection and analysis of the new driving mechanism of the hand rehabilitation robot are reviewed. Based on the reference, analysis and summary of several literatures, the work characteristics and safety applications of different actuators of hand rehabilitation robot are compared Transverse and Longitudinal. Through the analysis and reference of key data and its structure and other dimensions, a detailed comparison and comprehensive analysis were made on how to improve the wearable comfort of the hand rehabilitation robot, which can provide a reference for hand manufacturers or users.

Keywords: Hand rehabilitation robot; wearing safety; actuator.

1. Introduction

Cerebral stoke will bring great inconvenience to patients and their families, patients need families accompany for normally living, cerebral stoke exercise rehabilitation follows the principle of "from big to small", hand rehabilitation as the small stage needs longer treatment periods and high costs, this will cause many families financial difficulties, at the same time, the number of physical therapist in China are less than other developed countries, so, some patients cannot get enough rehabilitation support from traditional rehabilitation. So, in order to help patients to get better and personalized rehabilitation medicine and treatment, the hand rehabilitation robots have become the focus of mechanical research in recent years.

Current research for hand rehabilitation robots drives more and more deeply, but to hand the choice of the rehabilitation robot drive and its links with the wear safety research summary, there are certain gap, so this review focused on the choice of drive and rehabilitation robot hands wear scientific summary and analysis of security, this work hope to make a contribution to the selection of actuators for future hand rehabilitation robots.

This article is based on the existinghand exoskeletons, With the change of working conditions such as working temperature and working time, whether the change of working performance of different actuators can meet the requirements of wearable safety of hand rehabilitation robots.

2. Analysis of Motor Device used by Hand Rehabilitation Robot

2.1. Motor Actuator

Motor actuator is an electromechanical actuator that converts electrical pulse signals into line displacement or angular displacement through internal processing. The control method of stepper motor is simple and the cost is low. Only electrical pulse signal can realize the motor operation, suitable for mass production. The speed of the stepper motor is linearly related to the frequency of the input pulse signal. When used as the actuator of the hand rehabilitation robot, the motor actuator has the characteristics of cumulative error, which makes its control precision more accurate. At the same time, within the appropriate working range [1], its speed is linearly related to the frequency of

the input pulse signal, which makes the hand rehabilitation robot easier to control. These advantages can effectively reduce the safety injury caused by inaccurate control when the user uses the hand rehabilitation robot driven by the stepping motor.

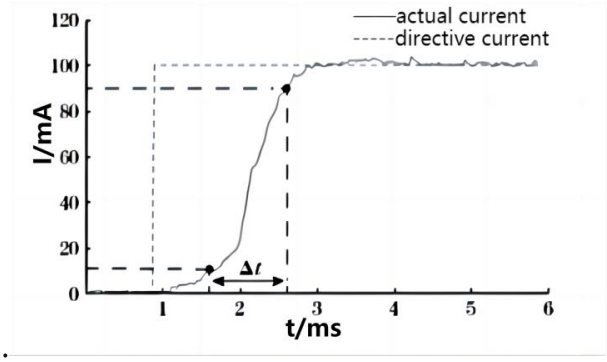


Fig. 1 Multilevel motor actuator step response rise time experiment [2]

It can be seen from Figure 1 that the response time of the motor actuator is about 1ms without obvious overshoot [2]. The quick response capability is in line with the safety of the hand rehabilitation robot and can help the hand rehabilitation robot synchronize with the user's behavior without significant delay.

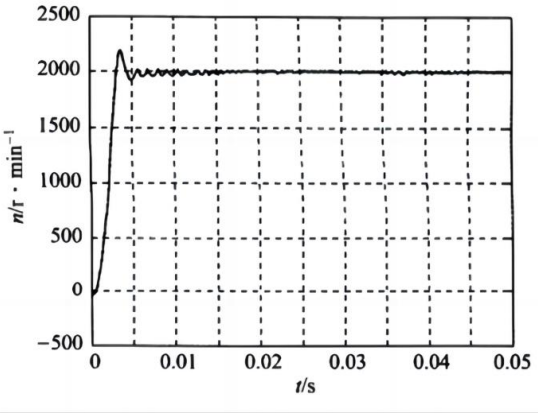


Fig. 2 Motor no-load start speed time image [3]

As can be seen in Figure 2, under no-load conditions, the speed of the motor actuator will start with a small jump and then drop to a stable speed. This process takes only a short time. For hand-held robot applications, this effect is ignored from the user's perspective.

2.2. Shape Memory Alloy Actuator (SMA)

Shape memory alloy (SMA) is a special alloy. At low temperature, shape memory alloy stiffness is small, easy to change shape. When the temperature rises to the critical value, the stiffness increases abruptly and the shape then returns to the state before deformation [4]. At the same time, the shape memory alloy has a large degree of freedom and no direction dependence, so the shape can be changed in any direction. The deformation of soft robot is driven by its expansion and contraction under temperature change and high degree of freedom. The extension range of linear SMA line is limited, and the deformation of the robot as a actuator is also limited. At present, a common practice is to make SMA into coil spring, which can significantly increase the expansion of the actuator [4]. As can be seen from Figure 3, MSAM is a representative SMA material series. Compared with the other three popular materials, MSAM has obvious advantages in deformation rate, energy density, energy conversion efficiency and energy conversion efficiency through comprehensive consideration from the four dimensions of deformation rate, energy density, energy conversion efficiency and response. The excellent deformation rate, energy density and energy conversion efficiency make MSAM have good driving characteristics [5].

Material	deformation quantity (%)	energy density /(kJ/m³)	energy conversion (%)	response time /μs
Piezoelectric crystal material	0.1	5	40	<1
Giant magnetostrictive material	1.5	25	60	<1
MSMA	10	90	90	<1 000

Fig. 3 The performance comparison of smart materials[5]

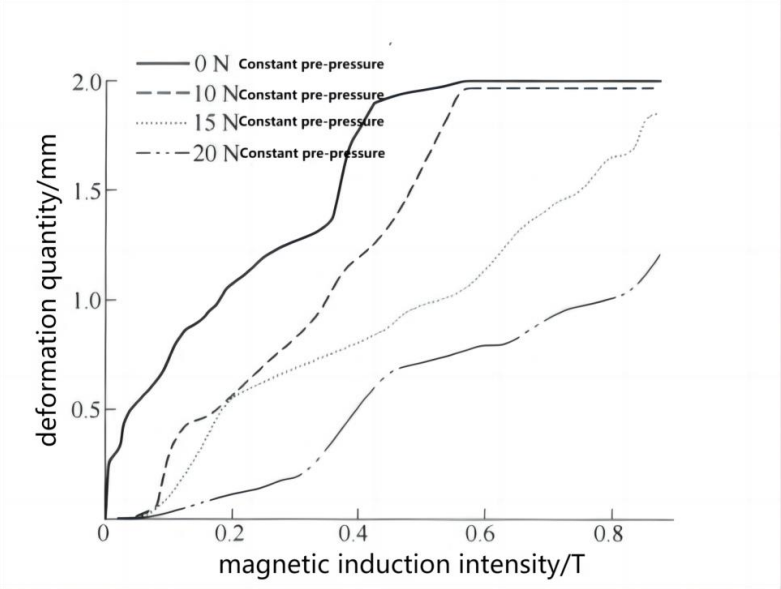


Fig. 4 Relationship between induction intensity and shape variable(22℃) [5]

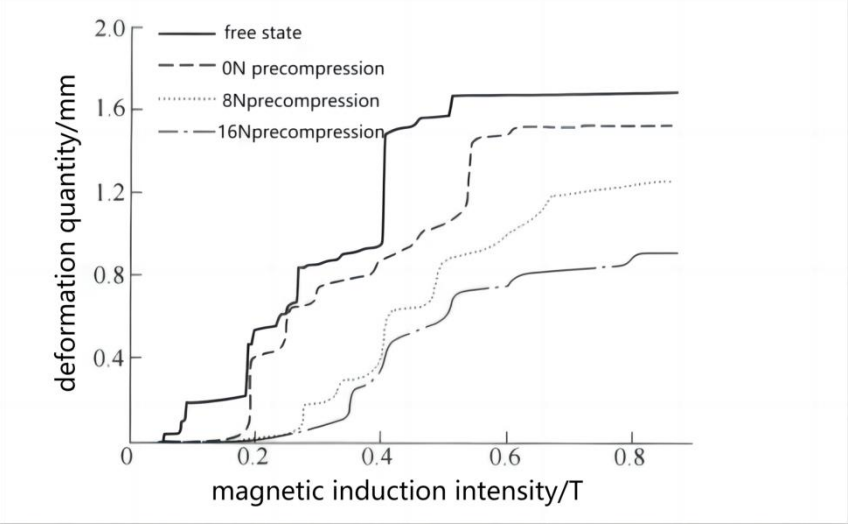


Fig. 5 Relationship between induction intensity and shape variable (28℃) [5]

From the induction intensity and shape variables of MSMA material actuators in Figure 4 and 5 at 22 degrees Celsius and 28 degrees Celsius respectively, it can be seen that the maximum shape variable of MSAM decreases with the increase of pre-pressure. When the ambient temperature is 22℃, the maximum size variable of MSMA material in the completely free state can reach 2mm, but when the temperature rises to 28℃, the maximum shape variable of MSAM is reduced to 1.6mm. At the same time, it can be seen from the figure that there is a threshold value of magnetic induction intensity in the deformation process of the material.Only when the magnetic induction intensity is

greater than the threshold value, the material will undergo obvious deformation. The threshold values of test samples are also different due to the difference in operating temperature and pre-pressure [5]. Therefore, SMA actuators have good shape degeneration, and there is a trend of drive deformation caused by environmental temperature with the increase of working time, which may cause the threshold deformation caused by the change of environmental temperature when users use the hand rehabilitation robot, resulting in the structural changes of the robot affecting the safety of wearing.

When the response curve with load based on SMA is used, as shown in Figure 6, the data show that the response time also changes significantly with the increase of load. Patients with hand rehabilitation may have insufficient driving power due to need, which may not be able to fully meet the demands of patients in the face of heavy load.

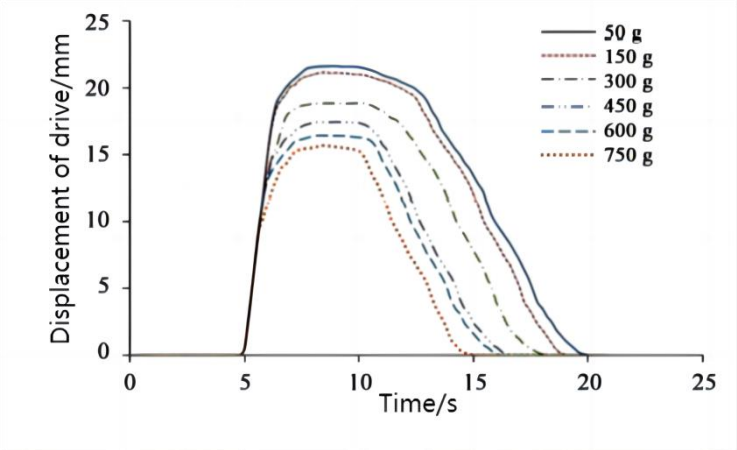


Fig. 6 Polygon SMA actuator load response curve [6]

SMA - based actuators may increase their operating temperature due to power loss during use. In order to further explore its working efficiency under the condition of temperature variation, the variation of driving voltage under different ambient temperatures is shown in Figure 7. As can be seen from the fitting figure of driving voltage and ambient temperature, the driving voltage of SMA actuator significantly decreases with the increase of temperature, and it is unable to maintain a stable driving voltage, which poses great safety risks for hand rehabilitation robots using SMA actuators. With the increase of working time, the accumulated power loss of the actuator is partially converted into heat energy, resulting in the increase of working temperature. As a result, the driving voltage of the actuator is reduced, resulting in reduced driving capacity. Therefore, for the patients who use the hand rehabilitation robot, there may be problems such as insufficient driving force and unsatisfactory driving effect after long-term use, resulting in potential safety hazards.

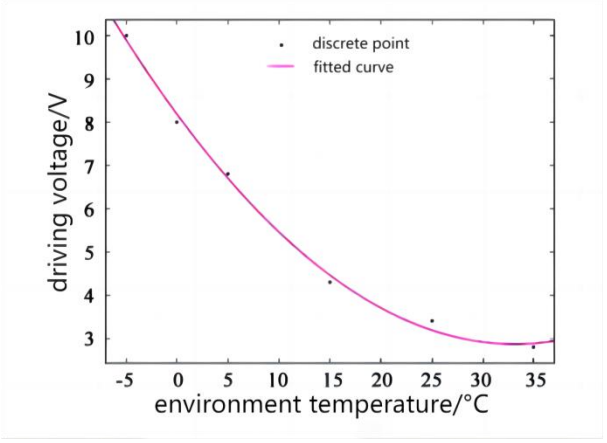


Fig. 7 Drive voltage and ambient temperature fitting diagram [6]

2.3. Pneumatic Artificial Muscle Actuator(PMA)

Pneumatic artificial muscle actuator has simple structure, compact structure and low price. Material costs are much lower than other actuators, such as shape memory alloys, and manufacturing costs are low because there are few machining accuracies issues. And easy to install. Compared with the actuator such as the cylinder, its installation does not need complex mechanism and accuracy requirements, and can even be installed along the corner, so the maintenance is very convenient. In addition, its smooth movement, rapid response, can achieve very slow movement. There are no sliding parts, no friction, and its movement is closer to the natural biological movement [7]. Artificial muscle actuators have a high-power output and a very high weight ratio. It is good to provide enough power to support the various motion commands given to the user.

The disadvantages of pneumatic artificial muscle are also very obvious. Compared with the traditional pneumatic actuator, the pneumatic artificial muscle has a small stroke, and the pneumatic artificial muscle can reach 20% under empty load. When loaded, it can only reach 10%, while some traditional cylinders can reach 40%. The deformation of pneumatic artificial muscle is nonlinear. It is very difficult to control its displacement accurately. In the process of working, the temperature of pneumatic artificial muscle will change. As the temperature changes. Its performance can also change - making it difficult for high-precision control [8]. Its deformation is nonlinear and large, so it is very difficult to accurately control its displacement. At the same time, its conveying pipeline is relatively long, the noise is relatively large, and the pressure loss is easy to be caused, which also forms a certain threat to the safety of wearing [9].

According to Fig. (a) and Fig. (b) in Figure 8, during the inflating process of the pneumatic artificial muscle, vibration occurs during the contraction stage of the pneumatic artificial muscle due to the flexible structure of the pneumatic manual muscle and the influence of the inertial load, accompanied by the phenomenon that the pressure in the chamber is slightly greater than the pressure of the air source. Fig. (c) and Fig. (d) show the variation curves of pressure and length in the working chamber during the exhaust elongation of pneumatic artificial muscle. As can be seen from the figure, in the process of exhaust elongation, the pressure in the working chamber of the pneumatic artificial muscle gradually decreases and its length extends, accompanied by vibration phenomenon. This is also due to the influence of the flexibility of pneumatic artificial muscle itself [10].

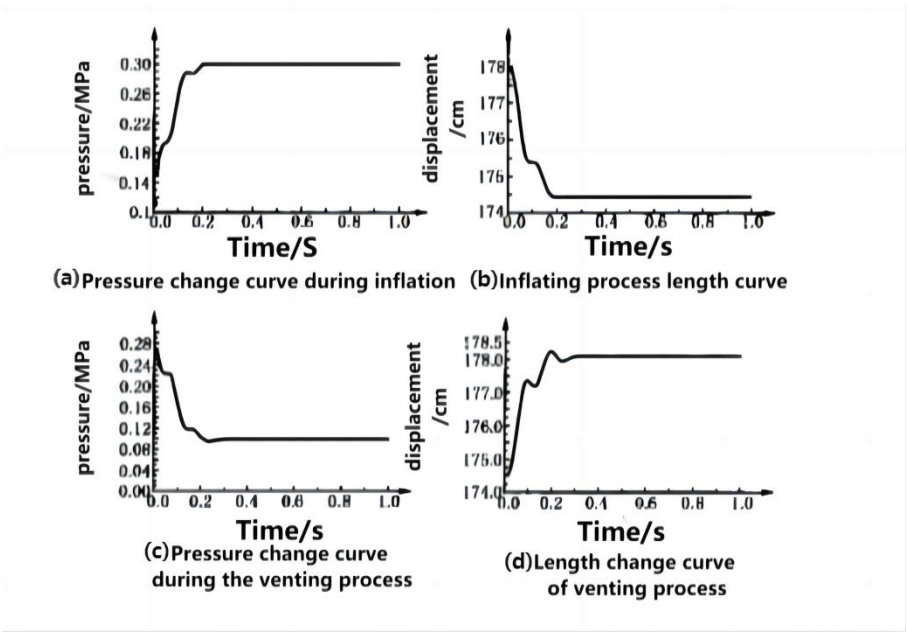


Fig. 8 Pneumatic artificial muscle change curve[10]

The vibration phenomenon will make the user use the hand rehabilitation robot to grab things, the vibration phenomenon at work may cause the captured object to fall, resulting in functional defects, and even directly endanger the user wearing safety.

2.4. Dielectric Electroactive Actuator Polymer (DEAP)

The dielectric electroactive polymer actuator is wound by DEAP film, which has compact structure and high output force. Under voltage excitation, cylindrical actuators can realize linear, bending and other multi-degree of freedom movements, similar to biological muscle bundles, and can simulate the movements of natural organisms, such as the arms of snakes and octopuses [11]. According to the actual stress-tension rate curve and fitting curve in Figure 9, it can be seen that the DEAP driver has good tensile performance and relatively accurate tensile control performance.

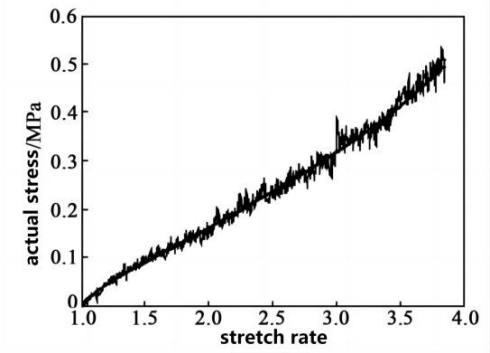


Fig. 9 Actual stress-tensile rate curve and fitted curve [11]

The main safety hazard of DEAP actuator is that there are three failure modes: mechanical strength failure, dielectric breakdown strength failure and wrinkle. The mechanical strength failure of the actuator is mainly determined by the strength of EAP membrane material. When the film of the driving material is stretched beyond its allowable stretching range, the internal molecular structure of the film will be destroyed, resulting in the film tearing and mechanical strength failure. When a voltage is applied to the electrode, the resulting electric field thinns the EAP film, while a stronger electric field thinns the film. This positive feedback process leads to rapid thinning of EAP in the direction of thickness. When a certain critical electric field E "is exceeded, the actuator will fail and lose its working ability. The dielectric breakdown strength is mainly determined by the physical and chemical properties of the material itself and can be determined by experiments. Creasing usually precedes the dielectric breakdown of EAP films, as shown in Figure 1. After wrinkling, the film becomes soft and the area increases. When the electric field it receives is greater than its breakdown strength, the film will be broken down and the driver will be destroyed [12].

When the actuator produces the above three failure modes, the hand rehabilitation robot based on DEAP actuator will suddenly stop working or its working efficiency will be greatly reduced, and it cannot carry out normal rehabilitation work. Serious safety risks may arise when users perform lifting operations such as grabbing.

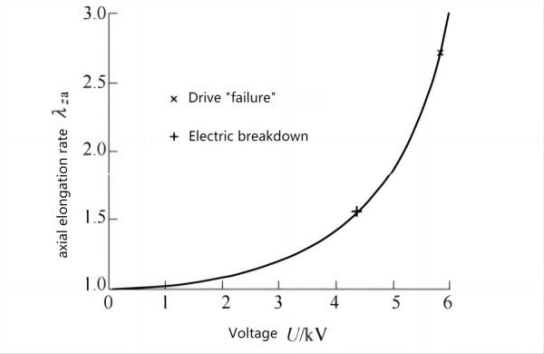


Fig. 10 Actuator U-λza curve[13]

As can be seen from Figure 10, with the increase of voltage, the axial elongation of the actuator increases and the displacement change slope increases. However, there is no electromechanical instability within the operating range of the actuator [13].

3. Discussion

The actuator is the core component and "switch" of the hand rehabilitation robot. Its importance and irreplaceability are self-evident. The working conditions and performance of different actuators are not the same, so in the face of different working environments, different users should choose according to the relevant characteristics of the actuator, in order to improve the work efficiency and safety. At present, the research on hand rehabilitation robot actuators is more and more comprehensive and in-depth, but the work characteristics of different actuators for different users and different uses are still less summarized. For example, when the manufacturers of hand rehabilitation robot design and manufacture actuators, it takes a certain amount of time to retrieve and read the relevant scientific research literature of hand rehabilitation robot actuators, and it may not be possible to quickly and systematically summarize the work types, working objects and situations of different actuators in a short time. This may make the results of design, manufacturing and research not very accurate and may affect the efficiency of the design, manufacturing and research process. This paper mainly introduces four kinds of common actuators: motor actuator, SMA actuator, PMA actuator and DEAP actuator, and summarizes their operating characteristics and application security characteristics. As stroke patients account for the majority of the elderly, the application safety of hand rehabilitation robot actuators is more important. Through this review, units producing and designing hand rehabilitation robots can understand the different application characteristics of these four kinds of actuators in terms of safety, so as to design and manufacture more conveniently and efficiently. In order to make the users of the hand rehabilitation robot have a more comprehensive and rapid understanding of the application safety of the hand rehabilitation robot actuator, it can provide a reference for the users when choosing the hand rehabilitation robot, avoid some safety errors caused by the performance of the actuator itself, and choose the products suitable for their specific conditions.

4. Conclusion

Every coin has two sides, things will never have the best, so different drives have different disadvantages at the same time, the motor drive from the perspective of the hand rehabilitation robot user wears the cost and the high cost of performance is relatively low, the control precision and synchronization drive and behavior, but at the same time, the traditional drive shell hard shell, easy to produce collisions and other user safety risks, and Easy to heat, these will have a certain negative impact on the use experience. As a new material, SMA has very small stiffness and soft texture at low temperature. When the temperature rises to a certain point, the stiffness increases sharply and the shape changes back to its previous deformation. It has the function of remembering the shape and type, which makes the change of its shape and type relatively small. When it is used as the driving structure of the hand rehabilitation robot, it has almost no influence on the hand rehabilitation robot. The flexible material and flexible properties have to escape the safety threats of the immediate users of the case, but because it is memory metal, its stiffness and flexibility change with temperature. When heat is generated during operation, the operating temperature will rise, which may cause the flexible SMA actuator to harden, which may bring potential safety problems to users. When using SMA drives, special attention should be paid to the heat dissipation capacity of the system. PMA has the advantages of simple driving structure, low material cost, and incomparable price advantages of SMA and other emerging materials. Compared to conventional motor drivers, the same flexible materials pose no immediate safety threat to the user housing. The exhaust process exists in its working state. If the scheduling process is carried out for a long time, the pressure in the working chamber of the pneumatic artificial muscle will continuously decrease, while the elongation of the pneumatic artificial muscle will increase, and vibration phenomenon will occur. When the hand rehabilitation robot is used to grab work items, the vibration phenomenon may cause the grabbed items to fall, resulting in functional defects, and even directly endanger the user's wearing safety. Dielectric EAP actuator has compact structure, large driving output force, and can carry out multi-

DOF transportation. This makes the entire structure of the hand rehabilitation robot more lightweight and allows the user to perform a set of actions comfortably and conveniently. However, from the point of view of wearing safety, it has certain defects. When the thin film of the driving material is stretched beyond its permitted stretch range, the structure of the DEAP drive is damaged, causing the film to tear. When the motor voltage exceeds the critical electric field E ", the film layer of the driving material will rapidly thin in the thickness direction, accompanied by wrinkling, and then the film layer will become soft, the area will increase, and the film layer will crack and break. The above symptoms may cause the drive to not work properly or even stop working immediately. For the DEAP driven manual rehabilitation robot users, if the driver suddenly fails when the user is carrying out the main power movement such as lifting and grasping, the user's main power movement with the assistance of the manual rehabilitation robot will suddenly stop, which may cause pain such as cramps and dislocation. If the user is a fragile constitution of the elderly, it will even lead to dislocation, fracture and other serious pain, there is a huge risk of wearing safety. In order to prevent the above phenomenon, the tension range of the driving material and the electric field of the input electrode in the DEAP driver must be strictly controlled.

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