Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

P2-36

POWER ASSIST WEAR FOR UPPER LIMB DRIVEN BY SHEET-LIKE PNEUMATIC RUBBER MUSCLE

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ABSTRACT

Along with declining birthrate and a growing proportion of elderly, to increase the number of people who requires nursing is anticipated. As a result, the shortage of the workers in medical welfare field is serious concerns in Japan. Then, if the wearable power assist device can be developed, many people can live independent life with a slight degree of assist. The purpose of this study is to develop a power assist wear to assist an activity of daily living of aged or disabled person. For the actuator, it is required to have a compact, light-weight and flexibility. Developed sheet-like curved type pneumatic rubber muscle is made of rubber band and has a high affinity for human skin. In this paper, the characteristics of the sheet-like curved type pneumatic rubber muscle and the power assist wear are described.

KEY WORDS

Pneumatics, Power assist, Soft actuator, Wearable device

INTRODUCTION

In Japan, the number of people who requires nursing is anticipated by the reasons below.

1. Declining birthrate and growing proportion of elderly
2. A muscular weakness associated with physical handicap

As a result, the shortage of the workers in medical welfare field is serious concerns. However, people accredit the nursing necessary level 2 or less are accounts for 64[%] of the whole [1]. Then, if the wearable power assist device can be developed, many people can live independent life with a slight degree of assist.

The McKibben type pneumatic rubber muscle is a typical actuator for a power assist device [2] and availability of power assist device such as muscle suit which using this actuator is confirmed [3]. However, it is required to be compact and light as clothes when using in daily life. If the development of power assist device which has soft structure and can be wore as a sense of wearing clothes can achieve, it is useful for the people who only requires slight degree of assistance.

The purpose of this study is to develop a sheet-like curved type pneumatic rubber muscle and the power assist wear to assist an activity of daily living of aged or disabled person [4]. The developed sheet-liked curved type pneumatic rubber muscle is made of rubber band which has anisotropy, and it has a high affinity for human skin. Also, the developed power assist wear using this rubber muscle is composed of clothing fabric and available to wear as clothes.

In this paper, the characteristics of the sheet-liked curved type pneumatic rubber muscle and the developed wrist and elbow power assist wear are described.

MECHANISM OF RUBBER MUSCLE

As shown in Figure 1, sheet-like curved type pneumatic rubber muscle consists of a rubber tube and two sheets. Head of the rubber tube is stopped up by urethane plug to seal-up, and two sheets are sewed to prevent the expansion of rubber tube by pressurization. By using the elastic member for sheet which has anisotropy like a rubber band, the radial expansion of rubber tube is converted to the axial movement.
Figure 2 shows the movement of sheet-like curved type pneumatic rubber muscle. With controlling the amounts of extension of each sheet by changing the number, material, it works out three different movements.
Figure 2(a) is the case when using same number of rubber band for ambilateral sheet. When it is pressurized, the amount of extension is equal, so it makes the movement of extension.
Figure 2(b) is the case when using different number of rubber band for ambilateral sheet. When it is pressurized, the amount of extension is different, so it makes the movement of curve and extension.
Figure 2(c) is the case when one-sided sheet is restricted by using the material which does not extends like nylon band. When it is pressurized, the band only extends, so it makes the movement of curve.
By combining this characteristic, assistance for various body sites can be accomplished.

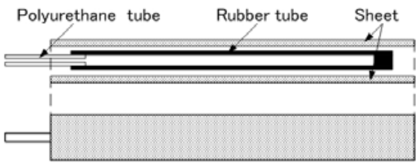
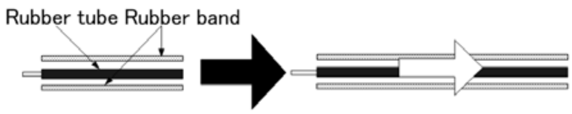
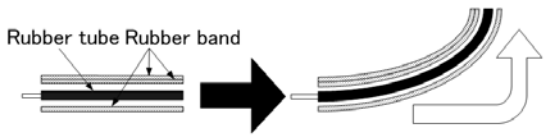


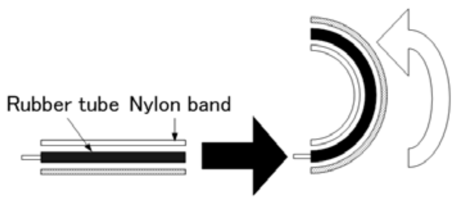
Figure 1 Basement of rubber muscle



(a) Extension



(b) Curve and Extension

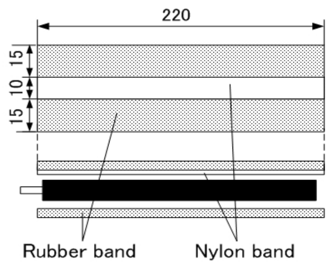


(c) Curve

Figure 2 Movement of rubber muscle

WRIST POWER ASSIST WEAR

Structure
As shown in Figure 3, sheet-like curved type pneumatic rubber muscle for wrist power assist wear makes the movement of curve (Figure 2(c)) by sewing the nylon band to the center of the one-sided sheet.
Wrist power assist wear is made of flexible material like clothing fabric and supporter for the interface to transfer the flexion force to wrist. Rubber muscle is unfixed with assist wear, and it moves in length direction by setting the slide mechanism. When the rubber tube is on the surface of the wrist, it can assist the flexion, but it interrupts the movement of dorsal flexion. So in the case when considering the multiple movement of wrist, it requires to be the structure which does not interrupt the movement of wrist. As shown in Figure 4(a), two rubber muscles are set up in both flanks of hand. As shown in Figure 4(b), upper rubber muscle makes the movements of flexion (Figure 5(a)), and rubber muscle below makes dorsal flexion (Figure 5(b)). The weight of one rubber muscle and wrist power assist wear is each 20[g] and 205[g].

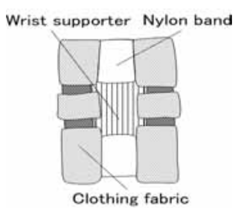


(a) Structure

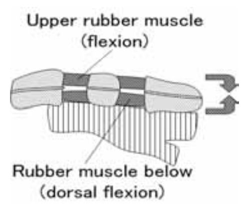
(b) 0[kPa]

(c) 250[kPa]

Figure 3 Outlook of rubber muscle for wrist



(a) Upper view



(b) Side view

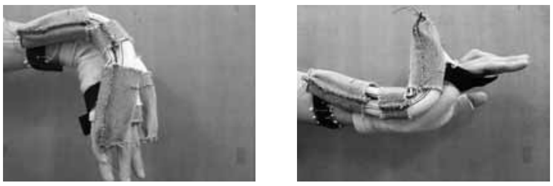
Figure 4 Structure of wrist power assist wear

Torque

Figure 6 shows the torque characteristic of wrist power assist wear. For the measurement, wrist model which only has degree of freedom in flexion and dorsal flexion are used. Torque is calculated from the force generated from the top of power assist wear in each angle. The range of the angle is below.

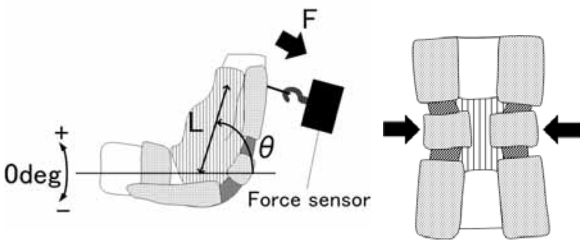
1. Flexion : 0 to 90[deg] by 15[deg] step
2. Dorsal flexion : 0 to 70[deg] by 10[deg] step

When the gravity center of the hand is assumed to be in the center between fingertips and the joint of wrist, required torque for adult male (height: 1.72[m], weight: 65.58[kg] [5]) to move wrist is about 0.5[Nm] [6]. From Figure 6(c), it is available to assist 90[deg] for wrist flexion and 70[deg] for wrist dorsal flexion by 350[kPa] pressurization. However, in the case of pressuring more than 400[kPa] for flexion in 0[deg], rubber muscle does not move in length direction as shown in Figure 6(b). This is because the seam of the rubber muscle is asymmetry and has different stiffness in both sides.

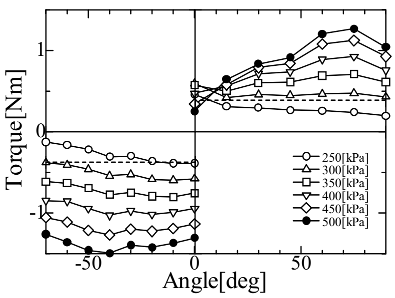


(a) Flexion (b) Dorsal flexion

Figure 5 Movement of wrist power assist wear



(a) Experimental condition (b) Dispersion



(c) Torque

Figure 6 Torque characteristic for wrist

Effect of assistance

To evaluate the effect of wrist power assist wear, it needs to move without human power. The experiment description is to measure the wrist angle and EMG when the wearer are wearing and not wearing the wrist power assist wear. As shown in Figure 7, the measurement position of EMG is flexor carpi ulnaris for flexion, and extensor carpi radialis longus for dorsal flexion. Considering the daily life, the experiment is held in two positions (Figure 8), and positions depend on the position of human body and upper limb. Experiment is held in the methods below and evaluated by the wrist angle and EMG.

1. 0～5[s]: in condition of weak
2. 5～15[s]: pressurize to 400[kPa] by lamp input
3. 15～20[s]: keep the assist with in condition of weak

Figure 9 and 10 show the result of wrist flexion in both positions. In vertical position, it can assist up to 80[deg] when wearer is in condition of weak. Also, in horizontal position, the relative angle θ of hand and body is 185[deg] (measured angle is 95[deg]). The maximum flexion angle of wearer is 95[deg], and the muscle potential is reduced. From this result, this power assist wear can assist more than 85[%] of the movement.

Figure 11 and 12 show the result of wrist dorsal flexion in both positions. In vertical position, it can assist up to 70[deg] and also in horizontal position, the relative angle θ of hand and body is 155[deg] (measured angle is 65[deg]). The maximum dorsal flexion angle of wearer is 70[deg], and the muscle potential is reduced. From this result, this power assist wear can assist more than 90[%] of the movement.

The assistance over the motion range involves pain, furthermore, it does not have to assist completely when using in daily life. Developed wrist power assist wear is using the flexible material and safe, because it has back-drivability. From these, the wrist power assist wear is available for the assistance of wrist movement.

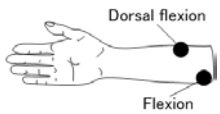
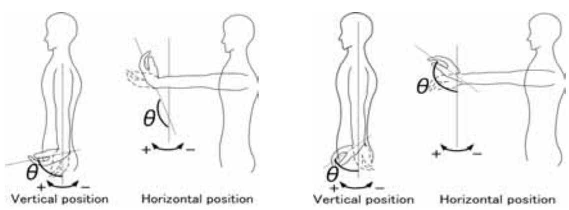
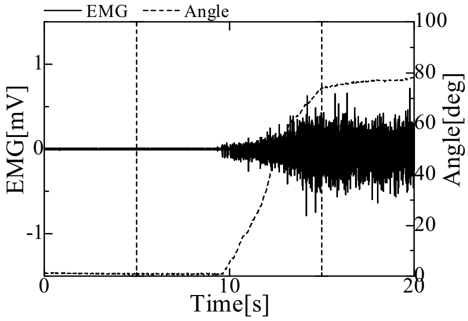


Figure 7 EMG part

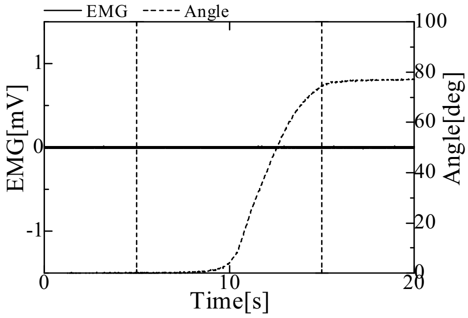


(a) Flexion (b) Dorsal flexion

Figure 8 Experimental position

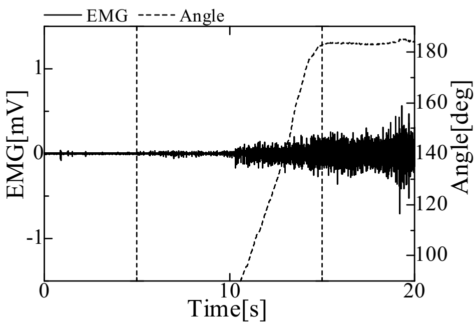


(a) Without assist

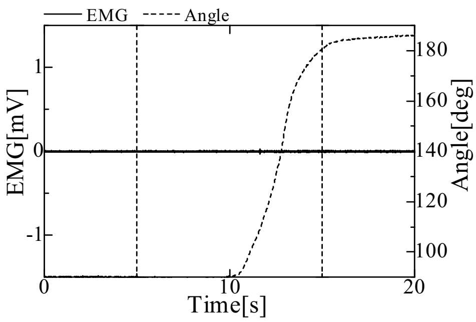


(b) With assist

Figure 9 Flexion (Vertical position)

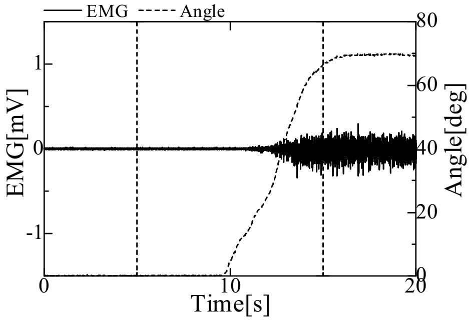


(a) Without assist

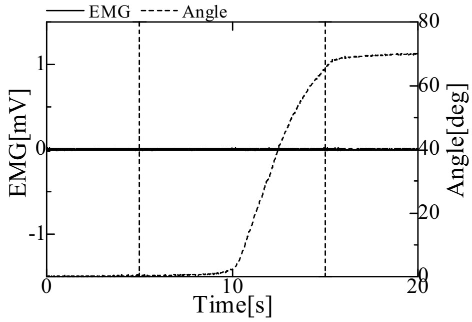


(b)With assist

Figure 10 Flexion (Horizontal position)

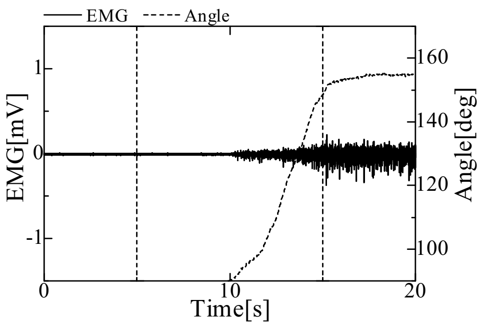


(a) Without assist

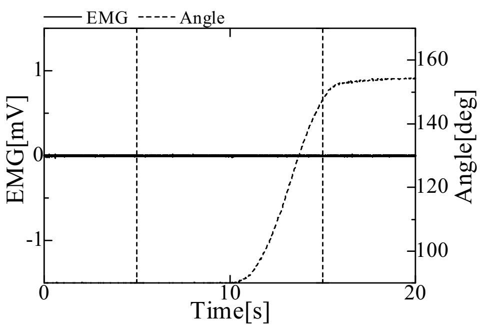


(b) With assist

Figure 11 Dorsal flexion (Vertical position)



(a) Without assist



(b) With assist

Figure 12 Dorsal flexion (Horizontal position)

ELBOW POWER ASSIST WEAR

Structure

As shown in Figure 13 and 14, sheet-like curved type pneumatic rubber muscle for elbow power assist wear makes the movement of extension (Figure 2(a)) and curve (Figure 2(c)). Two sheet A are sewed in parallel at the center of sheet B. As shown in Figure 15, elbow power assist wear is made of clothing fabric to transfer the flexion force to elbow.

Torque

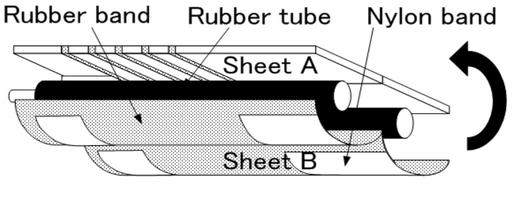
Figure 16 shows the torque characteristic of elbow power assist wear. When the gravity center of the arm is assumed to be in the center between fingertips and the joint of elbow, required torque for adult male to move elbow is about 4.0[Nm]. From Figure 16, it is available to assist below 100[deg] for elbow flexion by 320[kPa] pressurization.

Effect of assistance

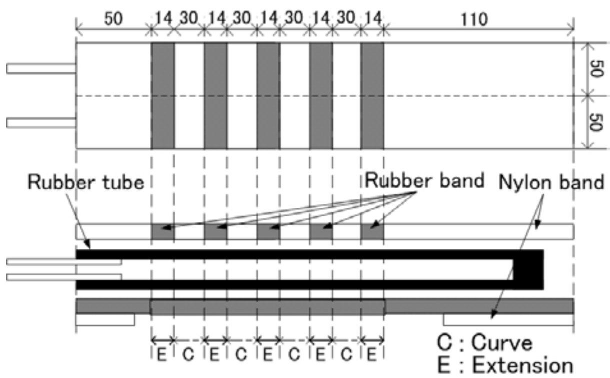
As well as wrist power assist wear, it needs to be evaluated when considering the use in daily life. As shown in Figure 17, the experiment is held in two positions and the measured part of EMG is biceps brachii. Experiment is held in the methods below and evaluated by the elbow angle and EMG.

1. 0〜5[s]: pressurize to 80[kPa]
2. 5〜15[s]: pressurize to 320[kPa] by lamp input
3. 15〜20[s]: keep the assist with in condition of weak

Figure 18 and 19 show the result of elbow flexion in vertical and horizontal positions. In vertical position, it can assist up to 100[deg] when wearer is in condition of weak. Also, in horizontal position, the relative angle θ of arm and body is 210[deg] (actual measured angle of elbow is 120[deg]). The maximum flexion angle of wearer is 120[deg] and this power assist wear can assist more than 80[%] of the movement.

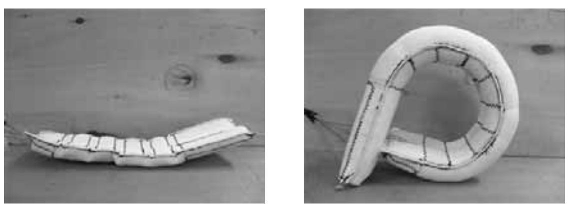


(a) Structure



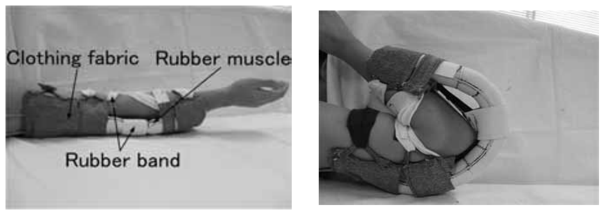
(b) Upper view

Figure 13 Structure of rubber muscle for elbow



(a) 0[kPa] (b) 250[kPa]

Figure 14 Movement of rubber muscle for elbow



(a) 0[kPa] (b) 250[kPa]

Figure 15 Movement of elbow power assist wear

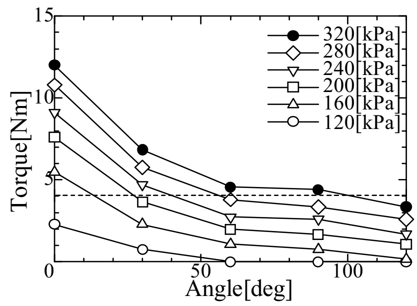


Figure 16 Torque characteristic for elbow

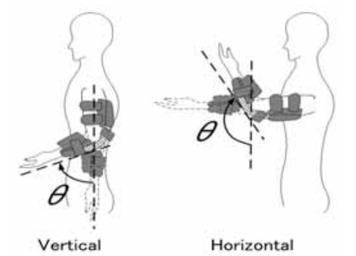
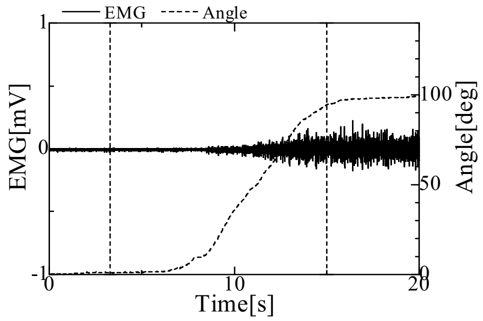
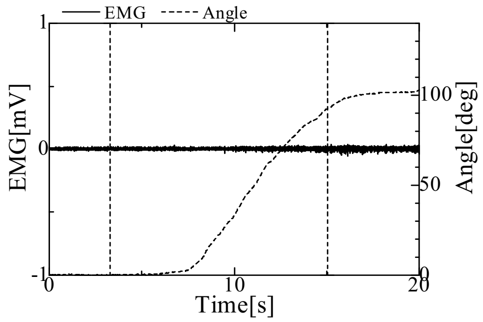


Figure 17 Experimental position

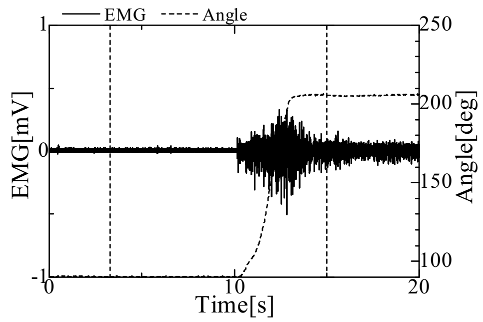


(a) Without assist

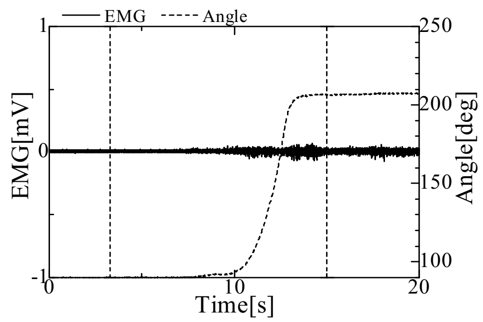


(b) With assist

Figure 18 Vertical position



(a) Without assist



(b) With assist

Figure 19 Horizontal position

CONCLUSION

In order to assist the movement of wrist and elbow, power assist wear with sheet-like curved type pneumatic rubber muscle has been developed. Sheet-like curved type pneumatic rubber muscle can make a movement of curve by itself and can transfer the force directly to human body. So the device using this rubber muscle does not need a link mechanism and can make the device light and compact. This power assist wear has the characteristic of light weight and flexible, and it is suitable for the usage in daily life. The assignment for the future is below

1. Improve the structure to transfer the force efficiently
2. Application for the movement of other body site
3. Realization of the movement which is commonly used in daily life

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