Proceedings of the 6th JFPS International
Symposium on Fluid Power, TSUKUBA 2005
November 7-10, 2005

Development of Pneumatically Assisted Walking System

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ABSTRACT

We have developed a human walking assist system for the people who have handicap or are injured.
A pair of orthosis which actuated by pneumatic liner actuators and shoes having a weight sensor makes up this system. The reason why we decide to use pneumatic actuators is that the pneumatic characteristic caused by air pressure is soft for human and also fits for environment. This assist system supports the lift of legs and stretch of knees when the human walks on ground or stairs. The supportable angles of knee are enough large and this system can be widely used.

We will evaluate the usefulness of this system by the factor of human power reducing for walk and his impression for use.

KEY WORDS

Force measuring sensor, Floor reaction force, Assist torque, Frictional torque, and Knee joint orthosis

NOMENCLATURE

α : Angle [deg]
β : Angle [deg]
γ : Angle of knee joint [deg]
θ : $180 - \gamma$ [deg]
P_S : Supply pressure [kPa]
T_A : Assist torque [Nm]
T_B : Frictional torque [Nm]
T_S : Synthetic torque [Nm]
L_S : Thrust of actuator [N]

1. INTRODUCTION

Walking is one of the most important functions to support our life. However, a decrease in walking ability by getting old or injury makes the inconvenience in various scenes. In the result researched yet, we have developed assisted walking system using pneumatic actuator. But this system didn't satisfy the support walking for daily life in both the mental and functional point in use. And the biggest subject in a present system is an improvement of the force sensor and outfit.

In this report, we develop the outfit and sensor system which can be co-used by various people.

2. Structure of system

2.1 Outline of system

Fig.1 shows how to control the pneumatically assisted walking system. We detect the floor reaction force by the sensors on the sole. The signals are amplified with the amplifier, and taken into CPU through an A/D converter. CPU identifies the three categories of walking mode by analyzing input signals. There are “climbing the stairs”, “descending the stairs”, and “walking flat ground” modes. CPU outputs the operate signals to the servo valves through a D/A converter when the joint of the knee starts to expand. Compressed air is supplied from servo valves to the air actuator. We think that this system can assist walking by expanding the joint of the knee.

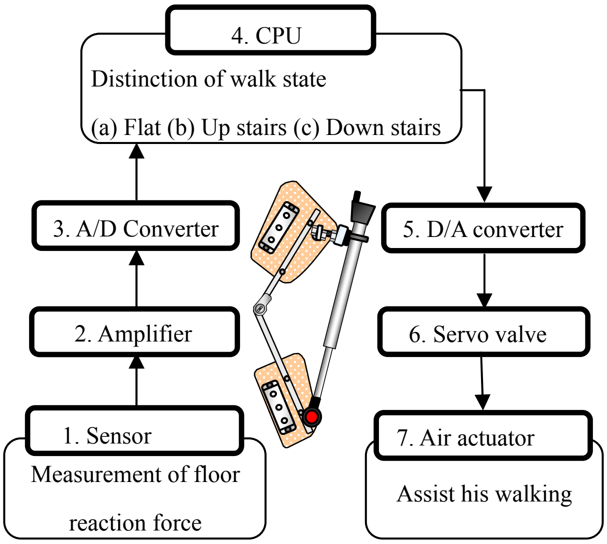


Fig.1 The assist walking system

2.2 Program to distinguish the assist timing

In this system, the signal wave which measured by the sensor are used to identity the mode of walking styles. We use a characteristic of the signal wave form of floor reaction force to identity the walking mode. In case of climbing the stairs, we observe that the peaks of floor reaction force at heel and thenar appear the same time. In case of descending the stairs, the floor reaction force of heal rises first, and then the reaction force of the thenar rises later. The last case of walking flat ground, we observe that the floor reaction force rises first at the contact of foot, and then the reaction force of the heel rises later, and the magnitude of the floor reaction force at thenar is larger than that of the heel.

We discern the walking mode using these features and decide the proper assist timing when the air is supplied to actuator, which fits for each walking modes.

3. Using the knee joint orthosis with many people

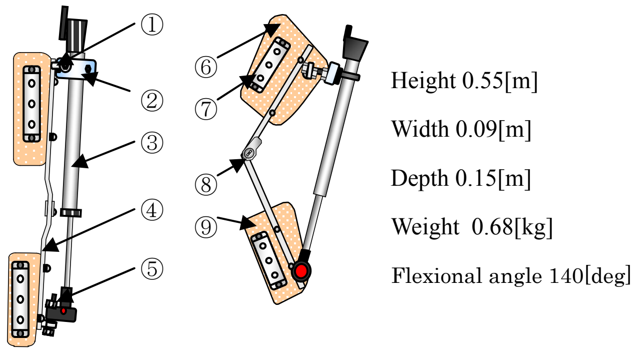
3.1 Purpose of using the only one orthosis with many people

In the past, we made the orthosis adapting tester’s own leg size and shape. But it was difficult to make many orthosis because of problems of both the time and cost. So if we needed a lot of walking test, the testers had to use other people’s orthosis which were not fit for him. Therefore, smoothly walking assistance couldn’t have been done.

To solve these problems, we make universal orthosis which can be used by many people and has light weight.

3.2 common orthosis

Fig.2 shows outline of orthosis we made.



①	Rod end bearing	⑥	Thigh pad
②	Acrylic unit	⑦	Belt guide
③	Pneumatic actuator for bicycle	⑧	Knee joint
		⑨	Calf pad
④	Duralumin brace		
⑤	Rod end bearing		

Fig.2 Knee orthosis for common use

We used the housing shaped by processing as the “low temperature degree sheet plastic”. The sponges with skid net were put in the pad. The purposes of these are to improve the feeling for wearing the orthosis. To fit the orthosis for the various people, we adopted supporter through the belt guide which made by “neo plain rubber stretch nylon”. The pneumatic linear actuator used in this orthosis has 0.025[m] inside diameter, 0.200[m] stroke length, and is yielded 5.0 [kgf/cm^2] supply air pressure. The maximum bending angle of orthosis has increased from previous 90[deg] to 110[deg], so the range of operation has extended. We used portable air pump for bicycle as the actuator and the weight of actuator becomes light as former pneumatic industrial actuator. Fig.3 shows uniting part of orthosis and actuator.

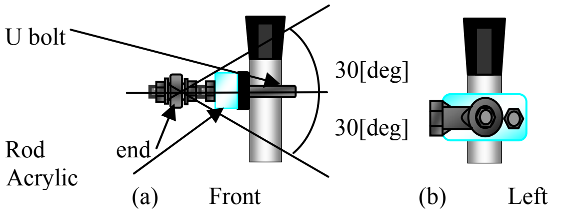
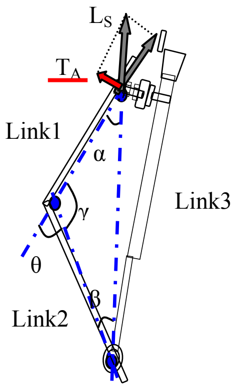


Fig.3 Knee orthosis – Actuator Unit

4. Theoretical characteristic of common knee joint orthosis

By generating the assist torque by the compressed air, the orthosis expands. We have analyzed the assist torque theoretically.



L_1:Length of link1

L_2:Length of link2

L_3:Length of link3

P_S : supply pressure [kPa]

L_S : Thrust of actuator [N]

α: [deg]

β: [deg]

γ: 50～180[deg]

θ : 180-γ[deg]

T_A : Assist torque [Nm]

Fig.4 Link model for assist torque

4.1 Theoretical value of assist torque

Fig.4 shows link model of knee joint orthosis. We deduce the theoretical assist torque T_A shown Fig.4 adopting sine and cosine theory.

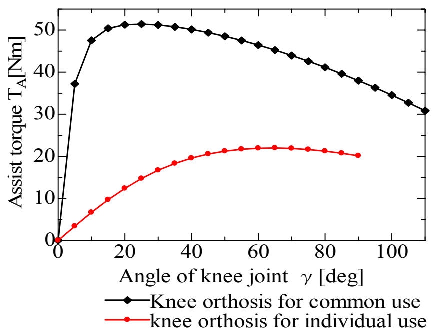


Fig.5 Theoretical value of assist torque

Fig.5 shows the value of T_A. The T_A dotted large mark shows common use type which newly developed and line dotted small shows the previous one. Comparing developed result and previous individual one, it is shown that the maximum assist torque differs large. The maximum of theoretical value of common use is 52[Nm] (Angle of knee joint is 25[deg]) while its value of individual use is 22[Nm] (Angle of knee joint is 65[deg]). We think user of newer orthosis can get stronger assist feeling because the mainly desired portion for assist angle of knee joint for assist is 20~30[deg] where is three times bigger than individual one as assist torque in this angle. We will execute much lower pressure compressed air so it will be possible to be reduced motive power.

4.2 Theoretical value of frictional torque

The difference of frictional torque by the change of actuator is compared. We calculate torque in order to know the frictional characteristic of actuator and frictional loss torque when the actuator expands and contracts. We use link model of assist torque to calculate it. The calculated frictional torque is defined as T_B in Fig.6..

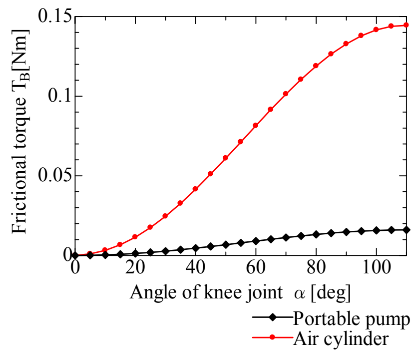


Fig.6 Theoretical value of frictional torque

According to the increasing the angle, the differences grow large as frictional torque. A former actuator has nine times bigger frictional torque than that of portable pump for bicycle. So we could reduce the frictional torque about 11% using portable pump.

4.3 Total theoretical torque of knee joint orthosis

By subtracting frictional torque T_B from theoretical value T_A of assist torque is shown as the theoretical value of synthetic torque T_S. Fig.7 shows the comparison of theoretical value of assist torque and the synthetic torque in common knee joint orthosis. And Fig.8 shows the comparison of knee joint orthosis for common use using the portable pump and knee joint orthosis for individual use using the pneumatic cylinder.

Fig.7 shows that the influence of frictional torque is rather small because it has been much smaller than the assist torque (Frictional torque is about 0.4 percent of assist torque). Influence of frictional torque in use of pneumatic cylinder is about 5 percent loss of assist torque. The losing torque from friction of actuator is small and is shown Fig.8, and the assist torque of knee joint orthosis decides the synthetic torque. So knee joint orthosis is important to decide the value of assist torque for walking assistance. It is thought theoretically that knee joint orthosis for common use is more useful than knee joint orthosis for individual use in the view point of assist torque.

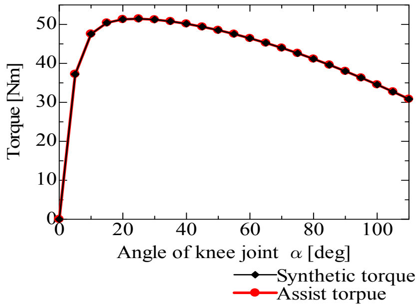


Fig.7 Synthetic torque and Theoretical value of assist

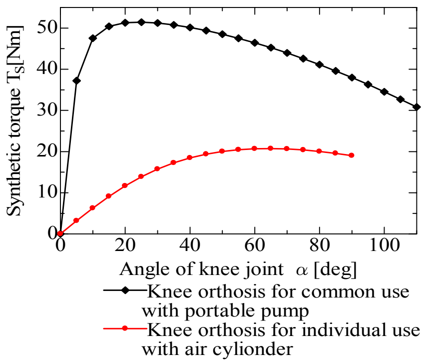


Fig.8 Theoretical value of Synthetic torque

5. Evaluation for knee joint orthosis

We have experimented to evaluate the feeling of knee joint orthosis for common use. And we examine the utility of knee joint orthosis with theoretical characteristic.

5.1 How to evaluate the knee joint orthosis

To evaluate the utility of knee joint orthosis for common use, we have scored it by tester's subjectivity. We judge its performance by follow methods.

① The testers wear orthosis.

② The testers operate as follows. (1) Climbing the stairs, (2) descending the stairs, and (3) walking ground.

③ The testers scored eight terms (A~H) by ten point full marks what they feel.

The testers walk in free speed, because we want to examine in the usual walk. The standards for admission are different by each tester. So we have done standardization and scored objectively. The orthosis which testers worn are knee joint orthosises for common use and for individually use respectively. Eight evaluation terms is shown respectively below.

A. Assist feeling for walking ground
B. Assist feeling for climbing the stairs
C. Assist feeling for descending the stairs
D. Assist timing for walking in the plain
E. Assist timing for climbing the stairs
F. Assist timing for descending the stairs
G. Fitness
H. Weight of orthosis

5.2 The results of evaluation.

The standardization result of objective estimation in knee joint orthosis after standardization is shown in Fig.9.

It can be shown that the knee joint orthosis for individual use gives good impression for tester because the size and shape fit him.

Fig.10 shows standardization result of tester's subjective evaluation of knee joint orthosis for individual use.

Knee joint orthosis for individual use has high evaluation score. But term of evaluation for orthosis wearing fitness has received low evaluation score.

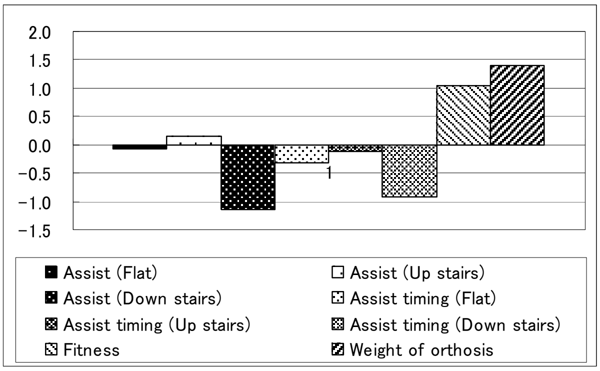


Fig.9 Tester's standardization evaluation of knee orthosis for common use

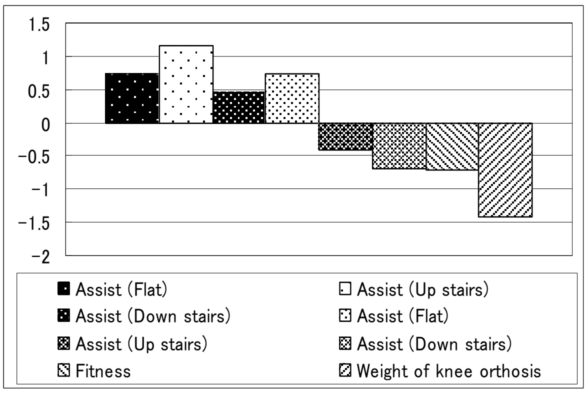


Fig.10 Tester's standardization evaluation of knee orthosis for individual use

5.3 Examination of the evaluation result

The knee joint orthosis for common use has high evaluation score of term as shown in Fig.9. Because, using new material of orthosis pad, the flexibility was improved, and covering the part of contact between foot and orthosis by elastic supporter enables the appropriate fixation. The weight of the knee joint orthosis for common use was 0.68[kg] while the weight of orthosis for individual was 1.5[kg] and the light weight of former gives good score.

The knee joint orthosis for individual use gives low evaluation score of term shown as Fig.10. Because the tester award high score to term of assist feeling rather than the term of its fitness feeling. The knee joint orthosis for individual use have satisfied the assist power, while the improvement is needed in the structure and shape in itself. The term of orthosis weight get low score because the heel part of this orthosis has additional weight in order to increase the fitness feeling and unexpectedly the tester feels reaction force when he raises the foot.

Finally, the evaluation of knee joint orthosis for common use is compared with evaluation score of knee joint orthosis for individual use. The knee joint orthosis for individually use is more suitable and get high score as fitness than that for common use. Because, knee joint orthosis for individual use was made for the specific user, it is natural. As the theoretical value of assist torque, the knee joint for common use is more large value than the individual use. So we expected that the common use yields the large assist torque. Actually, the experiment shows that knee joint orthosis for individual use get high score in this point. In a word, the influence of pad shape is larger than that of link length for assist torque. Therefore the knee joint orthosis for common use can be shared with many people but we need more examination about shape of pad or supply pressure to obtain larger assist torque.

6. Replacing the sensor system

6.1 Purpose of replacing the sensor

The next important device for this study is sensor to measure the floor reaction force. We have used small compression type load cell. Because it has good resolution and linearly to analyze the walking. But the load cell doesn't have proper shape for measuring the reaction force, so we decide to use newer sensor.

To use the current study, the sensor is placed by another type which is easy to match to foot shape.

6.2 Seat sensor

The newer force measuring sensor has structure of putting polymer into dielectric materials and we call the sensor as "seat sensor". The measurement principle is resistance changes if the load applies to the sensor, the load can be easily measured using the change of voltage change occurred in the resistance. As one of the most important characteristic, the sensor is very thin with 0.4[mm]. Tester can stick sensor on their sock of own shoes, so we don't have to change the shoes. And we can measure floor reaction force effectually. In addition, the sensor is high sensitivity i.e., the resolution of 10 grams and a delay time is very small because the signal transmission speed is fast. Fig.11 the shows force measuring sensor.

(a)Sensor (b) Sensor is stuck on an insole

Fig.11 Force measuring sensor

6.3 Experiment to evaluate the utility of sensor

We experimented to examine whether the seat sensor can be used in this system instead of load cell. The evaluation method is shown below.

① We stick the seat sensor on heel and thenar.

② The testers operate as follows. (1) Climbing the stairs, (2) descending the stairs, and (3) walking ground.

③ We measure the floor reaction force and analyze the characteristic of usefulness the seat sensor to evaluate.

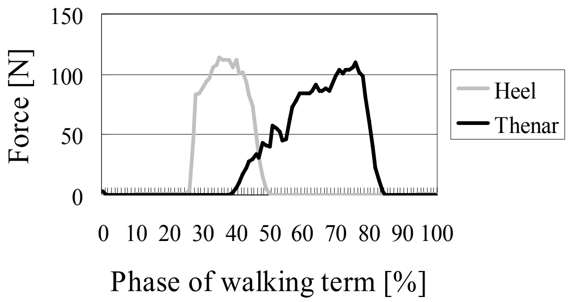


Fig.12 Floor reaction force (Flat course)

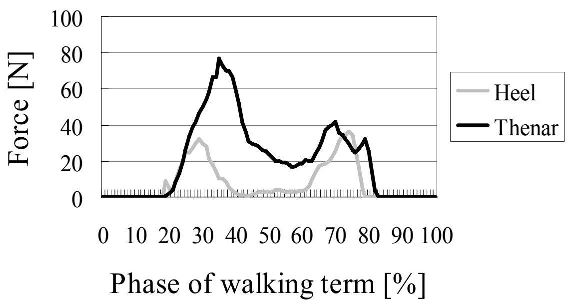


Fig.13 Floor reaction force (Up stairs course)

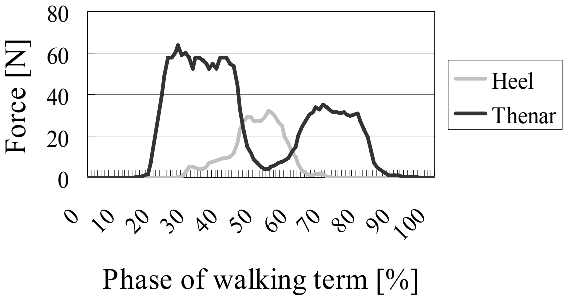


Fig.14 Floor reaction force (Down stairs course)

force measured by the seat sensor when tester walks the ground. Fig.13 shows that in the climbing of stairs, and Fig.14 shows in descending of stairs. By comparing the result of these experiments and the same one of load cell which we measured before, the characteristic of the wave shapes of output signal is very similar. In walking ground, the heel was loaded first, and the toe was loaded later. In climbing the stairs, the heel and the toe were loaded at once. And two peaks of the load change of heel and toe existed. At the end in descending the stairs, the toe was loaded first, and the heel was loaded later. And the load of the toe was bigger than the load of the heel.

6.4 Consideration of evaluation experiment in the force measuring sensor

The new force measuring sensor and the load cell has similar characteristic as detecting the signal wave of force reaction form from experiment.

The load cell detects only vertical load because of its transformation principle, so the structure of attachment influenced the accuracy of measurement. Moreover it was difficult for light weight person to measure the reaction force by using the load cell because the floor reaction force was relatively small in this case. And several time lags occur. The seat sensor solved these problems. Because the force measuring sensor has high sensitivity so this system will be able to assist walking for the light weight person more exactly. So the new force measuring sensor can use to identity the walking more instead of the load cell.

7. Conclusion

In this report, we could find the way of using the only one orthosis with many people. More high sensitive output of measuring system can be realized by using new seat sensor, so it will be possible to identity the state of walking more exactly.

As a problem in the future, to increase the number of tester and to improve program for assist will be important to certain better evaluation for assist feeling. And the parts for the signal such as D/A, CPU, and A/D will be able to miniaturized. So, this system will be able to use in the large field.

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