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

P2-33

ON THE DESIGN OF THE NOVEL PNEUMATIC POWER ASSISTED LOWER LIMB FOR OUTDOOR WALKING

Haifan WU*, Gang FENG* , Tiebing SUN* , Fuzheng QU*, and Wenjun LIU*

* Key laboratory for precision and non-traditional machining technology of ministry of education
Dalian University of Technology, Dalian 116024, China
(e-mail:wuhaifan@dlut.edu.cn)

ABSTRACT

In previous researches, a novel portable pneumatic power source, called a Dry Ice Power Cell, and a novel pneumatic power assisted lower limb for outdoor walking powered by Dry Ice Power Cell, called a DPAL were developed. In this paper, an improvement in design of the DPAL is presented. For those people whose muscle and balance remains in good condition but who have joint pain (hip or knee joint) in their leg and are unable to walk outdoors for long, the developed device can partially lift the patient in a comfortable way by pneumatic cylinder when the affected leg touches the floor, reducing the load to which it is subject as well as the pain joint forces, thus relieving pain during walking. The developed device has the characteristics of a simple structure, low weight, easy to don and doff, and with sufficient capability to bear about 40% of the body weight. In this paper, the structure, function and experiments are described.

KEY WORDS

Walking Assist, Joint Pain, Wearable Fluid Power

NOMENCLATURE

A	:	cross area of cylinder piston
c	:	load threshold
f_a	:	assist force
$f_{a\,ref}$	:	reference assist force
f_b	:	affected leg load
K	:	assist ratio
P_{ref}	:	reference cylinder pressure

INTRODUCTION

Since our society is rapidly aging, there are increasing needs of walking assistance device for the old people. In order to develop a comfort walking assist device with advanced function and liberate the hands, powered assist device is believed an effective way. However, because all components of such device including actuator, power unit and control system are required to be carried by a person, it is necessary for all the devices made in light weight and compact size.

Many efforts have been put on developing pneumatic powered walking assist devices in the past [1]-[3]. However, the lack of portable pneumatic power source makes them use bulky installed air compressor which will drastically impair the compactness of whole pneumatic system. It is believed that to realize a practical powered outdoor walking assist device, a portable pneumatic power source is necessary.

In the previous researches, a novel portable pneumatic power source, called a Dry Ice Power Cell[4], and a novel pneumatic power assisted lower limb for outdoor walking powered by Dry Ice Power Cell, called a DPAL were developed[5]. In this study, an improvement in design of the DPAL is proposed. It has the characteristics of a simple structure, low in weight, easy to don and doff and with sufficient capability to bear about 40% of the body weight during about 1000 steps of outdoor walking assist, using the power of the Dry Ice Power Cell.

BASIC CONCEPT

Use of Dry Ice Power Cell

Structure and photo of developed Dry Ice Power Cell is illustrated in Figure 1. Dry Ice Power Cell weighs 600g, and stores 430g dry ice, thus the total weight is about 1kg and can comfortably be carried on a waist belt. 430g dry ice can evaporate to 218NL gas of carbon dioxide and can provide various output flowrate at a constant pressure of 0.42MPa.

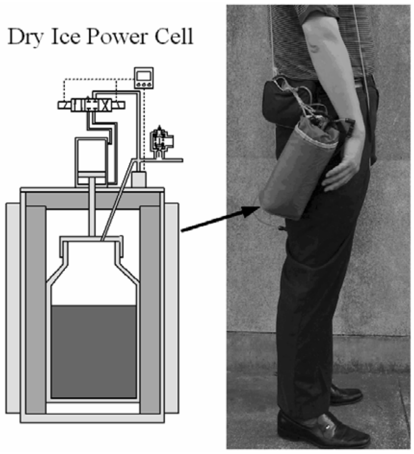

Figure 1 Structure and photo of Dry Ice Power Cell

When the maximum cylinder pressure is, for instance, 0.24MPa (57% of Dry Ice Power Cell's output pressure), a 4cm diameter cylinder can provide 30kgf force so that DPAL can be made in small size. Moreover, assuming the stroke of cylinder needed during one step assist is 3cm, the gas consumption will be 0.13NL which means all the gas evaporated from 430g dry ice can afford 1680 steps of walking assist. Even considering gas leaks at pipe and valve, Dry Ice Power Cell is supposed to drive DPAL for at least 1000 steps.

Proposal of DPAL

The concept of DPAL is illustrated in Figure 2. It comprises a saddle supplied with a hip fastening device (a suspender over the shoulders in this study), an air cylinder, a telescopic pipe with innerpipe lock mechanism inside, and a rubber foot. The lower part of the telescopic pipe is connected to the affected leg side shoe through furniture. When the foot at affected leg side touches the ground and steps the furniture downwards, the innerpipe lock locks, pipe2 is locked in pipe1, the extension force from the air cylinder can be transmitted from ground to the torso. On the other hand, when the affected foot starts to leg swing, the innerpipe lock unlocks, pipe2 slides inside the pipe1 freely and follow the movement of affected foot, so that DPAL makes no restriction on the swing movement of the affected leg.

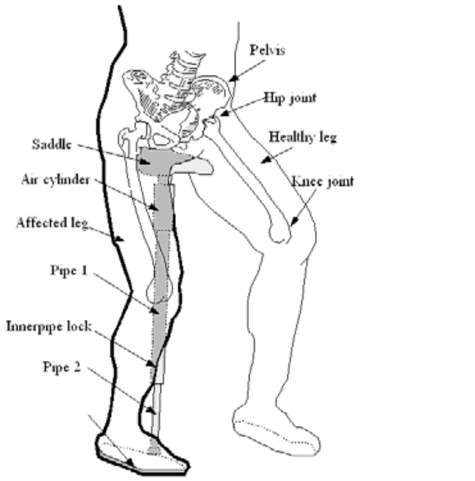

Figure 2 Concept of Pneumatic Power Assisted Lower Limb (DPAL)

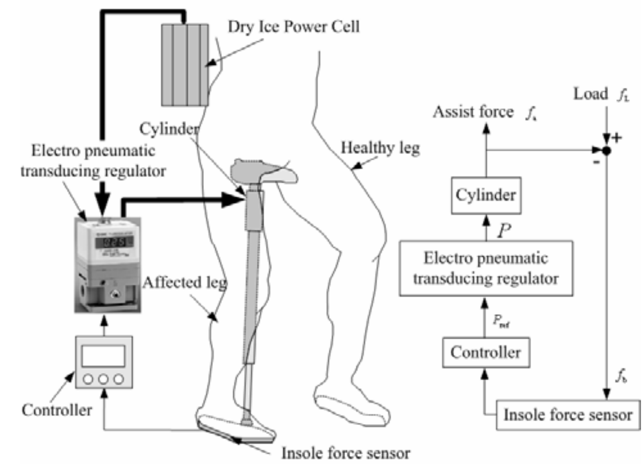

Figure 3 Control system with insole force sensor in ill leg

The concept of DPAL's control system is illustrated in Figure 3. An insole force sensor is set in the shoe to measure the body weight born by the affected leg. Then the measured data is sent to a controller. The controller calculates the control signal and sends it to electro pneumatic transducing regulator thus controls the pressure send to the cylinder. By this way the assist force from DPAL is controlled.

Control algorithm

The relationship between leg force and assist force from DPAL is illustrated in Figure 4.

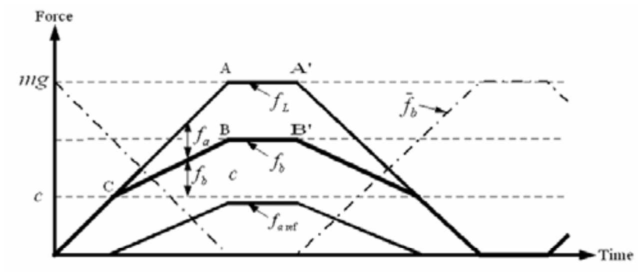

Figure 4 Concept of control rule of pneumatic power assist

When the affected leg is in stance phase, the affected leg load f_b is measured by the insole force sensor inside the affected leg shoe. When the measured data is lager than load threshold c ($c = 20kgf$ in this study), air cylinder starts to extend to provide assist force. When the reference assist force $f_{\mathrm{a\,ref}}$ to load increment $\left(f_b - c\right)$ ratio is defined as assist ratio, the following equation can be given.

$$f_{a\,\mathrm{ref}} = \begin{cases} K(f_b - c) & (f_b > c) \\ 0 & (f_b \le c) \end{cases} \qquad (1)$$

Assuming the retract spring of air cylinder is weak, and slide friction between piston and cylinder can be neglected, the reference pressure of air cylinder can be calculated by equation (2).

$$p_{\mathrm{ref}} = \frac{f_{a\,\mathrm{ref}}}{A} \qquad (2)$$

Such load threshold setting is because when the maximum affected leg load is reduced to a tolerable level, joint pain will be released. As shown in Figure 4, affected leg load is reduced from A-A' to B-B' level, the load incline is also decreased from CA to CB. Only by adjusting two parameters of c and K, even to random human motion, a continuance walking assist control can be achieved. That is another merit for such settings.

DESCRIPTION OF THE STRUCTURE

Construction of the developed DPAL is illustrated in Figure 5. It comprises a saddle, an air cylinder, a telescopic pipe with innerpipe lock mechanism inside, a rubber foot, furniture, and a electro pneumatic transducing regulator.

In order to extremely minimize gas consumption, and prolong the walking assist duration, a innerpipe lock mechanism is used.

The stageless adjustable telescopic pipe with innerpipe lock mechanism inside is a remake of a "Free lock stick" (SUMITA co.). In order to explain the principle of it, the sketch graph is illustrated in Figure 6.

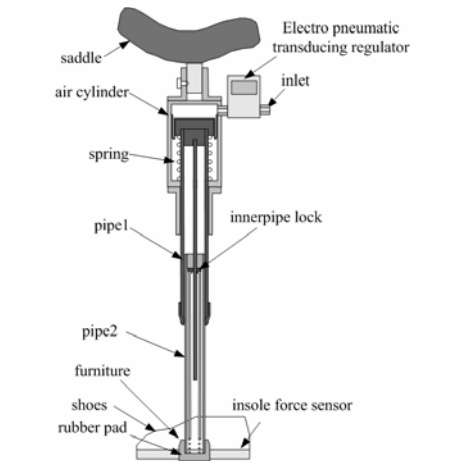

Figure 5 Construction of DPAL

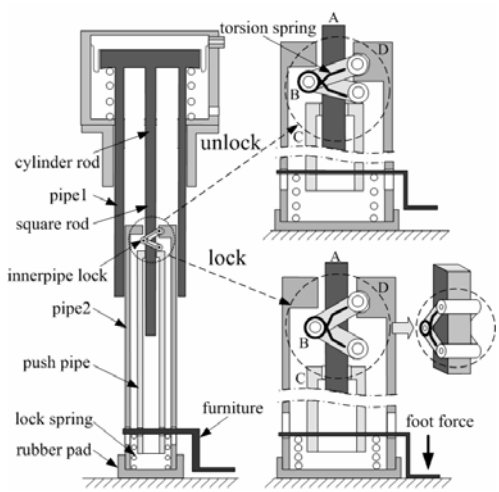

Figure 6 Principle of innerpipe lock mechanism (not to scale)

When the affected leg foot steps on the furniture, pipe C is lowered, the spring beneath it is compressed and C is separated from link B. The B will open wider by the force of a torsion spring thereon and its three shafts closely contact with a square rod A. B has a top end connecting with pipe2 through a pin, while the top end of A is fixed on pipe1. When A is pushed downwards, B will open wider and its three shafts strongly press against A to form a secured lock, thus pipe1 and pipe2 are locked together. On the other hand, when the affected leg is in swing phase, the compressed spring raises C, C push B to make it close narrower, three shafts of B separate from A without pressing it, thus A will pass B freely and pipe 1 and pipe2 are unlocked. By this way, B can lock the telescopic pipe at any position whenever the foot touches the ground and unlock it whenever the foot starts to swing. The telescopic pipe can change its length within 150mm, and can bear more than 100kg bodyweight. By this design, not only the swing movement is not restricted but also the gas consumption is decreased because the necessary stroke of the air cylinder is reduced to the minimum.

EXPERIMENT

The experimental setup for confirming the function of DPAL is illustrated in Figure 7. In order to examining the relationship between the foot load and the assist force, developed insole force sensor is not used, and a testing stand with three load cell is used to measure the foot force and assist force instead. An 80kg weight person stands on two load cells while DPAL is located on the third load cell. Torso weight is alternately transferred between the left and right legs while DPAL provides assist force simultaneously. The measured data is recorded into the computer. In addition, measured signal by load cell under the affected leg is transferred to the controller. Then the controller generates control signal, and sends it to electro pneumatic transducing regulator, thus controls the pressure of air cylinder according to the reference pressure calculated on equation (2).

Control parameter setting is load threshold $C = 20kgf$ and assist ratio $K = 1$. A sample of experimental results is illustrated in Figure 8 which show the maximum affected leg load is reduced about 30kg. The experimental results confirm the effectiveness of the DPAL. In addition, the experiment confirms that DPAL can assist walking for about 1600 times (about 1hour walking assistance).

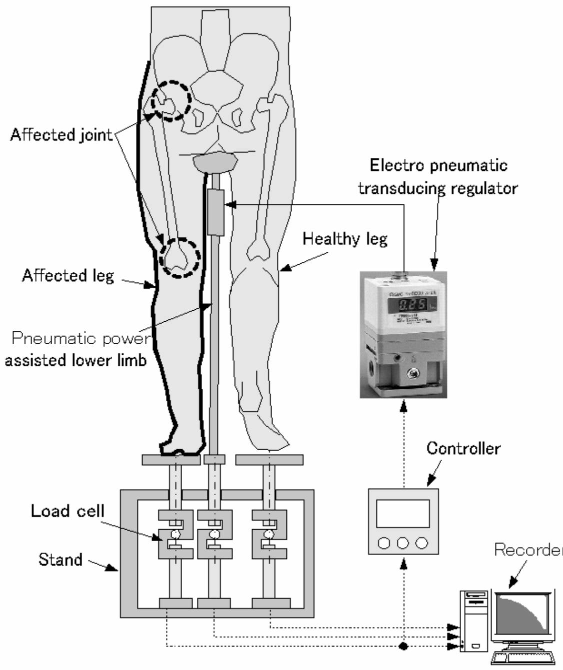

Figure 7 Experiment setup for testing the response of the DPAL

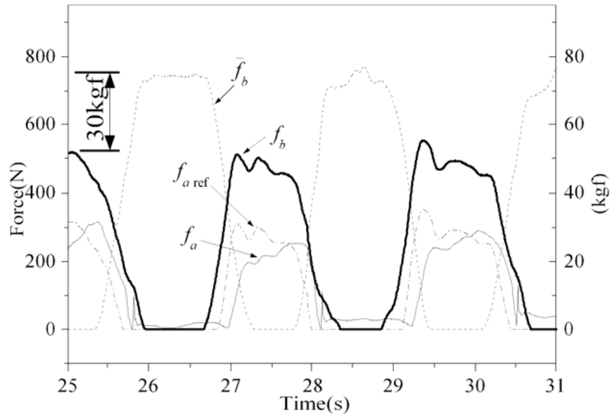

Figure 8 Experimental result sensed by load cell ($K = 1$)

CONCLUSIONS

In this study, a novel pneumatic power assisted lower limb, called a DPAL, is proposed by using Dry Ice Power Cell as its power source. It is confirmed useful for those people whose muscle and balance remains in good condition but who have joint pain (hip or knee joint) in their leg and are unable to walk outdoors for long. It can assist with outdoor walking not only over flat ground but also sloped and stair areas.

REFERENCES

1. Fabio Gazzani, Antonello Fadda, Marina Torre, and Velio Macellari, WARD: A pneumatic system for body weight relief in gait rehabilitation, IEEE Transactions on Rehabilitation Engineering, 2000, 8-4, pp.506-513.
2. Jerry E. Pratt, Benjamin T. Krupp, Christopher J. Morse, The roboknee: an exoskeleton for enhancing strength and endurance during walking, proceedings of the 2004 IEEE International Conference on Robotics & Automation, 2004, pp.2430-2435.
3. H. Yamamoto, K., Ishii, M., Hyodo, K., Yoshimitsu, T. and Matsuo, T., Development of power assisting suit for assisting nurse labor -miniaturization of supply system to realize wearable suit-, JSME International Journal, Series C, 2003, 46-3, pp.923-930.
4. Ato KITAGAWA, Haifan WU, Hideyuki TSUKAGOSHI, Sung-Hwan PARK: Development of a portable pneumatic power source using phase transition at the triple point, Transactions of the Japan Fluid Power System Society, 2005, 36-6, pp.158-164.
5. Haifan WU, Ato KITAGAWA, Hideyuki TSUKAGOSHI, Canghai LIU, Development of a novel pneumatic power assisted lower limb for outdoor walking by the use of a portable pneumatic power source, Transactions of the Japan Fluid Power System Society, 2006, 37-4, pp.43-49.