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

OS9-2

WEARABLE FLUID POWER COMPOSED OF FLAT TUBES TO ACTIVATE THE BODY

Hideyuki TSUKAGOSHI*, Shumpei KASE*, Toshiyuki KATO*,
Takeaki SUZUKI *, Ato KITAGAWA*

* Department of Mechanical and Control Engineering,
Tokyo Institute of Technology
2-12-1-S5-19 Ohokayama, Meguro-ku, Tokyo, 152-8552 Japan
(E-mail: htsuka@cm.ctrl.titech.ac.jp)

ABSTRACT

A novel fluid power actuator called Flat Ring Tube (FRT) is introduced in this paper. The mechanism of FRT is so simple that it only needs a urethane flat tube and water pressure power source. No valves or switches are required. Applying constant water pressure results in periodic oscillation of the tube. The frequency is proportional to the flow rate of water and inversely proportional to the tube length. By contacting the tube with a passively supported shaft, it rotates due to the periodic tube oscillation. This principle can also generate the linear driving force, when FRT is mounted so as to kick the ground. Such kind of performance can be also expected to stimulate the blood flow rate, when FRT touches on the skin of the human body appropriately. The experimental results showed us the developed wearable massage device could effectively improve both the circulation of the blood flow and the density of oxygen in blood, which resulted in let the people feel more comfortable than conventional massage devices.

KEY WORDS

Wearable Fluid Power, Self-excited Oscillation, Massage Actuator, Water Hydraulics, Rehabilitation

INTRODUCTION

An actuator with the flexible structure and the pliant performance would be useful for the driving system which is assumed to come into contact with the human body, considering that the human muscle and the skin are composed of soft tissues. To realize such kind of actuators, we have proposed a variety of fluid actuators based on a flat tube which was made of urethane with thermoplasticity. When the inside of the tube is pressurized, the cross sectional shape approaches a circle, while the circumference of the tube is almost kept constant. As a result, the tube becomes resistant to relatively high pressure so that large force is easy to be generated, even though the whole size is small. On the other hand, the structure piling up some tubes are required to increase the displacement, since that of each tube is small. A spiral shaped structure named Wound Tube Actuator and a zigzag shaped structure called Zigzag Tube Actuator are the examples to cope with it, which were designed to be applied to wearable actuators

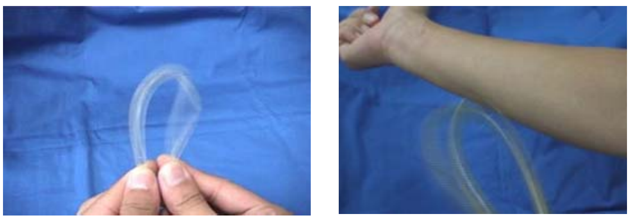


Figure 1 Overall view of the self-excited oscillation of FRT which stimulates the human skin

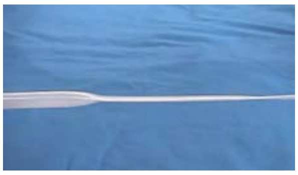
to stimulate the body motion[1-2] and rescue robots to go through small spaces to find survivors[3]. These actuators must have been operated by valves to switch from pressurized mode to decompressed one, which results in requiring at least a valve per an actuator.

In this study, a novel type of fluid power actuator with no use of valve to operate will be discussed, although it also takes advantage of the flat tube. It is based on the self-exited oscillation which occurs when the flat tube bent in the ring shape called Flat Ring Tube is pressurized by tap water pressure, as shown in Fig.1. This phenomenon is peculiar to a flat tube, which does not occur in the general pipe shaped tube. The oscillation discussed in this paper is basically different from that of Collapsible Tubes studied previously [4]. Then in this paper, after the oscillating principal and condition of FRT are illustrated, a couple of useful applications are introduced such as a novel water hydraulic motor and a wearable massage device.

BASIC PRINCIPLE

A fluid power actuator taking advantage of novel phenomenon will be introduced here. It is based on a flat tube whose cross sectional shape is flat and is made of urethane, as shown in Fig.2. When the inside of a flat tubes is pressurized by domestic tap water pressure of approximately 0.2 to 0.3 [MPa], and the tube is bent in the round shape, then the periodic self-excited oscillation occurs without using any valves to switch. This is the phenomenon peculiar to a flat tube bent in this form, which we call "Flat Ring Tube", abbreviated to "FRT" here.

(a) Top view of a flat tube.



(b) Side view of a flat tube.

(c) Overall view of Flat Ring Tube.

Figure 2 Composition of Flat Ring Tube

The principle of the oscillation can be illustrated as follows. As the inside of the FRT is pressurized, it curves more and more and then it buckles at some point reaching the curvature limit. Since the fluid passage is perfectly cut off at buckled point, this point is pushed from the upstream to the downstream as the tube continues to be pressurized, shown in Fig.3 i) and ii). At the same time, a new buckled point is also generated at the side of upstream shown in Fig.3 iii), which slides to the downstream shown in Fig.3 iv). Finally, it returns to its original shape. This is a cycle of oscillation.

In order to make the tube oscillate in the above way, there are a couple of conditions. If you replace the flat tube with the pipe shaped one, the above oscillation does not occur all, because the buckled point on the pipe shaped tube is difficult to slide from the upstream to the down stream due to the tube resistance to deform and the flow leak at the sides of the flat tube. In this sense, the above oscillation is peculiar to the flat tube.

The experimental results showed the frequency of the oscillation by FRT is proportional to the flow rate, while it decreases as the tube becomes longer under the condition of the constant flow rate, shown in Fig.5. This is because the velocity of the buckled point is also proportional to the flow rate and the longer sliding period for a cycle is required as the tube becomes longer. If the tube is too short, it does not oscillate because the second buckled point is hard to be generated. If the tube is too long, it neither oscillates because the buckling point is not generated. Due to the same reason, the frequency decreases, as the tube diameter increases, as shown in Fig.6.

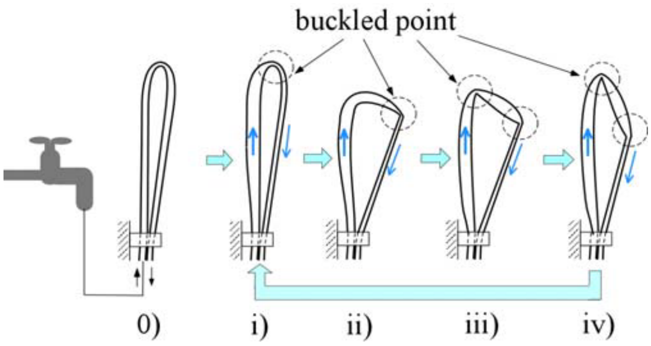


Figure 3 Principle of oscillation by FRT

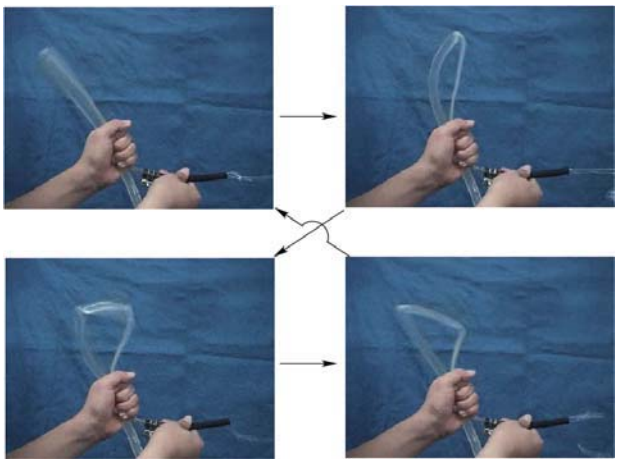


Figure 4 A cycle of oscillation by a developed FRT

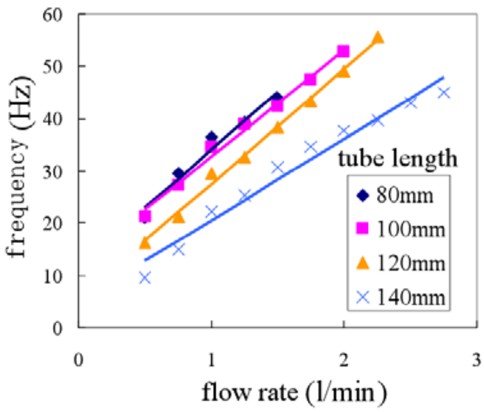


Figure 5 Experimental results of the frequency related to the tube length and the flow rate

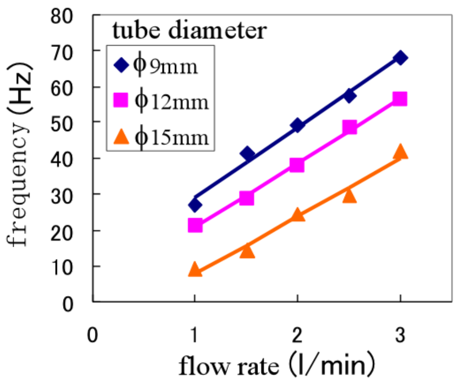


Figure 6 Experimental results of the frequency related to the tube diameter and the flow rate

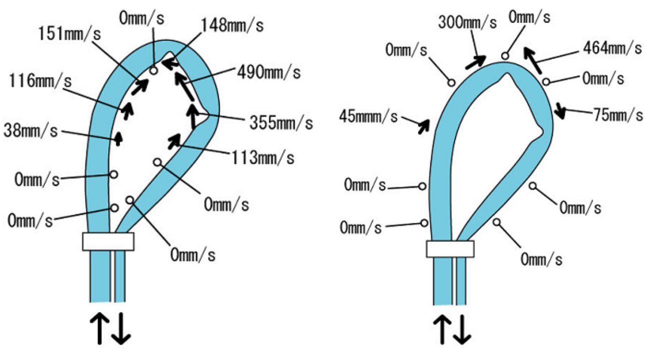


Figure 7 Tangent velocity of the contact point on FRT

To investigate the performance of FRT generating the infinite rotary motion, the tangent velocity of each contact point on FRT was experimentally examined by measuring the rotational speed of the shaft which was touched on FRT from both the inner side and the outer one. Here, the tube width and length was 9mm and 120mm respectively, while the oscillating frequency was 70Hz.

The experimental results in Fig.7 suggest us that there exists the turning point around the middle of FRT where the driving force direction changes inversely in both cases of the inner and outer touching. Furthermore, the fast point appears at the down stream side from the middle of FRT, which can be seen in any size of FRT. If the shaft touched from the outer side of FRT, two turning points appeared. In any cases, it was clear that there exists the optimal point in FRT to come into contact with the shaft to maximize the rotational speed.

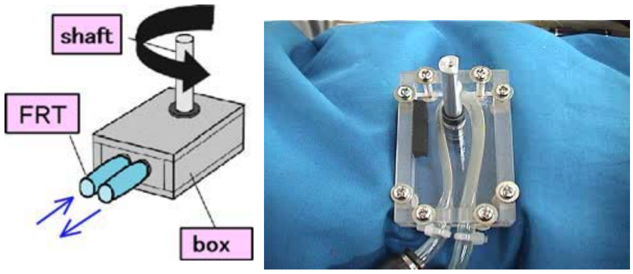


Figure 8 Application of FRT to a water hydraulic motor

Figure 8 shows a motor taking advantage of the above rotating drive function of FRT. It was designed for the shaft to touch on FRT at the optimal point. The developed motor, could generate 76[kg*cm] of torque and was 50g in weight with extremely simple mechanism composed of a flat ring tube and a shaft. The relationship between the rotational speed and the torque was as shown in Fig.11. Since the rotational speed increases monotonously as the flow rate is gained, it can be also applicable for a flow meter. Particularly, the mechanical driving part does not come into contact with the fluid directly, this kind of meter is useful for measuring the flow of the industrial waste water, for example.

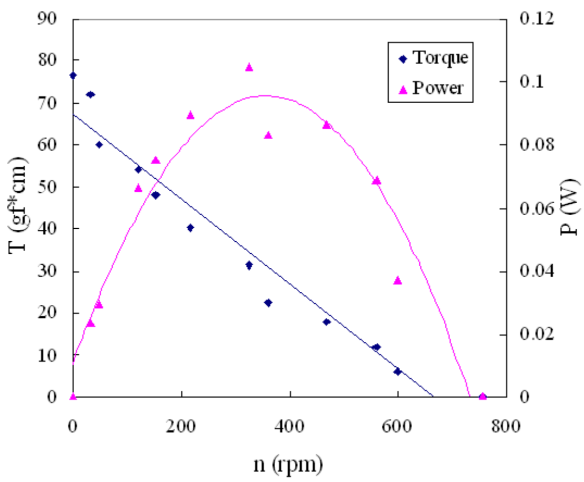


Figure 9 Relationship among the rotational speed, the torque and the power of the developed FRT motor.

APPLICATION TO A MASSAGE DEVICE

If you take advantage of this principle, it is expected to promote the blood flow. Then, we tried to apply it for massage devices, shown in Fig.7. Since it can generate the frequency of 0.5Hz～10Hz with soft touchiness to human body, it can let them feel comfortable. In addition to the good feeling, the muscle blood flow meter showed that the muscle blood flow increased at 12% after 5 minutes massage, and that the effect of its increasing continues after 30 minutes, shown in Fig.8. The thermography also showed that the body temperature of the skin surface rose at 10 % after 5 minutes massage by FRT. Unlike the conventional massage machine using the electricity, the FRT massage device does not generate the electromagnetic at all.

Figure10 Massage device by the handy type of FRT

Figure 11 Wearable massage device mounting two pairs of FRT on the jacket

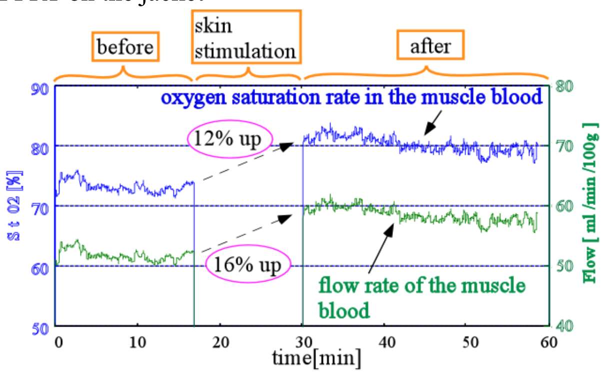


Figure 12 Effect of FRT on the human body

Therefore, this device can be also applicable for a pacemaker user without any fear. At present, a wearable massage device is being developed which can massage shoulder, back and waist so as to promote the muscle pressure around the whole body.

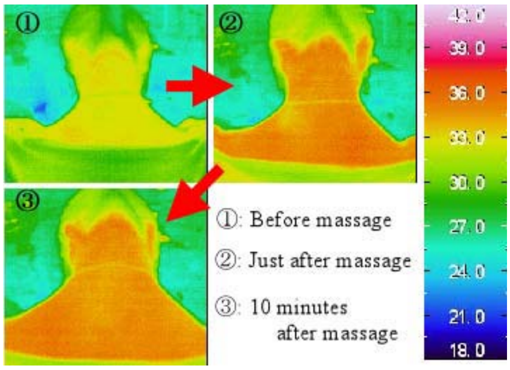


Figure 13 Transient of the skin temperature while taking massage of the wearable type of FRT massage device.

CONCLUSIONS

A novel fluid power actuator called Flat Ring Tube (FRT) was introduced in this paper, which was composed of a urethane flat tube pressurized by domestic tap water pressure and no valves or switches were required. Applying constant water pressure resulted in periodic oscillation of the tube. The applications of FRT for the water hydraulic motor and the massage device were introduced. The experimental results showed us the developed wearable massage device could effectively improve both the circulation of the blood flow and the density of oxygen in blood, which resulted in let the people feel comfortable.

REFERENCES

1 H.Tsukagoshi, A.Kitagawa, Y.Kamata, "Wearable Fluid Power Composed of Transformed Flat Tube Actuators," IEEE／RSJ International Conference on Intelligent Robots and Systems, 1178-1183(2002)

2 H.Tsukagoshi, S.Nozaki, A.Kitagawa : Versatile Water Hydraulic Motor Driven by Tap Water, IEEE／RSJ International Conference on Intelligent Robots and Systems,(CD-ROM:F-AII-2)(2000)

3A.Kitagawa, H.Tsukagoshi, M.Igarashi, "Development of Active Hose with a Small Diameter for Search and Life-prolongation of Victims," Journal of Robotics and Mechatronics, 15-5, 474/481(2003)

4 Conrad, W.A., IEEE Trans. Bio-Med. Eng., BME-16, 284(1969)