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A Study on Control and Measurement of a Power-Assisted Chair

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ABSTRACT

A power-assisted chair using pneumatic system has been studied by the authors. The chair aims to help the user to stand up with assistance force generated by a pneumatic cylinder. In this study, a pneumatic cylinder, control valves, a compressor, a microcomputer and electric power sources are integrated in the chair. Control and measurement techniques using the microcomputer are described in this paper.

KEY WORDS

Pneumatics, Power-assisted chair, Microcomputer control

1. INTRODUCTION

The shift to aging society is progressing rapidly in advanced countries including Japan. Lack of nurses becomes a social issue. Therefore, equipments for welfare attract interests of many researchers. For examples, assist systems for human walking were studied by Tsuchiya [1] and Raparelli [2]. A silicone outer fence mould actuator was studied by Hayakawa [3]. A flat tube actuator was studied by Tsukagoshi [4]. Human friendly robots were studied by Noritsugu [5]. In these studies, pneumatics was applied because of the advantage of compressibility and cleanliness of air. As a key word to cover this research field, a term "Soft Mechanisms" has been proposed by Prof. Noritsugu [5]. The authors also have studied a power-assisted chair that helps the user to stand up using a pneumatic cylinder [6]. The seat is tilted by a pneumatic cylinder and the seat angle is detected in order to control assist force. In this paper, control and measurement techniques of an integrated power-assisted chair using a microcomputer are described. A pneumatic cylinder, control valves, a compressor, and a controller are installed inside the chair. In a section 2, the integrated power-assist chair is introduced. In a section 3 and 4, the system configuration and control and measurement techniques are described in details. Experimental results are discussed in a section 5. Finally, the results are summarized in a section 6.

Nomenclature

F	assistance force	(N)
M	weight	(kg)
P	pressure	(Pa)
θ	seat angle	(degree)

2. Integrated Power-assisted Chair

The integrated power-assisted chair is shown in Fig. 1. A pneumatic cylinder, a proportional pressure control valve, a compressor and a tank were mounted on a base frame of the chair. The pneumatic cylinder was connected to the seat by a link mechanism. The link mechanism is shown in Fig. 2. Cylinder force was generated almost in a horizontal direction, and it is transferred to the seat by the slider crank mechanism. Force of the seat assists user's motion of standing-up and sitting-down. A ratio of the assist force to the cylinder force is named as a force transfer ratio in this study.

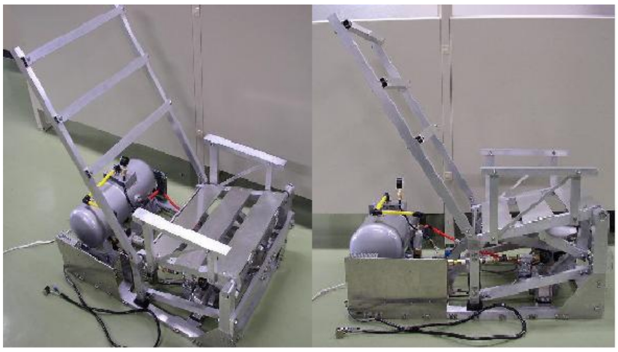

Fig. 1 Integrated power-assisted chair

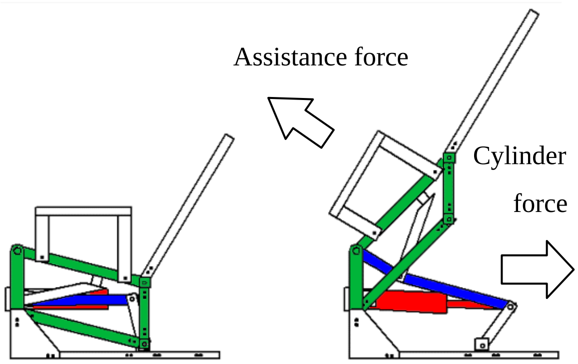

Fig. 2 Slider crank mechanism

3. System Configuration

System configuration is shown in Fig. 3. A microcomputer board (H8 microcomputer shown in Fig. 4) was used in order to control the pneumatic cylinder and the compressor. The microcomputer has not a display and a keyboard. Therefore, a remote control panel was made as the interface device. Using the control panel, main power supply can be switched. In addition, a rotary potentiometer was used in order to input the weight of the user.

A commercial compressor for tires and balls was used. It is enough small to be installed inside the chair. Compressed air is supplied to a proportional pressure control valve through a filter, a drier, and a check valve. Cylinder pressure is controlled by the proportional pressure control valve.

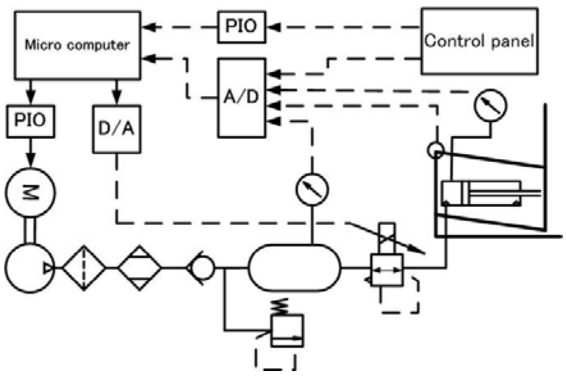

Fig. 3 System configuration

Fig. 4 H8 Microcomputer board

Seat angle is detected by a rotary potentiometer attached at the rotary joint of the seat. Seat angle, cylinder pressure, and tank pressure are input to the microcomputer through AD or PIO interfaces. The main role of the microcomputer is to control cylinder pressure. The pressure control technique is based on calculation using the seat angle, the weight specified by the control panel, and the pressure of the cylinder. The details will be described in the next section. Another role is on/off control of the compressor. If the tank pressure is larger than the high value, the compressor is turned off. If it is smaller than the low value, the compressor is turned on. The control signal is sent to the compressor through a solid-state relay switch.

4. Control System

First of all, static characteristics of the proportional pressure control valve were measured. The results are shown in Fig. 5 as a function of input voltage. Hysteresis was observed corresponding to standing-up and sitting-down motion. Therefore, the characteristics were approximated using two straight lines representing stand-up and sit-down motion, respectively.

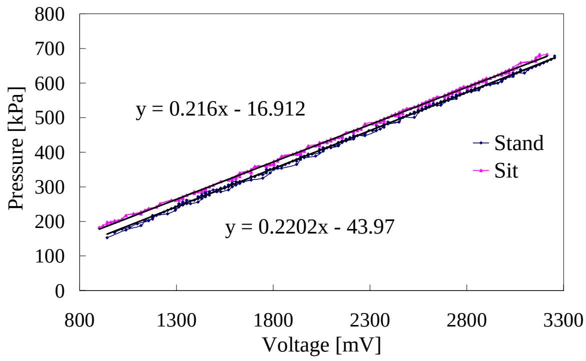

Fig. 5 Static characteristics of a proportional pressure control valve

A control technique of assistance force is explained. Assistance force was determined based on a concept of knee torque compensation. Human body was approximated by a link model as shown in Fig.6. The link parameters, such as mass, inertia and center of gravity, can be found in a reference [7].

According to our experiments, in the case of standing-up motion, the angle of the upper body with respect to a vertical line does not change so much. Therefore, the angle of upper body is assumed to be constant ($\theta_3 = 30°$).

A static balance of moments around a knee joint is written as:

$$T_2 = m_2 g d_2 \sin\theta_2 - l_2 F + m_3 g (l_2 \sin\theta_2 + d_3 \sin\theta_3)$$

$$\therefore T_2 + l_2 F = m_2 g d_2 \sin\theta_2 + m_3 g (l_2 \sin\theta_2 + d_3 \sin\theta_3) \quad (1)$$

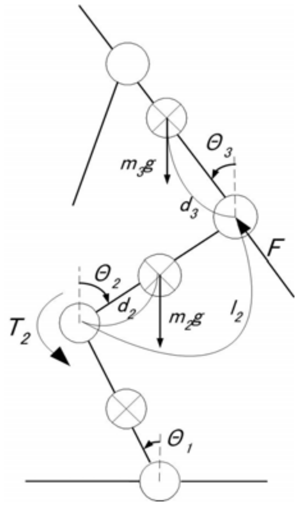

Fig. 6 Three link model of a human body

The assistance torque in the knee joint $l_2 F$ is controlled to be a half of knee torque without the assistance force. Therefore,

$$T_2 = l_2 F \tag{2}$$

Substituting Eq.(2) into Eq.(1), the assistance force F is obtained as:

$$F = \frac{m_2 g d_2 \sin\theta_2 + m_3 g (l_2 \sin\theta_2 + d_3 \sin\theta_3)}{2 l_2} \tag{3}$$

According to the design of the chair, a geometrical relationship between θ and θ_2 is written as:

$$\theta_2 = \frac{\pi}{180}(105 - \theta) \tag{4}$$

Substituting parameter values into Eq(3) and approximating the curve of the assistance force F as a function of the angle θ by a second order polynomial of θ, the approximated equation is obtained as:

$$F = (-0.0004\theta^2 - 0.022\theta + 4.9908) \times M\,, \tag{5}$$

where M is mass of the human body that will be input by the user.

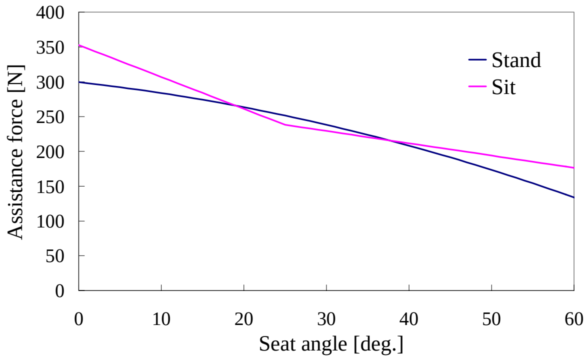

Fig. 7 Assistance force (M = 60kg)

Therefore, the assistance force for standing-up motion can be plotted as a function of the seat angle as shown in Fig. 7 for the weight M=60 kg. Assistance force for sitting-down motion can not be obtained at present. Therefore a virtual spring concept [6] was applied.

The block diagram of the control system is shown in Fig. 8. Valve characteristic $V(P)$ and assistance force $F(\theta)$ are obtained according to above mentioned techniques. $D(\theta)$ is a force transfer ratio.

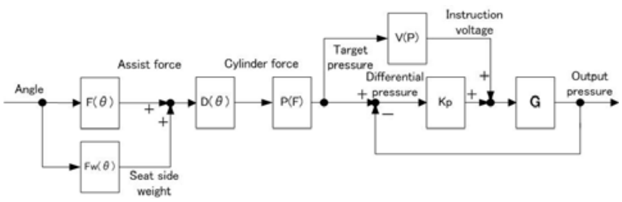

Fig. 8 Block diagram of a control system

The seat angle is detected and desired assistance force is calculated. To determine cylinder pressure, a force component of the seat weight that is parallel to the assistance force or perpendicular to the seat should be added to the desired assistance force.

Multiplied by the force transfer ratio, desired cylinder force and desired cylinder pressure are determined. The cylinder pressure is controlled by feedback and feed-forward control.

There are two main control modes corresponding to standing-up motion and sitting-down motion. In experiments where only these two modes were considered for the valve control, chattering phenomena occurred and the valve became unstable. The chattering may be caused by noise. In order to suppress the chattering, a state transition chart having six modes shown in Fig.9 was applied. In the figure, $\Delta\theta$ is the increment of the seat angle during one control period. The initial state is "Start", and it transits to "Sit", "Stand" or "Stop" mode depending on the value of $\Delta\theta$. For an example, the "Sit" mode is a buffer mode for going to the next mode "Down". In the "Sit" mode, the valve is not controlled. When $\Delta\theta$ is negative, the state transits from the "Sit" mode to the "Down" mode. Otherwise, the state stays there for $\Delta\theta = 0$ or it goes to the "Stand" mode for $\Delta\theta > 0$. In the "Down" and "Up" mode, the valve is controlled. During the "Down" mode, when $\Delta\theta$ becomes positive, the state transits from "Down" to "Start" mode. Using the state transition chart, chattering was suppressed in experiments.

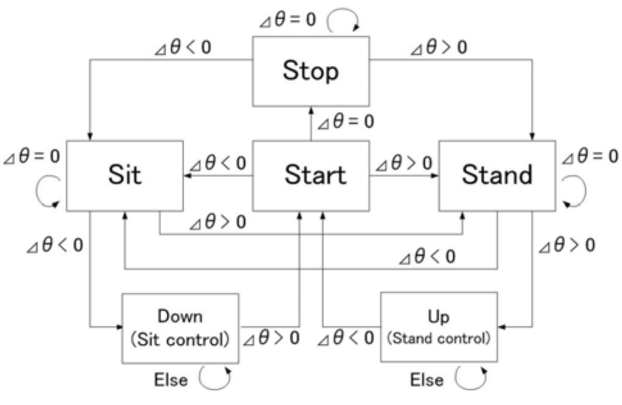

Fig. 9 State transition chart

5. Experimental Results

Controlling the chair by the proposed method, experiments were carried out. Cylinder pressure was measured for standing-up and sitting-down motions. Measured results of cylinder pressure are shown in Fig. 10. The cylinder pressure well followed the target values. The system stability was very much sensitive to the proportional gain of the feedback control of cylinder pressure.

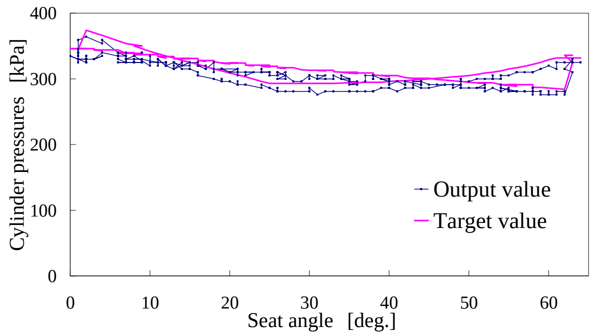

Fig. 10 Experimental results of cylinder pressures

6. Conclusion

In this research, control and measurement techniques of the integrated power-assisted chair were proposed. A concept of knee torque compensation was applied. A microcomputer (H8 microcomputer) had an enough performance. State transition chart was useful to avoid chattering. Because the commercial compressor produced noise and vibration, a silent and small size compressor must be designed in the future.

Acknowledgement

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