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Fabrication of a Breathing Assist Device for Saxophone Players with Breathing Problems

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Abstract: The aim of this study was to establish a breathing assist system for saxophone players with breathing problems. Although the saxophone is a popular wind instrument with a reed in its mouthpiece, it can be difficult for people with breathing problems to play this instrument, as it requires adequate breath support for deep and even long breaths. To solve this problem, the authors propose a breathing assist device, which functions like a pneumatic master–slave amplifier, for saxophone players with breathing problems. First, the proposed device is fabricated. Second, the effectiveness of the breathing assist device as a master–slave amplifier is confirmed through experiments. Third, the dynamic characteristics of the device are tested up to 10 Hz, and they demonstrate that the device responds well for up to approximately 5 Hz.

1. Introduction

A_1 : pressure amplitude of reference signal, Pa
A_2 : pressure amplitude of slave side, Pa
E_i : control voltage to servo valve, V
f : frequency, Hz
G : mass flow rate, kg/s
G_{in} : mass flow rate into the chamber, kg/s
G_{out} : mass flow rate out of the chamber, kg/s
K_{AG} : amplifier gain
K_p : proportional gain of controller, 1/s
K_{PA} : gain of driving piezo-electric actuator, V/Pa
K_{pd} : integral gain of controller, V/Pa
K_{sv} : gain of servo valve, (kg/s)/V
P : pressure, Pa (gauge)
P_1 : pressure of master side Pa (gauge)
P_2 : pressure of slave side Pa (gauge)
P_{2ref} : reference pressure of slave side Pa (gauge)
R : gas constant J/(kg K)
s : Laplace operator [1/s]
st : sampling time s
t : time s
T_f : time constant of low-pass filter s
V : volume m^3
θ : temperature K

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1. Introduction

The saxophone is a very popular wind instrument with a reed mouthpiece. Since its invention in the mid-19th century in Belgium, it has been recognized as one of the most sophisticated wind instruments, and it is widely used throughout the world.

However, it requires the movement of two hands and substantial breath support (for deep and even long breaths), making it difficult for a person with a hand or breathing disability to play it satisfactorily. Numerous studies have been conducted on the development of robotic systems that can play a musical instrument[1-3]. In addition, a group at Tsukuba University proposed a “robot-assisted playing” method that can help people with hand or finger disabilities play the saxophone[4]. However, no previous research on the development of a device that assists the breathing of a saxophone player was found. Therefore, in a previous paper[5] the authors proposed a breathing assist device, which works like a pneumatic master–slave amplifier, for saxophone players with breathing problems.

In this paper, the proposed device is fabricated, and its effectiveness and characteristics are examined through experiments.

2. Proposed Breathing Assist Device

2.1 The concept

The concept of the proposed breathing assist system is illustrated in Figure 1. This system acts as a master-slave system on the basis of the rate at which air is blown into the mouthpiece. In Figure 1, the right side corresponds to the master system, and the left side corresponds to the slave system. The two containers on either side are completely separate. When a person blows air into the mouthpiece (the master system), the air flow rate is amplified in the slave system, and the amplified air flow is supplied to the saxophone. Therefore, the person playing the instrument does not need to blow air at the same rate that is generally required to play the saxophone.

2.2 The fabrication

The authors fabricated the proposed device, as shown in Figure 2(a) (the master side) and (b) (the slave side). On the master side, a pressure sensor (Nagano Keiki KL-17, +10kPa) was attached to the bottom of the mouthpiece. The hole (3 mm in diameter and 20 mm in length) drilled through the rubber stopper functions as an air flow restrictor, providing a realistic feeling of playing a wind instrument to the person being assisted. On the slave side, a servo valve and a pressure sensor (Nagano Keiki KL-17, +10kPa) are connected to a chamber with volume V = 500 cm^3, and a Yamaha Venova YVS-120 mouthpiece (a casual musical wind instrument is used in this study instead of a saxophone because it has the same mouthpiece as a saxophone and it is much cheaper as well)[6] is inserted into the chamber. Because the A note is commonly used as a baseline in the tuning of musical instruments, the reed of the mouthpiece on the slave side is fixed with a rubber band at the position where “la” (A4, 440 Hz) is expressed.

The working scheme of the device and a photo of the spool-type servo valve (SP valve) used on the slave side (FESTO MPYE-5-M5-010B-30L-SA) are shown in Figure 3. The spool-type servo valve is a flow rate control-type servo valve. Although the spool-type servo valve has five ports, it was used as a three-port servo valve in the proposed system, and the two unused ports were closed. Compressed air was supplied to port 1. The output flow rate at control port 4 can be adjusted using the control signal E_i V. Based on the previous experiment investigating the static characteristics of the system, when the supply pressure to port 1 is 0.1 MPa (gauge) and the pressure at port 4 is atmospheric, the gain of the servo valve (K_{sv}) can be approximated as 2.155×10^4 (kg/s)/V.

A block diagram showing the control of the proposed breathing assist system is shown in Figure 4. To control the pressure in the chamber on the slave side (P_2), the pressure in the chamber on the master side (P_1) is detected. This is followed by multiplying the amplifier gain (K_{AG}) by the value of P_1. This value is used as the reference value for P_2, and is denoted as P_{2ref}. In order to control P_2, not only is the simple feedback control utilized (as the main loop), but the feedback

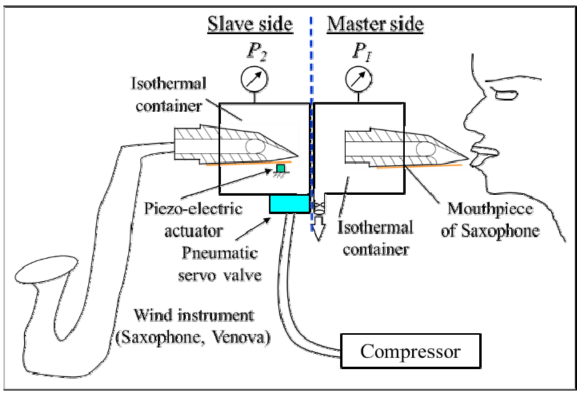
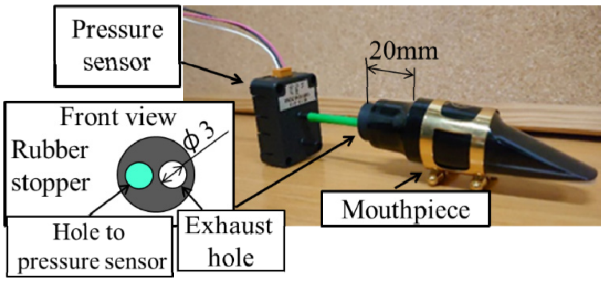
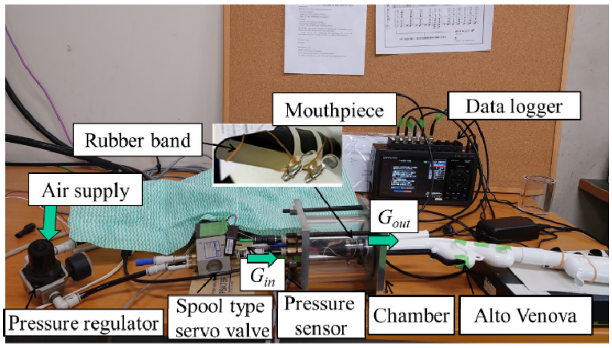


Fig. 1 Concept of the breathing assist device



(a) Fabricated device (master side)



(b) Fabricated device (slave side)

Fig. 2 Fabricated breathing assist device

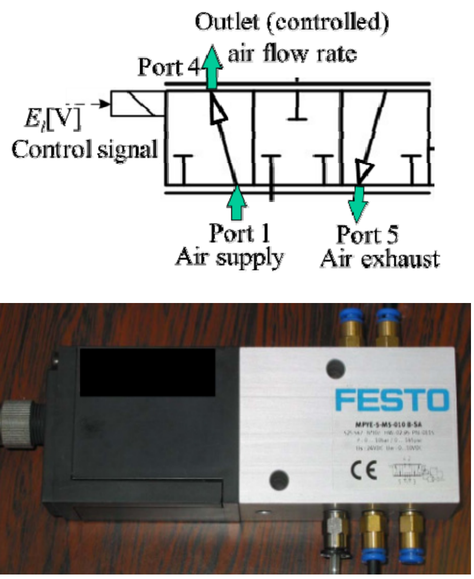


Fig. 3 Spool-type servo valve

of the differentiated value of P_2 (minor loop) is utilized as well. This combination of feedback loops constitutes derivative-preceding proportional-integral-derivative (PID) control, which reduces the influence of the nonlinear characteristics of the SP valve, thus quickly providing precise pressure control.

The digital signal processor (DSP) used in the experiments in this study was the sBOXⅡ (MIS corporation), and MATLAB/SIMULINK was employed as the software.

In the controller, the differentiated value of P_2 is calculated using the first order derivative. The discrete form of the first order derivative using the Z-transform is formulated for the DSP as:

$$\frac{dP_2}{dt}[i] = \frac{1+e^{-st/T_f}}{2T_f}(P_2[i-1] - P_2[i]) + e^{-st/T_f}\frac{dP_2}{dt}[i-1] \tag{1}$$

Here, the sampling time (st) was set at 0.001 s, and the time constant of the low-pass filter (T_f) was assigned a value of 0.01 s.

The proportional gain of the pressure control loop (K_p) was set at 23.68 s^{-1} and the integral gain of the minor loop was fixed at 46.40×10^4. These gain settings resulted in a value of 0.1 s for the time constant of the main loop and 0.01 s for the time constant of the minor loop. Because the time constant of the minor loop was much smaller than that of the main loop, the minor loop could compensate for the influence of the nonlinear characteristics of the SP valve, thereby allowing precise and quick pressure control.

In Figure 4, the product of the gain (K_{PA}) and P_2 is used as the driving signal of the piezoelectric actuator. The variation in K_{PA} may be nonlinear because the optimum force generated by the piezoelectric actuator may vary depending on the tone of the music. This relationship will be calibrated in future studies.

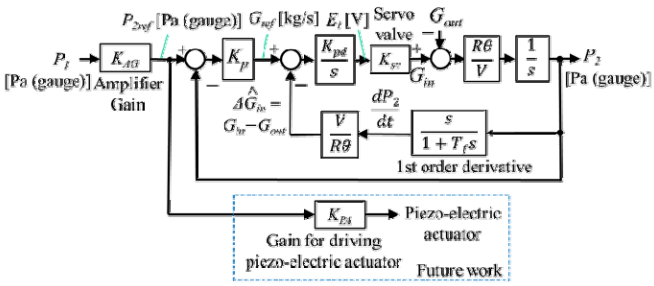


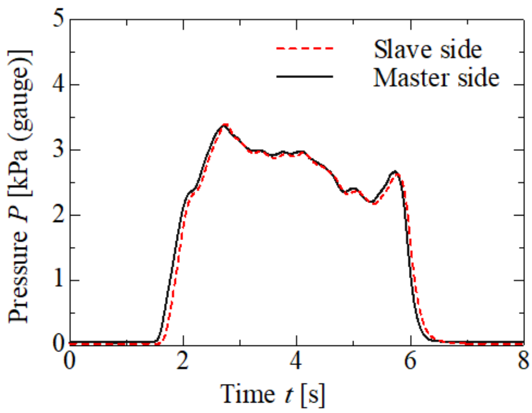
Fig. 4 Block diagram showing the control for the proposed master‐slave breathing assist device

3. Experiments

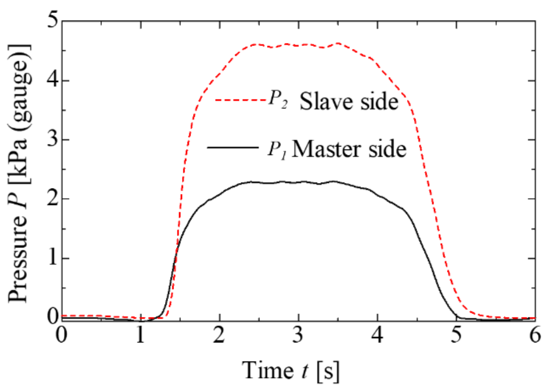
3.1 Blowing air experiment

To examine the performance of the device, experiments were carried out. As shown in Figure 5, a person blew into the mouthpiece on the master side, ensuring that the proper sound was produced (La, A4) by the slave side, as indicated by a musical tuner.

Fig. 5 Experimental setup



(a) K_{AG} =1.0



(b) K_{AG} =2.0

Fig. 6 Pressure profiles for different amplifier gains

The experimental results are shown in Figure 6, where panel (a) shows the result when the amplifier gain was K_{AG} = 1.0 and panel (b) depicts the result for K_{AG} = 2.0. These results indicate that the device performs well as a breathing assist device as well as a master–slave amplifier.

For reference, a previous study conducted by a group from Université du Maine measured the pressure in the mouth of a person who played an alto saxophone[7]. According to the report, the maximum mouth pressure was approximately 40–50 mbar (4–5 kPa gauge). This indicates that the fabricated device is applicable not only to a Venova, but also to a normal saxophone.

3.2 Dynamic characteristics experiment

In this section, the dynamic characteristics of the device are described. In the experiments, the reference value of P_{2ref} was given by:

$$P_{2ref} = 5.8 + 0.3\sin 2\pi ft \quad \text{kPa (gauge)} \tag{2}$$

The frequency (f) was varied from 0.1 Hz to 10 Hz. The values of P_{2ref} and P_2 were compared by defining the gain (G) as:

$$G = 20\log_{10}\left|\frac{A_2}{A_1}\right| \quad \text{dB} \tag{3}$$

where A_1 is the amplitude of the pressure of the reference signal P_{2ref} and A_2 is the amplitude of the pressure P_2.

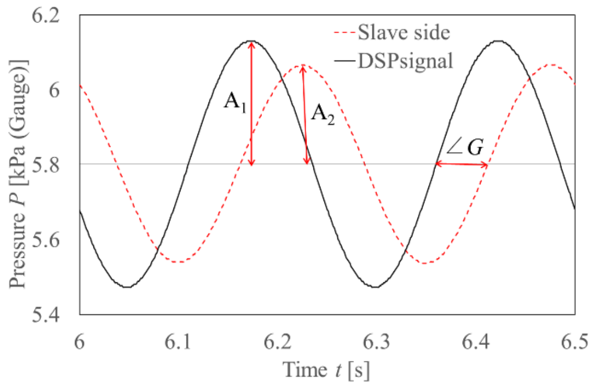
Figure 7 shows the experimental results for the frequency response of the device. Figure 7(a) shows the result for 4 Hz as an example, and panel (b) shows the summarized frequency response as a Bode diagram. The results show that the fabricated device responds up to approximately 5 Hz.

4. Conclusion

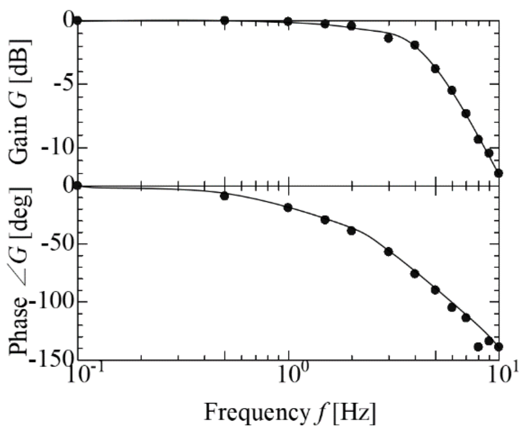
In this study, a breathing assist device for saxophone players with breathing problems was fabricated. The effectiveness of the breathing assist device as a master–slave amplifier was confirmed through experiments. The dynamic characteristics of the device were tested up to

10 Hz, and it was demonstrated that the device can respond well for up to approximately 5 Hz.

Future research will include investigations into the effectiveness of using an isothermal chamber, the improvement of the dynamic characteristics of the device, and the control of the reed holding position through a piezoelectric actuator.



(a) Time domain (4 Hz)



(b) Bode diagram (A_2/A_1)

Fig. 7 Experimental results for the frequency response

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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