Proposal of the Concept of a Breathing Assist System for Saxophone Players with Breathing Problems*

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***Abstract*—This research aims to propose the concept of a breathing assist system for saxophone players with breathing problems. First, the quantity of pressure and air flow rate required to play an alto saxophone is determined by certain investigations and experiments. Second, the above-mentioned concept, which works like a pneumatic master-slave amplifier, is proposed and the details of each component are explained.**

Keywords—pneumatics, music engineering, breathing assist device, wind instrument, saxophone

I. Introduction

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

However, as it requires movement of two hands and a breath support (sometimes deep and even long), it can be difficult for a person with hand disability to appropriately play it. To assist those people in playing the saxophone, a group from Tsukuba University proposed an assisting method called “robot-assisted playing” [1]. During the research, modular devices such as sensory mouthpiece and fingering support, which can be attached to the traditional saxophone, were developed.

Numerous researches have been conducted regarding the development of the robot system that can play a musical instrument [2]. In recent years, the authors of this paper also carried out a research to develop a wind-instruments-playing robot for recorder and khlui [3]-[6]. However, no previous research for the development of a device that assists the breathing of a saxophone player was found.

In this paper, the quantity of pressure and air flow rate required to play an alto saxophone is determined by certain investigations and experiments. This is followed by providing explanations and details of the concept of a breathing assist system for saxophone players.

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II. Investigation and Experiment (the Quantity of Pressure and Air Flow Rate Required to Play an Alto Saxophone)

Before addressing the development of the breathing assist system for a saxophone, we should know the quantity of pressure and air flow rate required to play it. We selected the most commonly used type of saxophone, the alto saxophone, as the subject in this research.

A. Investigation

A research conducted by a group from Université du Maine measured the pressure in the mouth when a human played an alto saxophone [7]. According to the report, the maximum mouth pressure was approximately 40–50 mbar (4–5 kPa gauge).

B. Experiment

To calculate the flow rate required to play an alto saxophone, the experimental configuration shown in Fig. 1 was used to conduct experiments. In Fig. 1, a mouthpiece and a mouth-pipe of an alto saxophone are connected to a sensor called Air Power Meter (APM). The APM is a sensor that can measure physical quantities such as flow rate, pressure, and temperature. By using these physical quantities, the APM can calculate the air power (value of energy consumed by pneumatic components)[8].

Fig. 1. Blown air flow rate measurement configuration

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In this research, the APM is used as a flow sensor. The APM-400S (Tokyo Meter Co., Ltd.) model was used in our work because it is a flow sensor with sufficient resolution and dynamic characteristics that can measure the quantity of air blown in a saxophone. As a flow sensor, the structure of APM is practically the same as that of the Quick Flow Sensor (QFS) [9]. The APM and QFS are both composed of a laminar flow element and a differential pressure gauge.

In previous research, the dynamic characteristics of the QFS were tested using a device called unsteady flow generator (UFG). The UFG can generate arbitrary air flow oscillations up to at least 50 Hz [10]. The QFS model used herein was QFS-0.3-50-30 (Tokyo Meter Co., Ltd.). The resolution of the QFS was 25.6 mL/min (ANR). Fig. 2 presents a schematic of the dynamic characteristic test of the QFS. It was set downstream from the UFG, which was open to the atmosphere.

The generated flow rate from the UFG (considered as the standard) and the flow rate measured using the QFS were recorded and compared. In the experiments, the standard value of the generated flow rate from the UFG was defined according to (1).

$$G \quad [\text{g/s}] = 0.216 + 0.108 \sin(2\pi f t) \qquad (1)$$

Fig. 3 summarizes the experimental results in the Bode plot, where the flow rate generated using the UFG was the denominator, while that measured using the QFS was the numerator. The experimental results demonstrated that when f = 20 Hz, the gain was −0.8 dB, and the phase was −9°. Therefore, the APM is considered suitable to measure the flow rate of the blown air because the structure of the APM is almost the same as that of QFS.

In the experiment, one of the authors, who has played the alto saxophone for several years, blew air into the mouthpiece that generated a sound, as shown in Fig. 4. The flow rate signals measured by the APM were logged with a data logger (Gl-240, Graphtec). Two types of pattern for the blown air flow were put to test in the experiment. One was a normal sound without vibrato, and the other was a sound with vibrato. The experimental results for both are shown in Fig. 5 and 6. These results show that the maximum flow rate of the blown air is 20–30 L/min (ANR), and the frequency of the vibrato is 10–20 Hz.

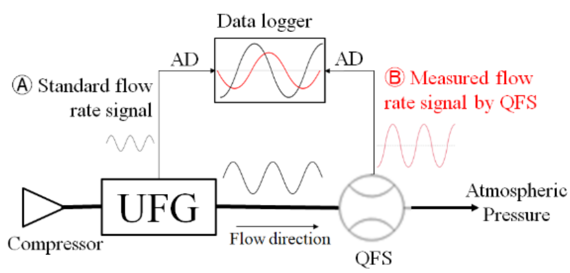

Fig. 2. Schematic of dynamic characteristic test

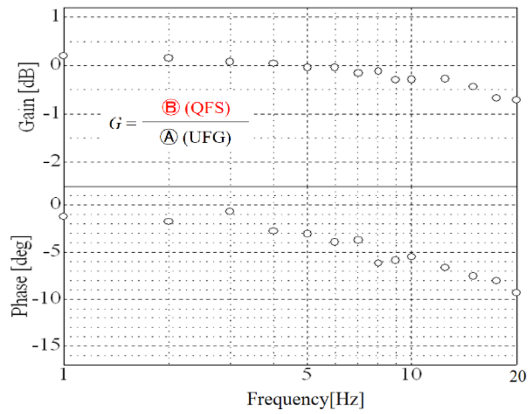

Fig. 3. Bode plot of the dynamic characteristics of the QFS

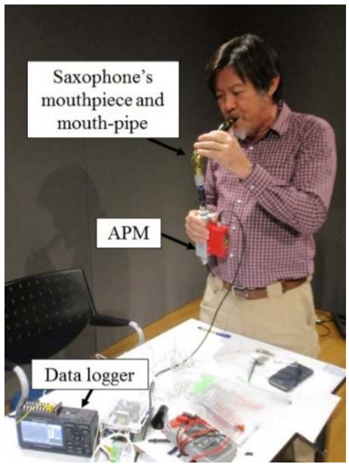

Fig. 4. Blown air flow rate measurement experiment

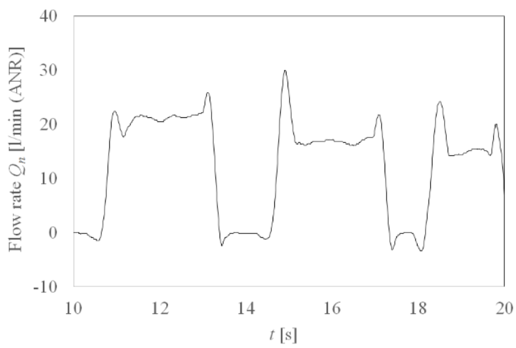

Fig. 5. Experimental result (blown air flow rate) without vibrato

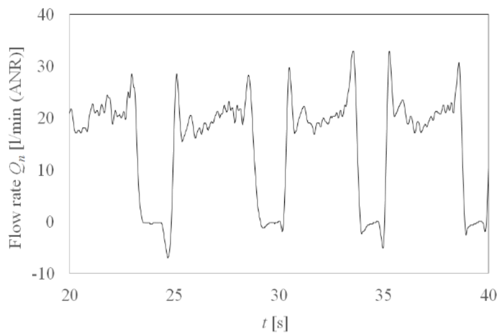

Fig. 6. Experimental result (blown air flow rate) with vibrato

III. Proposal of the Concept of a Breathing Assist Device

In this section, the concept of a breathing assist system for saxophone players, which works like a pneumatic master-slave amplifier, is proposed and the details of each component are explained.

A. The concept and the configuration

The concept of the proposed breathing assist system is shown in Fig. 7. This system acts like a master-slave system for the blown air flow rate. In Fig. 7, 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 separated. When a human player blows air into the mouthpiece on the right end (master system), the air flow rate is amplified in the slave system and the amplified air flow is given to the alto saxophone. Therefore, the human player does not need to apply the same amount of air flow rate that is generally required to play a regular alto saxophone.

B. Components of the device

The components and their roles in the breathing assist system are explained in this section.

1) Mouthpieces

Both master and slave sides in an alto saxophone require mouthpieces. A reed is fixed on the mouthpieces. On the slave side, the force required to hold the mouthpiece is adjusted by using a piezoelectric actuator to generate the proper sound by inducing the vibration of the reed.

2) Isothermal container

An isothermal container is a container stuffed with a little amount of thin metal wool. By stuffing the metal wool (such as copper wire), the heat capacity in the container will significantly increase and the temperature change in the container will almost be constant during air charge and discharge.

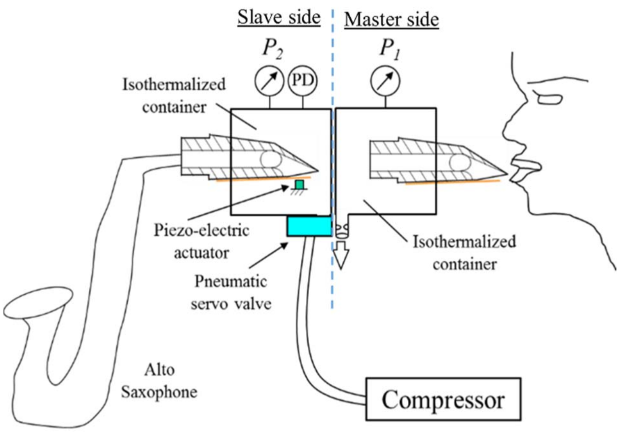

Fig. 7. Concept of a breathing assist system

Fig. 8. Isothermal chamber

In a previous research, the authors had applied the technique of an "isothermal chamber" (Fig. 8) [11] to various pneumatic servo-control systems [12]. The isothermal container used in this research is derived from a similar isothermal chamber used in the above-mentioned research.

In the isothermal container, the mass flow rate G [kg/s] (the difference between the air entering and leaving the container) can be expressed as equation (1).

$$G = \frac{V}{R\theta}\frac{dP}{dt} \tag{2}$$

Here, V is the volume of the container [m^3], R is the gas constant [J/(kg K)], θ is temperature[K] (which should be almost constant), and P is the pressure in the container [Pa].

3) Pressure sensor

Commercially available pressure sensors are used to measure the pressure in containers P_1 and P_2. KL-17 (Nagano-keiki), a diaphragm-type pressure transducer, can potentially be used because high resolution and high dynamic characteristics are required around the atmospheric pressure.

4) Pressure differentiator

Pressure differentiator (PD) sensor is a sensor that was developed by the authors referenced in [13]. The PD sensor can measure the differentiated value of pressure with high resolution and high dynamic characteristics. Fig. 9 shows its structure and image. The PD sensor is composed of an isothermal chamber, a cylindrical slit channel, a diaphragm-type differential pressure gauge, and a pressure sensor. When the measured pressure changes, air flows through the narrow slit channel, followed by a slight change in pressure in the chamber. By measuring the differential pressure with the gauge, the differentiated value of pressure P_j becomes T times the value of differentiated pressure with a first-order lag filter, as shown in equation (2).

$$P_j = \frac{T}{1+Ts}\dot{P} \tag{2}$$

DTP-8 (Tokyo meter) is the PD sensor model used in the proposed system.

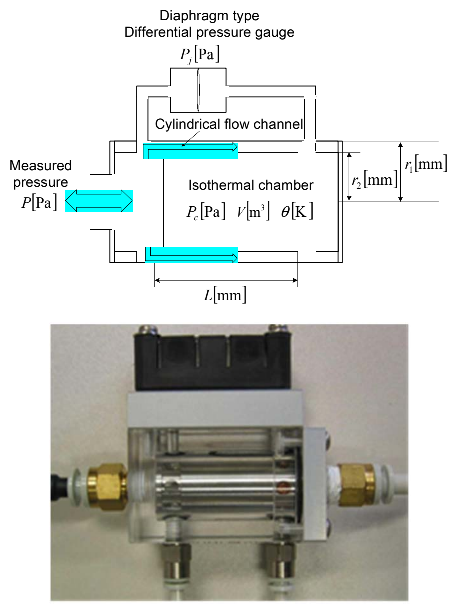

Fig. 9. Structure and image of pressure differentiator

5) Spool-type servo valve

Spool-type servo valve (SP valve) is a type of flow rate control servo valve. Its working scheme and image are shown in Fig. 10. This assumed SP valve is proportional to directional control valves (MPYE and FESTO). Although the SP valve has five ports, it was used as a three-port servo valve in the proposed system and the two unused ports were closed. The compressed air is supplied to the Port 1. The output flow rate at the control port 4 can be adjusted by the control signal E_i [V].

C. The control method

The proposed breathing assist system shown in Fig. 7 can be controlled by the block diagram shown in Fig. 11. The feedback and feedforward control can be configured using a Digital Signal Processor (DSP) and software (such as MATLAB).

To control the pressure in the isothermal container of the slave side P_2, the pressure P_1 (in the isothermal container of the master side) is detected. This is followed by multiplying the amplifier gain (K_{AG}) to the value of P_1 and adding the atmospheric pressure as bias adjustment. This calculated value is used as the reference value of P_2, denoted by P_{2ref}. In Fig. 11, the feedback of the differentiated value of P_2, measured by a PD sensor, is determined. The feedback of pressure P_2 is also calculated. This derivative preceding PI (PI-D) control is useful in reducing the influence of the nonlinear characteristics of the SP valve, thus determining precise and quick pressure controllability.

The value of the gain K_{PA} multiplied to P_2 is used as the driving signal of the piezoelectric actuator. K_{PA} might be a nonlinear value because the optimum force generated by the piezoelectric actuator may vary depending on the tone of the music. This relationship should be calibrated in future work.

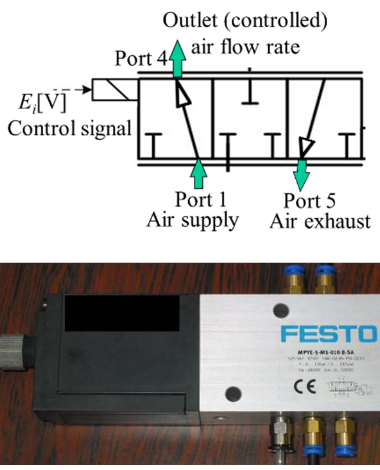

Fig. 10. Working scheme and image of spool-type servo valve

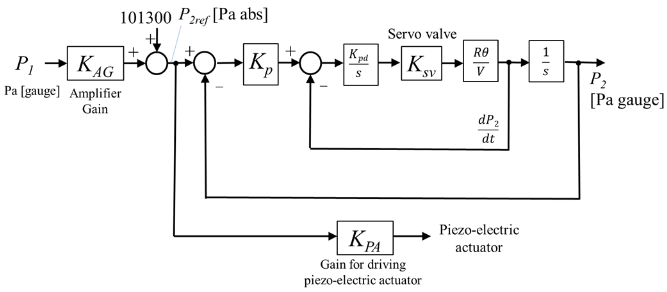

Fig. 11. Block diagram for controlling the proposed breathing assist system

IV. CONCLUSION

In this paper, to develop a breathing assist system for saxophone players with breathing problems, first, the quantity of pressure and air flow rate required to play an alto saxophone were determined by certain investigations and experiments. It was followed by describing this concept that works like a pneumatic master-slave amplifier and explaining the details of each component.

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