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MEASUREMENT OF AIR FLOW PATTERN THROUGH A MECHANICALLY DRIVEN OSCILLATING SLIT:

- A PRELIMINARY REPORT -

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Introduction

To get a more quantitative insight into the relationship between the pattern of vocal cord vibration and a resulting source sound, we have started experiments to measure the air flow pattern through a model of the vibrating glottis.

A slit simulating the glottis was constructed, and its opening and closing movements were driven mechanically using a step motor. The waveform of the open area of the slit can be varied and controlled by the step motor. The velocity of the air flow out of the slit and the corresponding acoustic sound can be recorded simultaneously. This paper presents a preliminary results of the experiment obtained using this model.

Method

The experimental set up in the present study is explained in Fig. 1. An aclyl tube 30mm in diameter was set in a vertical position. At the upper end of the tube, half of the cross section was covered by a rubber sheet 5mm in thickness. The remaining half of the cross section was covered by a rubber membrane, the edge of which was a rubber string 2 mm in diameter. The edge of the rubber membrane was kept in contact with the edge of the rubber sheet so that no open space was left between then. To the edge of the rubber membrane was attached a steel bar which was connected to the rotation axis of a step moter. Small angle, back and forth rotations of the step motor generated vibratory movements at the edge of the rubber membrane and, thus, produced opening and closing movements of the slit between the edges of the rubber membrane and the rubber sheet. The lower end of the acryl tube was conected to an air gas cylinder through a vinyl tube. The air flow was supplied from this gas cylinder. The edge of the rubber membrane was glued to the edge of the rubber sheet except for the central portion, whict was 15mm in length. Thus, the length of the slit for the airflow was 15mm.

The velocity of the air flow out of the slit was measured by placing a hot wire sensor above the slit. Its position was varied vertically and horizontally, and the flow velocity at several different positions relative to the slit were measured.

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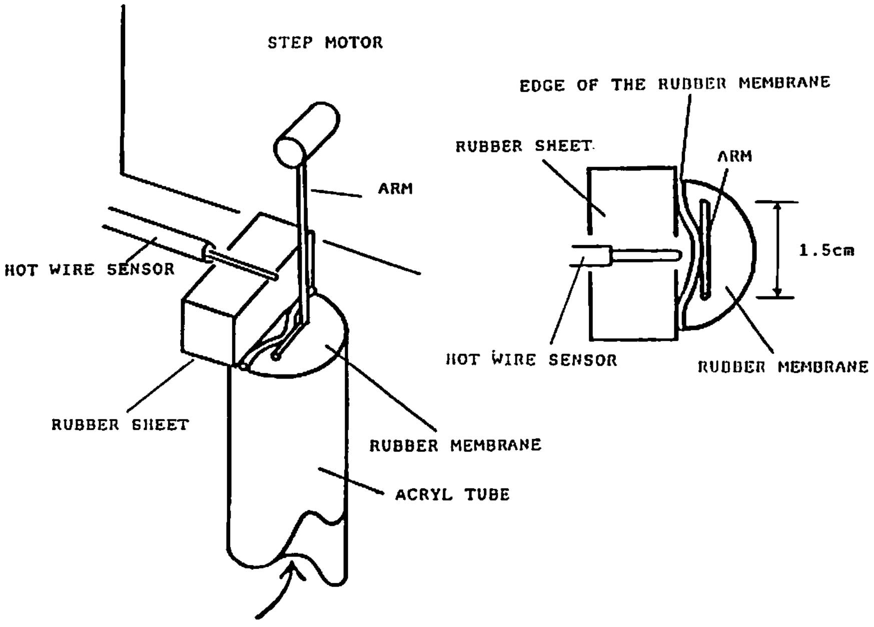


Fig. 1 Experimental set-up.

The acoustic sound was also recorded using a miniature condenser microphone located 5cm above the slit and 4.2cm from the center of the acryl tube.

An LED was attached to the step motor arm, and its movement was recorded using a PSD (Position Sensitive Detector) system. The Image of the moving slot was also recorded using a stroboscope and a video camera. The video camera was placed right above the slit and viewed downward toward the slit.

The angle of the unit rotation of the step motor was 0.36, and the length of the step motor arm was 35mm. Thus, to produce 1mm displacement at the edge of the slit, a train of 5 control pulses was given to the step motor. However, when the train of 5 control pulses each for the opening movement and closing movement were simply given, the step motor arm showed a complex oscillatory movement (Fig. 2 (a)). This oscillatory movement due to the inertia of the step moter could be suppressed by giving additinal control pulses with selected timing. An appropriate pattern of additional pulse trains was determined for each desired pattern for the movement of the step motor arm through a trial and error procedure.

Three movement patterns (1),(2),(3), and the correponding patterns of control pulses, used in this study are shown in Fig.2 (b),(c)and(d), respectively.

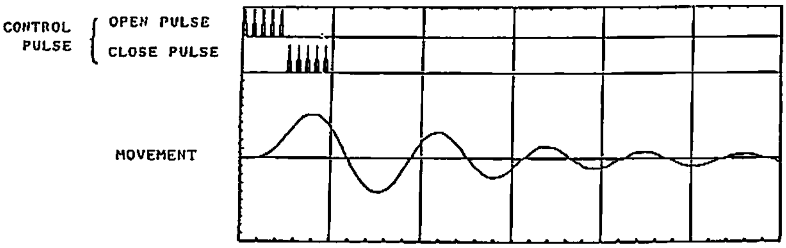


Fig. 2. (a)

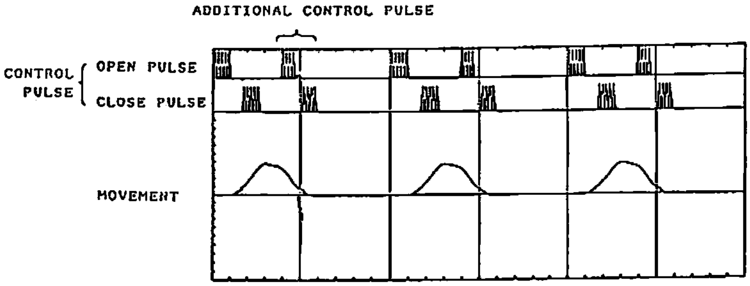


Fig. 2. (b)

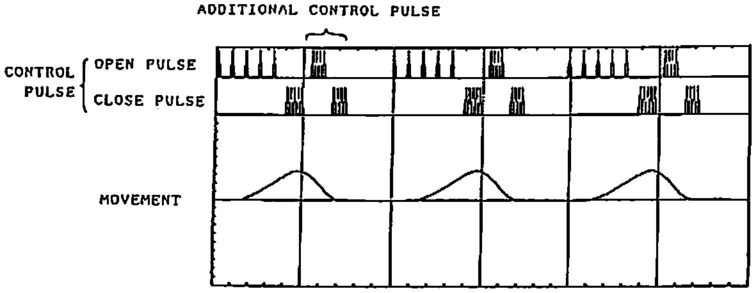


Fig. 2. (c)

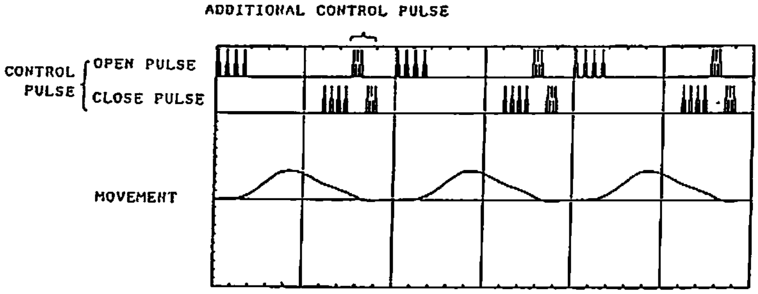


Fig. 2 Movements of the arm of the step motor and the corresponding patterns of control pulses.
(a) Simple pattern of a control pulse train.
(b), (c), (d) Movement patterns (1), (2) and (3) with addittional control pulses for suppressing oscillatory movement.

Results and Discussion

Fig. 3 shows the time functions of the flow velocity measured for the three different patterns of the opening and closing movements of the slit. Fig. 3(a) is the result for the movement pattern (1) shown in Fig.2. The flow velocity was measured at several different positions on a horizontal plane 15mm above the slit. At the top of this figure is shown the movement of the step motor arm, together with the control pulses to the step motor. In the left panel of the figure are shown the flow velocities at several different positions along the X-axis. In the right panel are shown the flow velocities at several defferent positions along the Y-axis. Here, the Y-axis is defined as the direction along the slit, and the origin of the coordinate system is the center of the tube.

It can be seen in Fig.3 that the air flow is confined spatially to a considerably narrow area. The peak velocity at the point X=+8mm is only approximately 1/10 of that at the center position. It can aiso be seen in this figure that, although the opening and closing movements of the step motor arm are nearly symmetric as in time, the time function of the flow velocity exhibits asymmetry. Namely, the rising slope in the waveform of the flow velocity at the opening phase is very steep. Compared to this, the falling slope near the closing phase is more gradual.

In Fig.3, a simultaneously recorded sound wave is also shown with the curve of the flow velocity at the position X = 0mm. As a first crude approximation, the waveform of the sound may be regarded as the first order differential of the flow velocity waveform. Namely, it has a positive peak for the opening phase and a negative peak for the closing phase. It should be noted, however, that the absolute magnitude of the peak is larger for the negative peak at the closing phase, although the slope in the flow velocity waveform is larger at the opening phase. Although this is an intersting point to be examined, we need to know the time function of the open area of the slit, and the corresponding volume velocity through the slit, before we can draw more detailed conclusions.

Fig. 3(b) also shows flow velocities for the movement pattern of the step motor arm (1), but at 25mm above the slit. Even at this height, the air flow is still confined to a considerably narrow area. The flow velocity at X = 10mm is about 1/5 of that at the center position. Figures 3(c) and (d) show the flow velocities for the movement pattern of the step motor arm (2) and (3). In the case of the movement pattern (2), the closing movement is steeper than the opening movement. In the case of the movement pattern (2), the closing movement is more gradual than the opening movement. It can be confirmed in the figure that the waveform of the flow velocity shows changes corresponding to the changes in the pattern of the opening and closing movements of the slit.

Although the experiment described above is a very preliminary one, the results show that we have a good control over the pattern of the opening and closing movements of the slit, and that we can measure the corresponding changes in the air flow pattern and the acoustic sound. Further experiments are now being performed using a more realistic model simulating the shape of the glottal constriction. We believe that experiments along these lines will be useful future quantitative analysis of the relationship between the pattern of vocal cord vibration and resulting sounds.

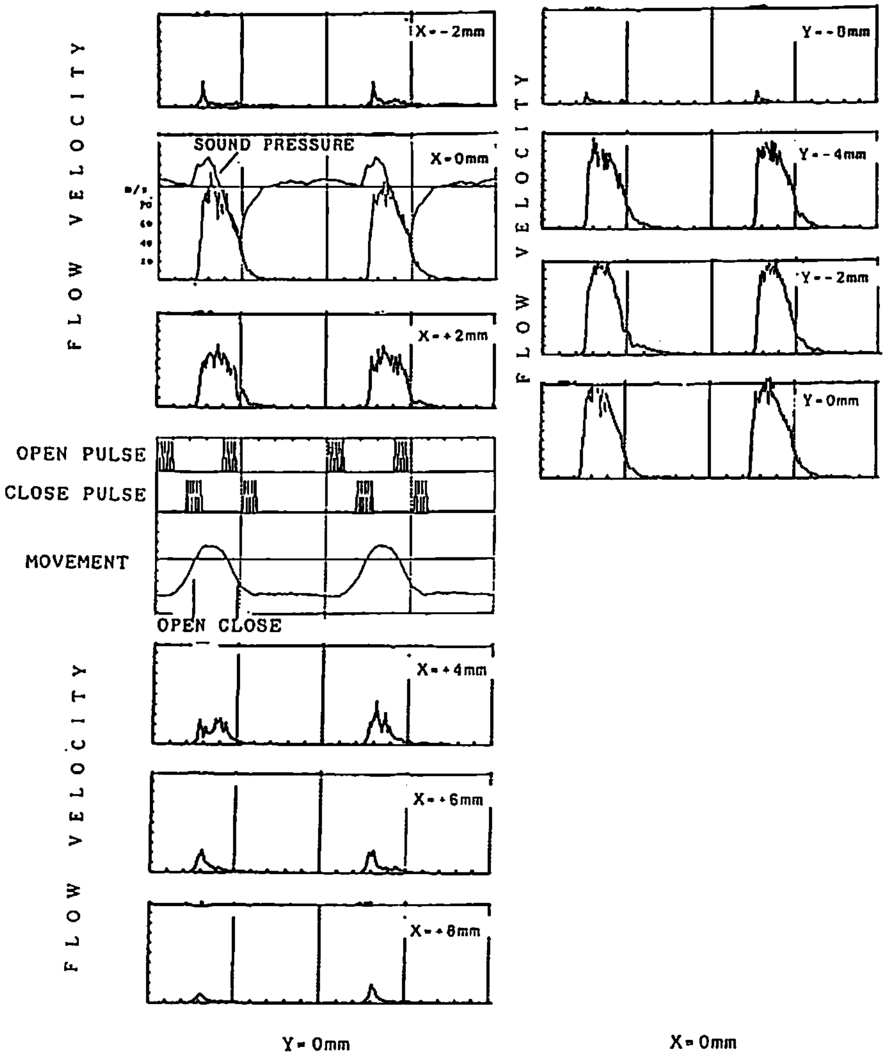


Fig. 3 Flow velocities measured at several positions above the slit. The Y direction is along the slit.
(a) Movement pattern (1), 15mm above the slit.

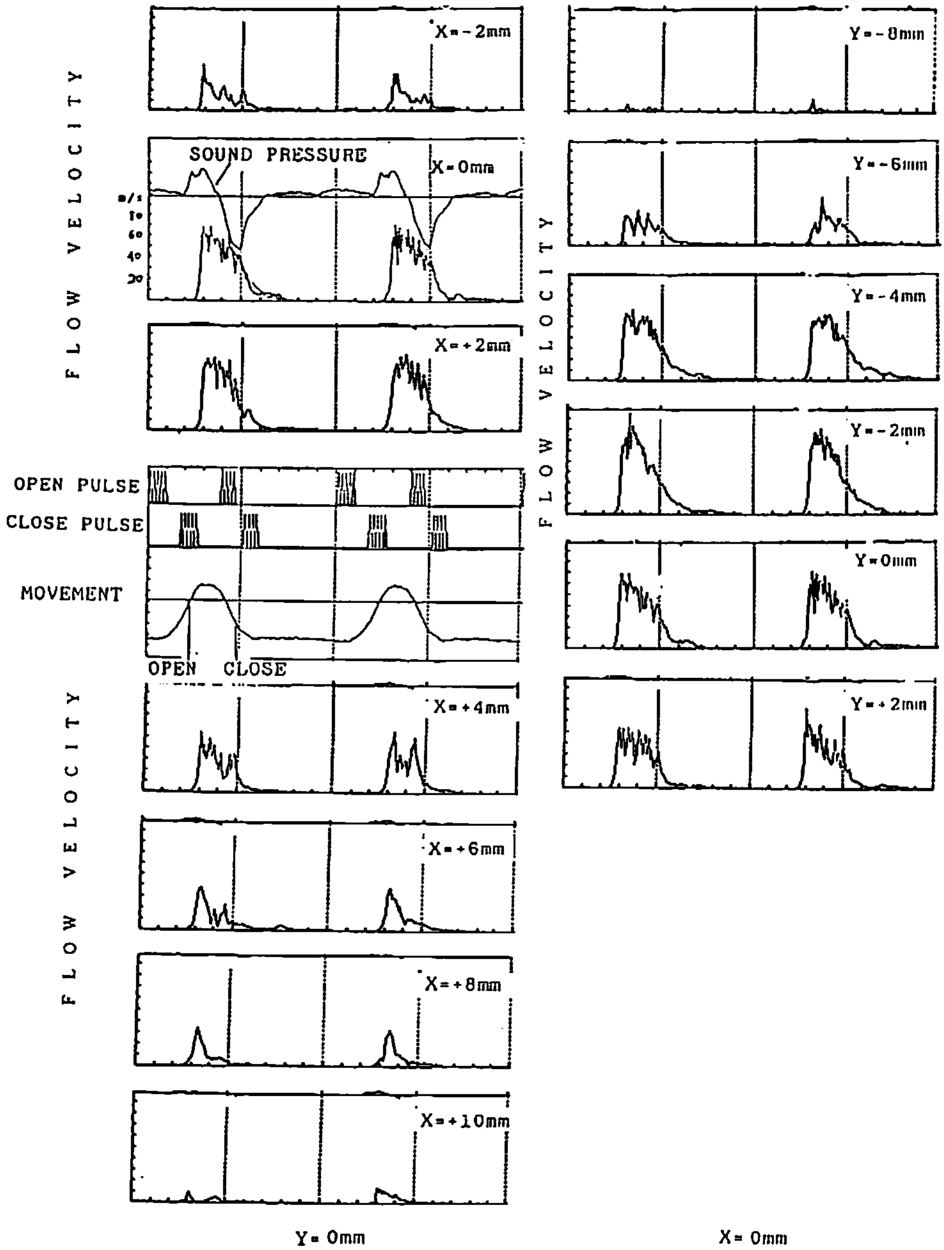
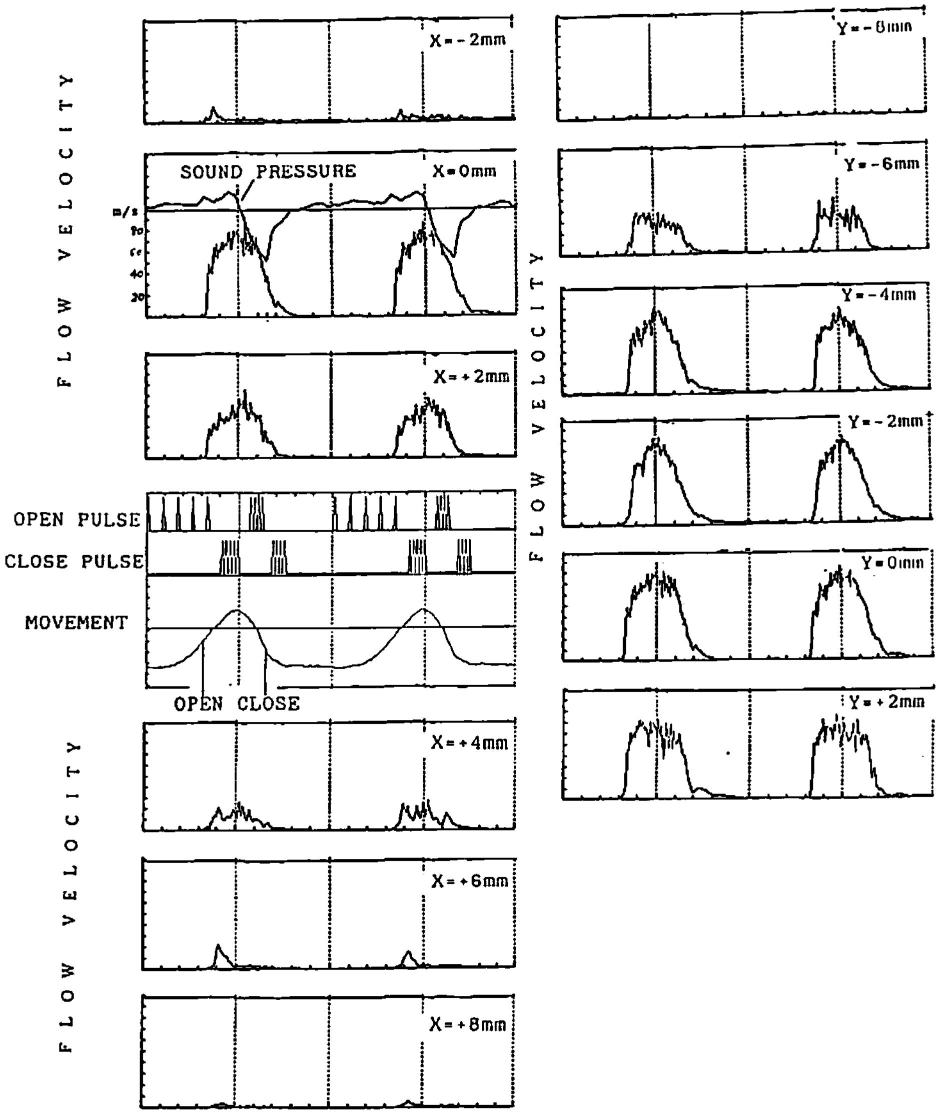


Fig. 3 Flow velocities measured at several positions above the slit. The Y direction is along the slit.
(b) Movement pattern (1), 25mm above the slit.



Y=0mm

X=0mm

Fig. 3 Flow velocities measured at several positions above the slit. The Y direction is along the slit.
(c) Movement pattern (2), 15mm above the slit.

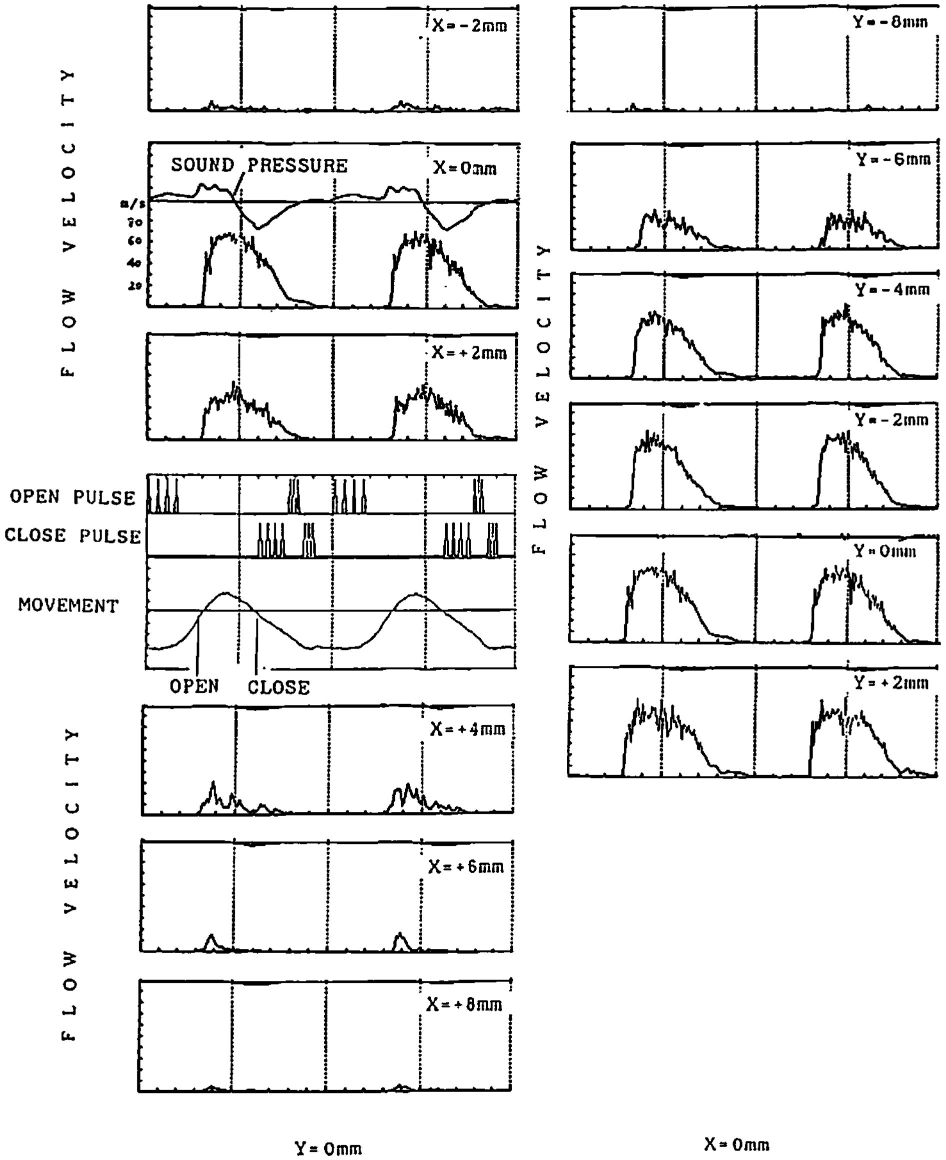


Fig. 3 Flow velocities measured at several positions above the slit. The Y direction is along the slit.
(d) Movement Pattern (3), 15mm above the slit.