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ACOUSTICAL BEHAVIORS OF AN OBOE AND A SOPRANO SAXOPHONE ARTIFICIALLY BLOWN

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ABSTRACT

An oboe and a soprano saxophone have been artificially blown with all the tone holes being closed. Many states of reed vibrations were found, when the blowing pressure was changed under several lip-adjustments. Even at a given blowing pressure and under a fixed lip-adjument, many vibratory states were observed, especially in the oboe; it depended on the preceding state which vibratory state took place. Once a vibratory state was excited, it was quite stable. This is important for the instrument player.

1. INTRODUCTION

Acoustical behaviors of the reed woodwind instrument artificially blown have been studied, by Backus [1] for the clarinet, and by Shimizu, Naoi and Idogawa [2] for the bassoon. In this paper, we present complicated acoustical behaviors of an oboe and a soprano saxophone artificially blown. Experiments were carried out with all the tone holes of the instruments being closed. For comparison, a cone has also been artificially blown using the mouthpiece of the soprano saxophone. Its air column has about the same apex angle as that of the bassoon, and it is slightly shorter than the soprano saxophone.

Section 2 describes methods of experiments except the same as those for the artificial blowing of the bassoon [2]. Sections 3, 4 and 5 present the results of the observations obtained for the oboe, the soprano saxophone and the cone, respectively. In section 6, the results shown in sections 3-5 are compared and discussed.

Notations used in this paper are:

l = the length of the part of the reed that projects into the blowing chamber;

H = the opening of the reed at rest under the lip pressure;

$p(t)$= sound pressure in the reed or in the mouthpiece;

$y(t)$= reed opening from its position at complete close;

P = pressure in the blowing chamber;

P_{th} = lower limit of P which can excite the instrument;

P_s = P where an instrument is set into sounding, when P is increased from 0;

P_c = upper limit of P which can excite the instrument;

f = fundamental frequency of the sound emitted from the instrument;

where t is time. Some of the notations are shown in Fig.1.

2. EXPERIMENTS

Methods and set up of experiments performed for the present paper are the same as those described in a former paper on the bassoon [2], except 2 items below. (1) p(t) was not observed for the oboe, becuase the motin of the reed, which was smaller than that of the bassoon, was greately disturbed by the insertion of the microphone probe. (2) y(t) was determined by a photodiode which recieved paralell light projected through the reed aparture. The light source was placed opposite to the bell of the instruments.

Fig.1 is the blowing chamber for the soprano saxophone. This chamber can be used also for the clarinet. The blowing chamber for the oboe is same as that for the bassoon described in the former paper [2].

3. AN OBOE (Yamaha, YOB-811, No.860211)

For the artificial blowing, 13 cane reeds and 21 plastic reeds (Rucles) were prepared. The plastic reeds were used, because the cane reeds became dry and did not vibrate during the artificial blowing. The plastic reeds used had about the same dimensions as shown in Fig.2, however, the openings d_o were distributed from 0.38 to 0.61 mm. Among them, 5 reeds could hardly blow the lowest note of the oboe B^{b}_{3} (233.08 Hz) artificially; these were also not accepted when blown by a player.

When P was varied between 0 to Pc under a fixed lip-adjustment, many states of the reed vibration were found. An example is shown in Fig.3 and Fig.4. Here, Fig.3 is called a distribution map of vibratory states, and Fig.4 is called the transition diagram of the vibratory states of Fig.3.

In Fig.3, the ordinate indicates f by an interval (cent) from the nearest note of the tempered scale, and the abscissa gives P (kPa). Every enclosure in Fig.3 is designated by On-m (a), (b) or (c); "O" means the oboe, distinguished from the soprano saxophone; n (= 1, 2, 3, 4) expresses the nth harmonics of B^{b}_{3}; m is simply a number which distinguishes a vibratory state from the others; (a), (b) or (c) is the name of a branch to which the vibratory state belongs (see Fig.4).

Fig.4 presents transitions between vibratory states shown by blocks. The transition is the sudden irreversible change of the vibratory state. A transition encountered by increasing P, which is called a forward transition, is shown by a real line with an arrow; a transition encountered by decreasing P, which is called backward transition, is shown by a broken line with an arrow.

The example shown in Figs.3 and 4 was obtained under a fixed lip-adjustment, namely, l=9 mm and H=0.52 mm. This contained the most vibratory states, among many examples obtained by different reeds and different lip-adjustments. In this example, P_s = 3.5 kPa, P_{th} = 2.2 kPa, and P_c = 20.6 or 21.6 kPa. In a zone 2<P<5 kPa, 11 vibratory states were found (see Fig.3). Among them, musically acceptable sound $B^b{}_3$ of the oboe was radiated in the vibratory state 01-1(a). When P was increased from 0, the musically undesirable state 01-2(a) or 02-1(a) was excited at first at Ps = 3.5 kPa, depending on the speed of the increase of P. The musically favorable state 01-1(a) can be obtained by decreasing P from the undesirable state 01-2(a) or 02-1(a) via transition. This is important for the "attack" of the stationary tone $B^b{}_3$ as will be discussed in a later section in relation to the soprano saxophone.

The more complicated situations of the transition can be clearly understood by examples: A vibratory state 02-1(c) in the lowest line (the branch (c)) of Fig.4 was excited in a region 5.4<P<8.8 (kPa). Within this regeon, f increased from 5 to 25 cent above $B^b{}_4$ (466.16 Hz) with P as shown in Fig.3; y(t) waveform varied continuously and reversibly with P varied. At P = 5.4 kPa, or at P = 8.8 kPa, another vibratory state was excited. It is shown in Fig.4 that the state 02-1(c) is obtained from the state 01-2(c) via forward transition, and from the state 01-1(c) or 04-1(c) via backward transition. The transition between the states 01-2(c) and 02-1(c) was bilateral, namely, forward and backward transitions were found between these states. The bilateral transitions are mostly hysteretic as in this case, that is , the forward transition from 01-2(c) to 02-1(c) happened at P = 5.7 kPa, and the backward transition from 02-1(c) to 01-2(c) took place at P = 5.4 kPa. The transition between the states 02-1(c) and 04-1(c) is unilateral, namely, only the backward transition from 04-1(c) to 02-1(c) was found and the forward transition from 02-1(c) to 04-1(c) could not arise. The transitions from 01-7(a) to 02-3(a) and from 02-3(a) to 01-8(a) are forward unilateral. Branches (b) and (c) are the results of these forward unilateral transitions.

The reed is important for the instrument performance. Some reeds can not blow the 2nd or 3ird harmonics of $B^{b}{}_{3}$. The vibratory state distribution and the transition diagram of the vibratory states depended on the reed used and the lip-adjustment, even if the same instrument was artificially blown. Figs.3 and 4 were repeatedly obtained under the same lip-adjustment by using the same reed.

In Fig.5, y(t) waveforms are presented for every vibratory state of the example described above.

4. A SOPRANO SAXOPHONE (Yamaha, YSS-62, No.1671)

Fig.6 is an example of distribution maps of vibratory states obtained by the artificial blowing of a soprano saxophone with all the tone holes being closed. Its transition diagram is shown in Fig.7. In the name of the vibratory state, for instance S2-1, "S" means the soprano saxophone, and "2" assigns the note $G^{\#}{}_{4}$ (415.30 Hz), further, "-1" is for comparison with Fig.9, although it is of no use in Figs. 6 and 7.

By the artificil blowing, 4 vibratory states were excited. They were S(1-1), S(2-1), S(3-1) and S(1-1,2-1) which emitted respective tones around $G^{\#}{}_{3}$ (207.65 Hz), $G^{\#}{}_{4}$, $D^{\#}{}_{5}$ (622.25 Hz) and beat like soundings. When all tone holes are closed, the player blows $G^{\#}{}_{3}$ radiated by the state S(1-1) as for the usual stationary sounding; however, he can excite the other states as well.

Fig.8 shows examples of the y(t), p(t) and its power spectrum for S(1-1) and S(2-1). These p(t) and y(t) waveforms are similar to those of the bassoon and the oboe.

For S(1-2,2-1), only the p(t) is shown. Beat like tones were produced also by the artificial blowing of the bassoon.

A soprano saxophone without tone holes was also artificially blown. The results are shown in Fig.9. The vibratory state is denoted by "S#", instead of "S". More vibratory states were found compared with the real soprano saxophone.

5. A CONICAL BORE

A conical bore shown in Fig.10 was also artificially blown, being fitted with the mouthpiece of the soprano saxophone. It was 630 mm long, so, longer than the clarinet (600 mm) and shorter than the soprano saxophone (646 mm). Its apex angle (0.014 rad) was much smaller than that of the soprano saxophone (about 0.06 rad). Fig.11 shows two distribution maps of vibratory states. Fig.12 shows p(t) and its power spectrum for several states. As seen from Figs.11 and 12, acoustical behaviors of this conical bore combine those of the clarinet with those of the soprano saxophone.

Behaviors similar to those of the soprano saxophone are: (1) Tones around F_3 (174.61 Hz) were emitted in a lower region of P where the fundamental mode of the conical bore must be excited. Fig.12(A) shows the p(t) waveform which is similar to that of the soprano saxophone in $G^{\#}_3$ sounding. (2) Tones around $F^{\#}_4$ (369.99 Hz) were emitted in a higher region of P. The p(t) waveform is shown in Fig.12(B).

Clarinet-like behaviors [3] are: (1) In a higher region of P, the p(t) waveform shown in Fig.12(H) was excited, and $D^{\#}_3$ (155.56 Hz) tone was emitted. The waveform is quite similar to that of the clarinet in D_3 (146.83 Hz) sounding. (2) Vibratory states of higher frequencies, such as $C^{\#}_6$ (1108.7 Hz) or G_6 (1568.0 Hz) are found in lower region of P. These frequencies are independent of the bore length.

Further, it is quite strange that: (1) The frequency of the emitted tone changed continuously from about B_2 (123.47 Hz) to around $D^{\#}_5$ (622.25 Hz) without transition, which has never been found in any other reed woodwind instrument. (2) The frequency of B_2 is lower than F_3 and $D^{\#}_3$. (3) The amplitude of p(t) waveforms shown in Figs.12 (C)-(F) is unstable. A p(t) waveform in Fig.12(G) seems to be chaotic.

6. DISCUSSION

Many different vibratory states are excited in the oboe, and in the bassoon [2], compared with those found for the soprano saxophone. It is thought that this comes from the different dynamic characteritics of the single and the double reed. The soprano saxophone must be relatively easy to perform.

In the soprano saxophone, the vibratory state S2-1 or S3-1 was excited at first at $P = P_s$, when P was increased from 0. Then, P must be reduced to obtain the most favorable state S1-1 which emits the tone of $G^{\#}_3$. When the lowest note of the soprano saxophone was blown by a player, a transient of its reed vibration was obtained as shown in Fig.13 which was the voltage output obtained from the strain gauge pasted to the reed. A small arrow in Fig.13 indicates the use of tonguing. At the "attack", during the short duration of time (about 25 ms), reed vibrations of higher frequencies are observed which suggest the excitation of the vibratory state S2-1 or S3-1 before the stationary tone of $G^{\#}_3$.

In the oboe, the musically undesirable state O1-2(a) or O2-1(a) was excited at first at Ps = 3.5 kPa, instead of the most favorable state O1-1(a), when P was increased from 0. If we were able to observe the reed motin of the oboe in the real playing, we might observe the vibrations of higher frequencies during the attack.

The y(t) and p(t) waveform patterns and the frequency of the reed vibration changed abruptly at the transition. At the transition, no lip displacement was observed even by using an ocular micrometer. Once a vibratory state is excited, it is very stable within its region of P which is bounded by two transition pressures; when the lip was slightly displaced by the tip of a pencil, the transition did not arise, although the reed vibration frequency varied slightly. This is important for the player; otherwise, the instrument performance would be very difficult. Behaviors of the cone were strange, especially in a vibratory state; the vibration frequency changed continuously without transition, from B_2 to $D^{\#}_5$ with changes of P.

SUMMARY

The soprano saxophone must be easier to perform, compared with the oboe, because it has the simple transition diagram, while the oboe has complicated transitions.

When the soprano saxophone was blown by a player, its reed vibrations were observed, and it is believed that he blows the other vibratory state at the attack than the state appropriate for the desired stationary sounding.

A vibratory state excited is very stable against a slight lip-displacement intentionary added within a range of P bounded by two transition pressures; otherwise, the instrument performance would be very difficult for the player.

A special conical bore fitted with the single reed, which was an unreal woodwind, had unacceptable properties; it was very sensitive to the lip-adjustment and no transition was found in some cases. This system is interesting because it reveals some secrets of the woodwinds.

REFERENCES

1) Backus,J., "Vibrations of the reed and the air column in the clarinet", J.Acoust.Soc.Am. 33, 806-809 (1961).
2) Shimizu,M., Naoi,T. and Idogawa,T., "Vibrations of the reed and the air column in the bassoon", J.Acoust.Soc. Jpn. 10, 269-278 (1989).
3) Iwaki,M.,"Unpublished master thesis" (1991) (in Japanese).

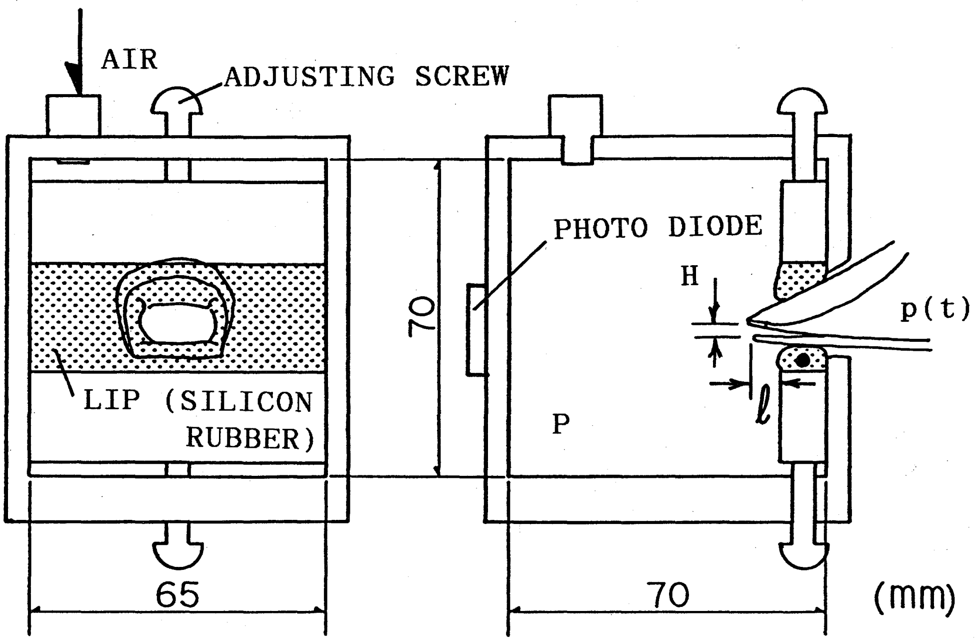


Fig.1 A blowing chamber for the soprano saxophone.

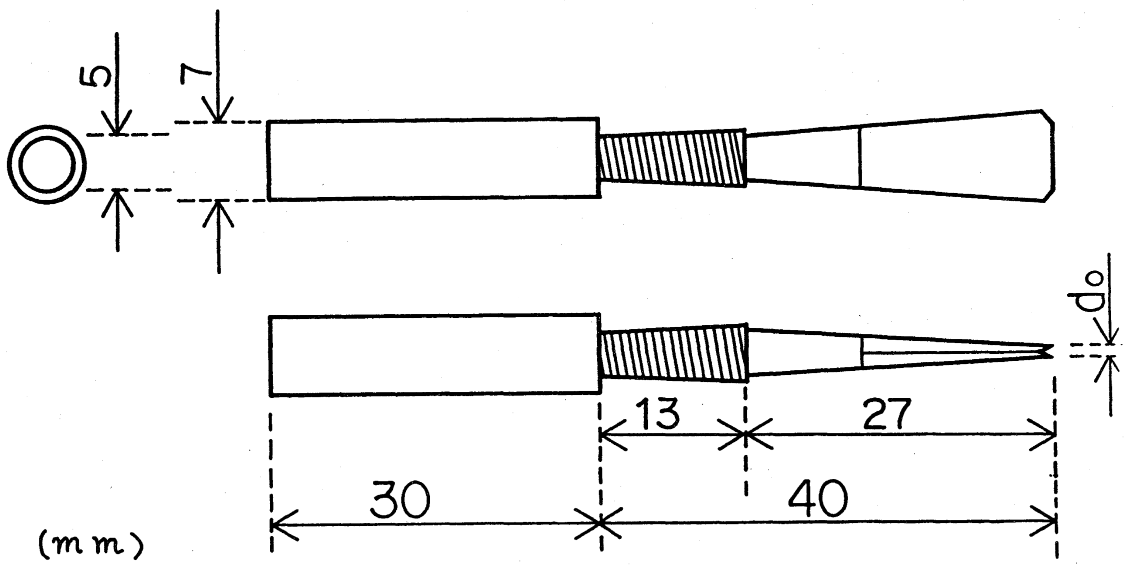


Fig.2 Actual size of the plastic reeds used.

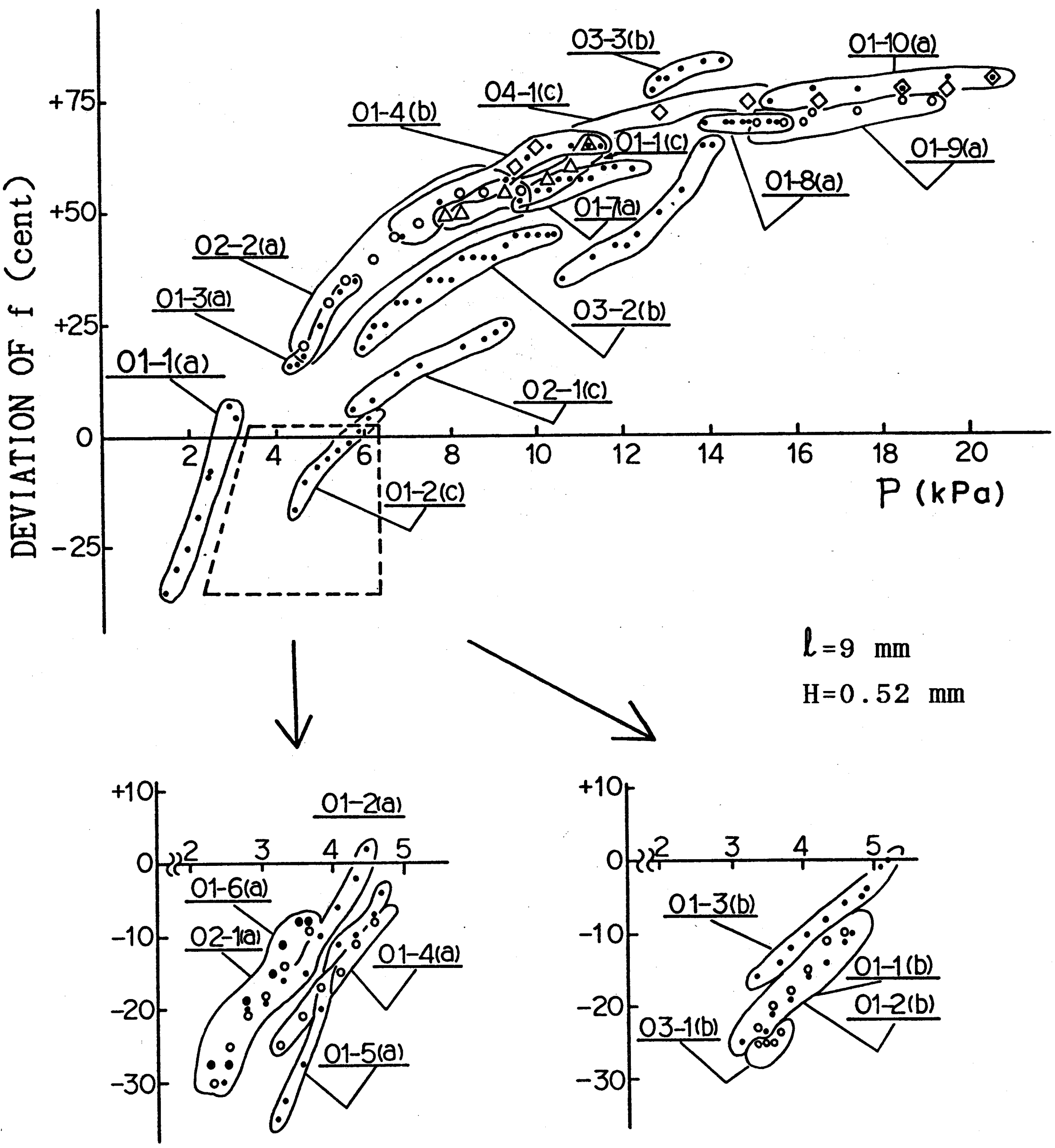


Fig.3 A distribution map of vibratory states of the oboe artificially blown. The ordinate is the fundamental frequency of the emitted tone given by the interval from the nearest note of the tempered scale. The abscissa indicates the blowing pressure.

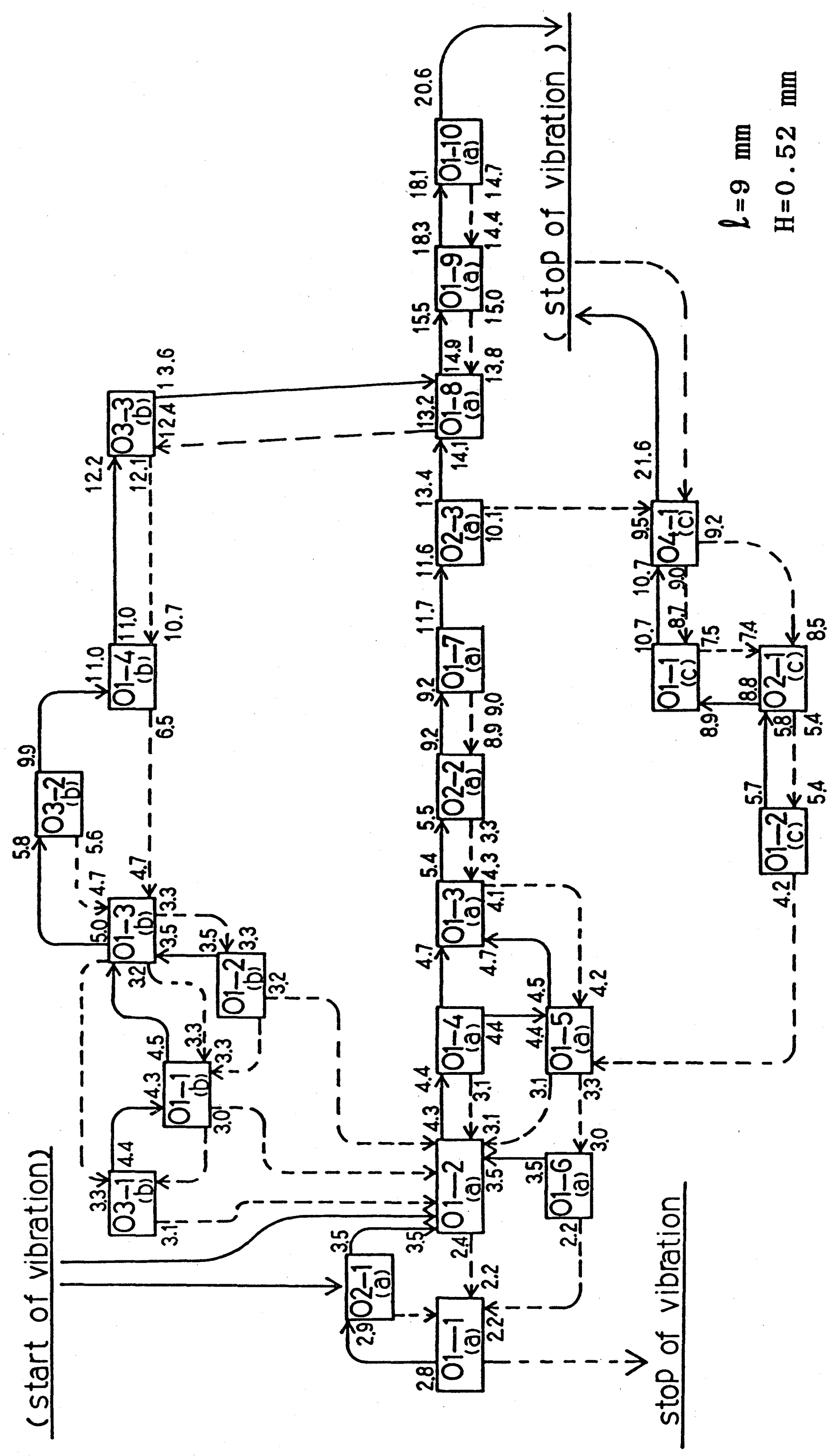
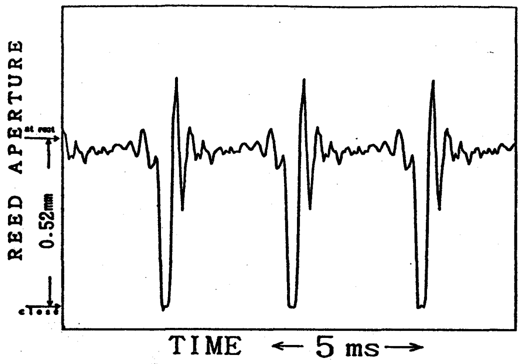
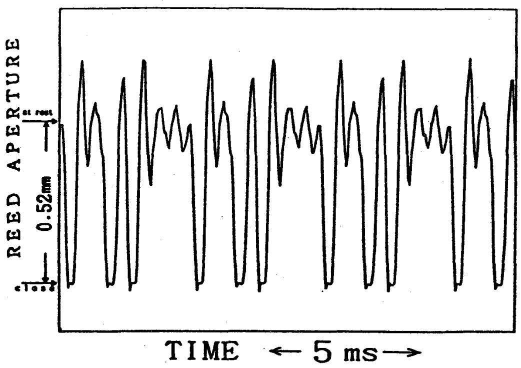


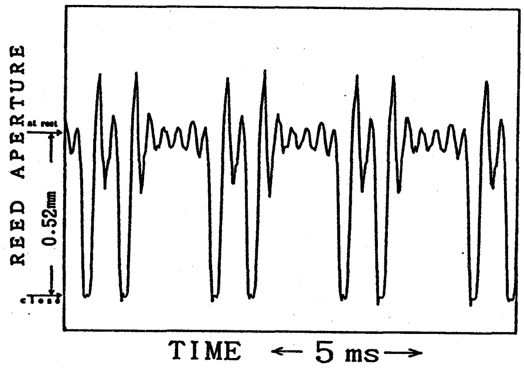
Fig.4 The transition diagram of the vibratory states shown in Fig.3.



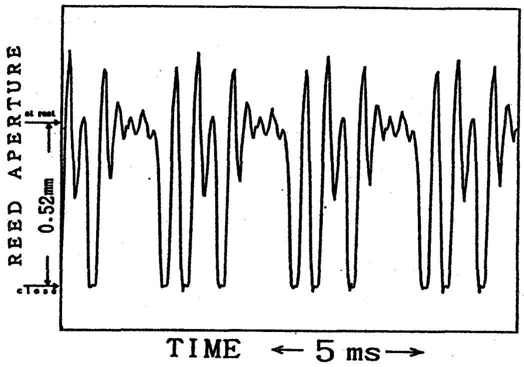
01-1(a) (P=1.96 kPa)



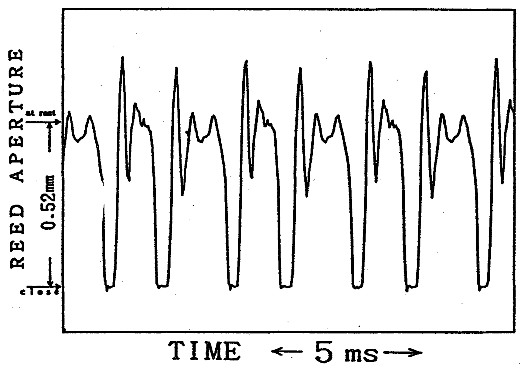
01-4(a) (P=4.21 kPa)



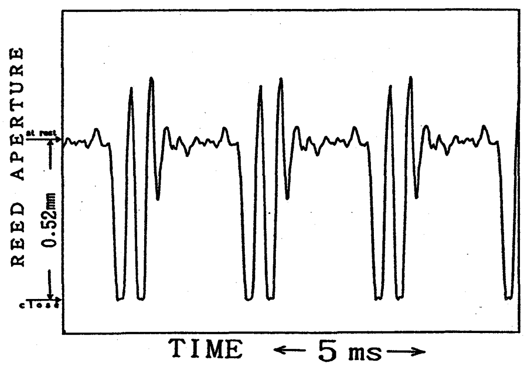
01-2(a) (P=2.94 kPa)



01-5(a) (P=3.72 kPa)

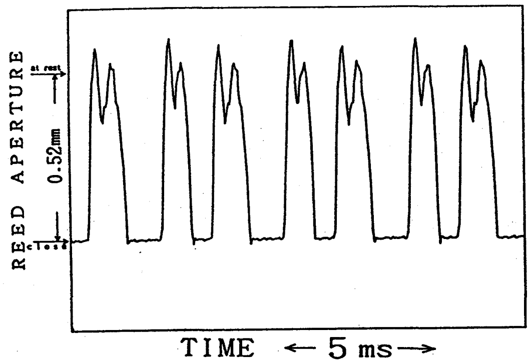


01-3(a) (P=4.70 kPa)

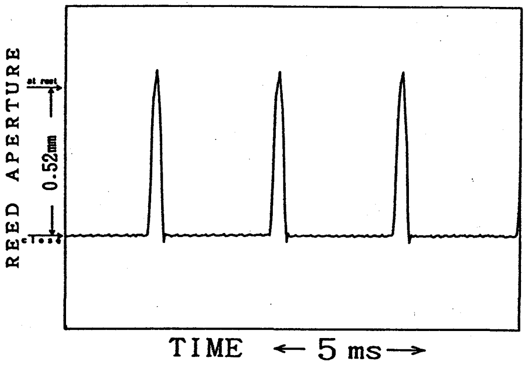


01-6(a) (P=2.74 kPa)

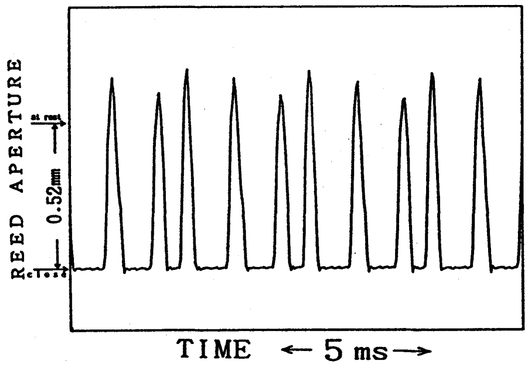
Fig.5 Reed vibrations of the vibratory states shown in Fig.3.



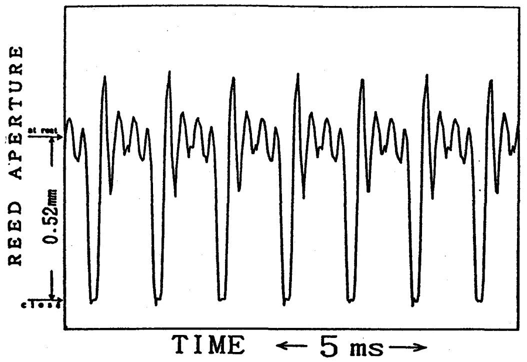
01-7(a) (P=9.80 kPa)



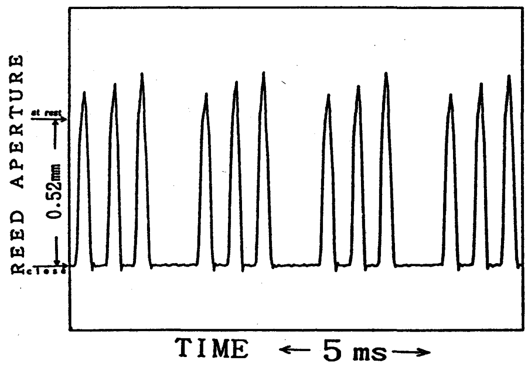
01-10(a) (P=18.13 kPa)



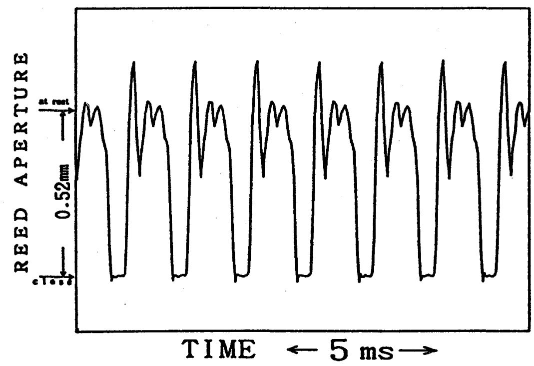
01-8(a) (P=13.18 kPa)



02-1(a) (P=2.74 kPa)

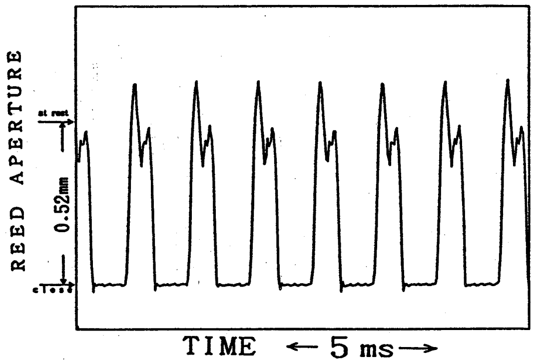


01-9(a) (P=15.68 kPa)

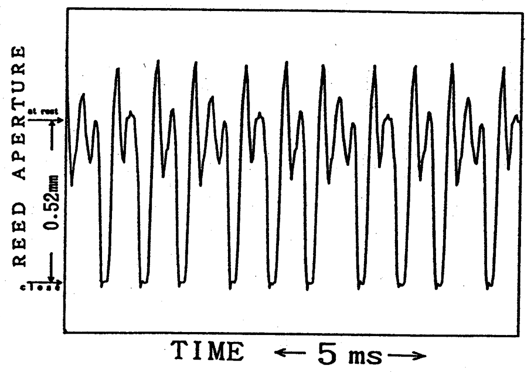


02-2(a) (P=6.37 kPa)

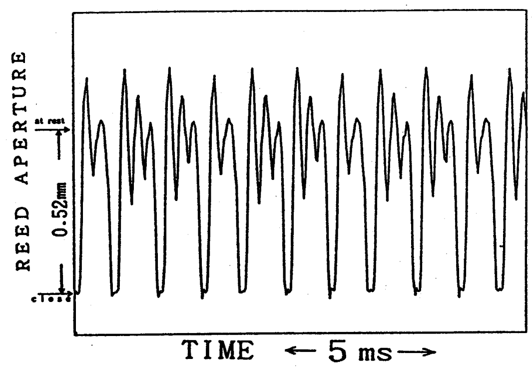
Fig.5 (Continued.)



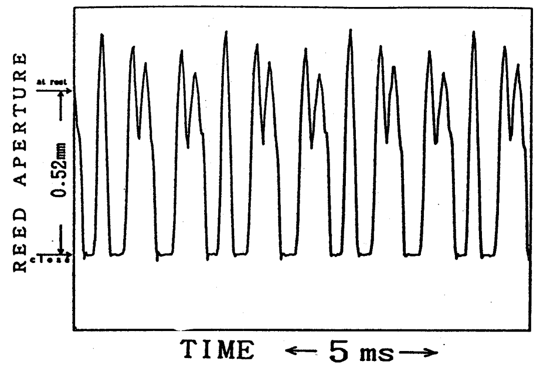
02-3(a) (P=11.47 kPa)



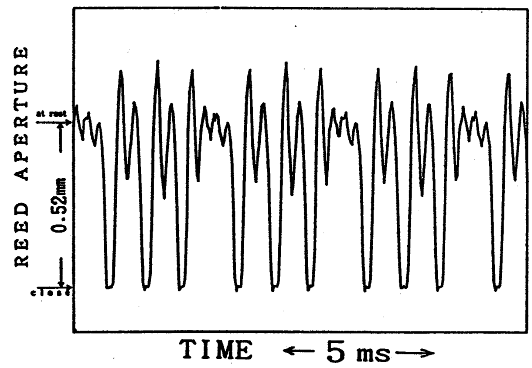
01-3(b) (P=4.41 kPa)



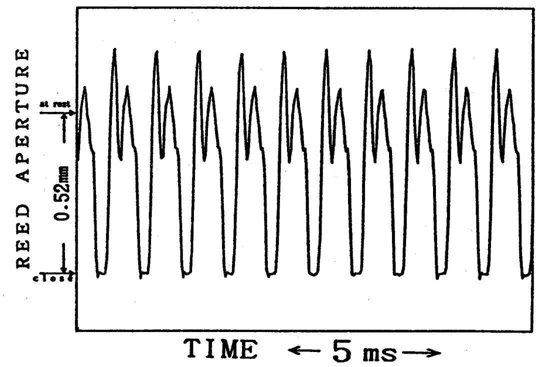
01-1(b) (P=3.63 kPa)



01-4(b) (P=8.33 kPa)

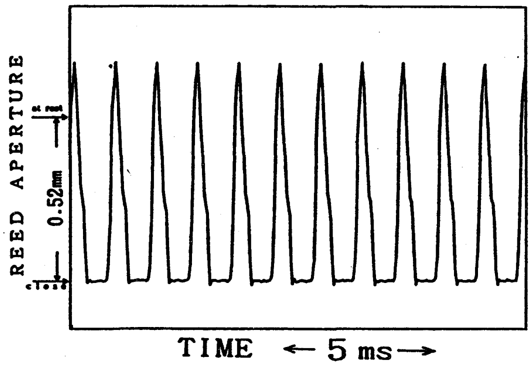


01-2(b) (P=3.38 kPa)

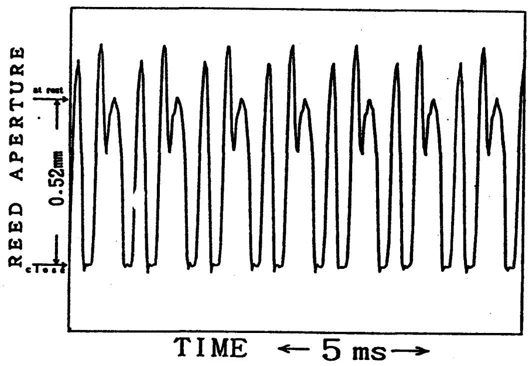


03-2(b) (P=5.88 kPa)

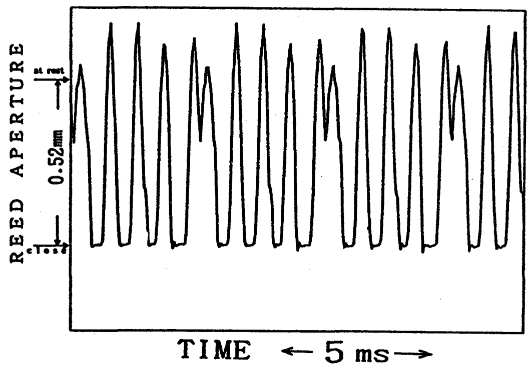
Fig.5 (Continued.)



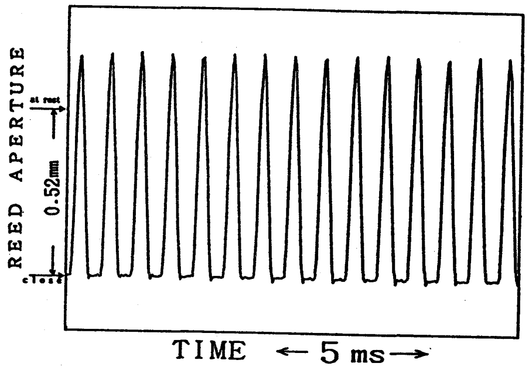
03-3(b) (P=12.45 kPa)



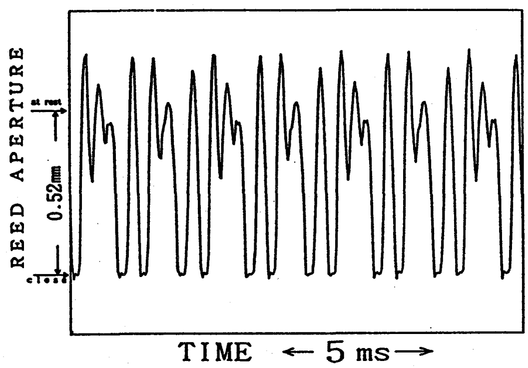
02-1(c) (P=6.86 kPa)



01-1(c) (P=8.33 kPa)



04-1(c) (P=10.78 kPa)



01-2(c) (P=4.90 kPa)

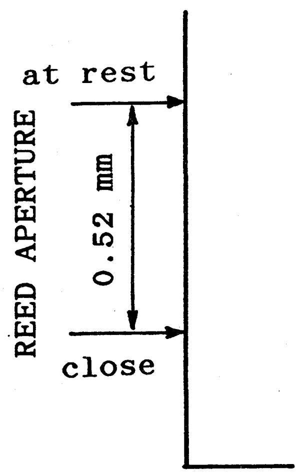


Fig.5 (Continued.)

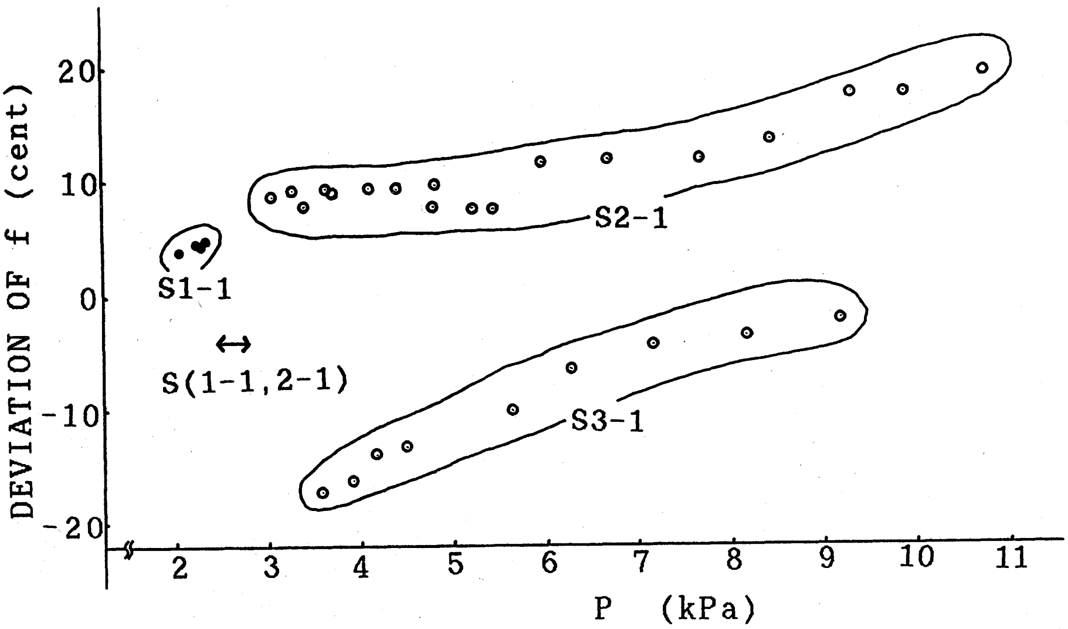


Fig.6 A distribution map of vibratory states of the soprano saxophone artificially blown. The ordinate is the fundamental frequency of the emitted tone given by the interval from the nearest note of the tempered scale. The abscissa indicates the blowing pressure.

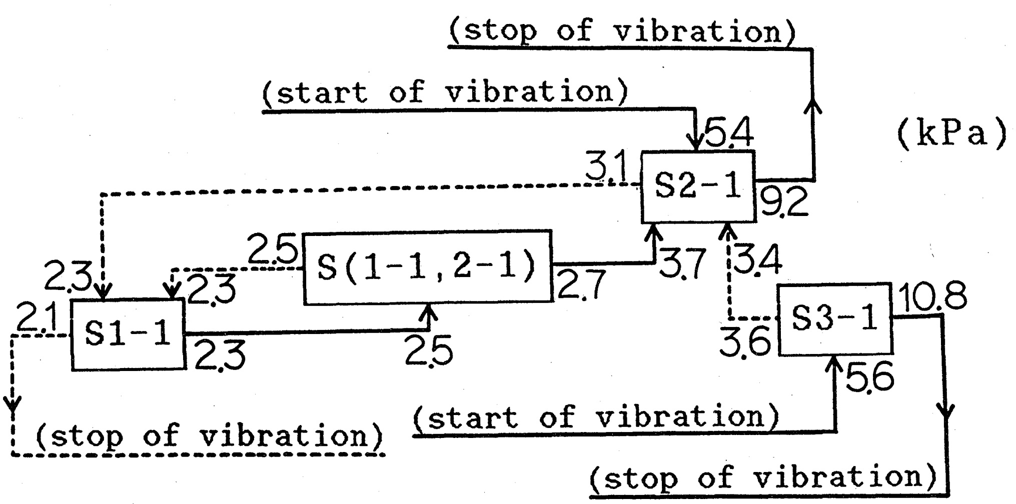
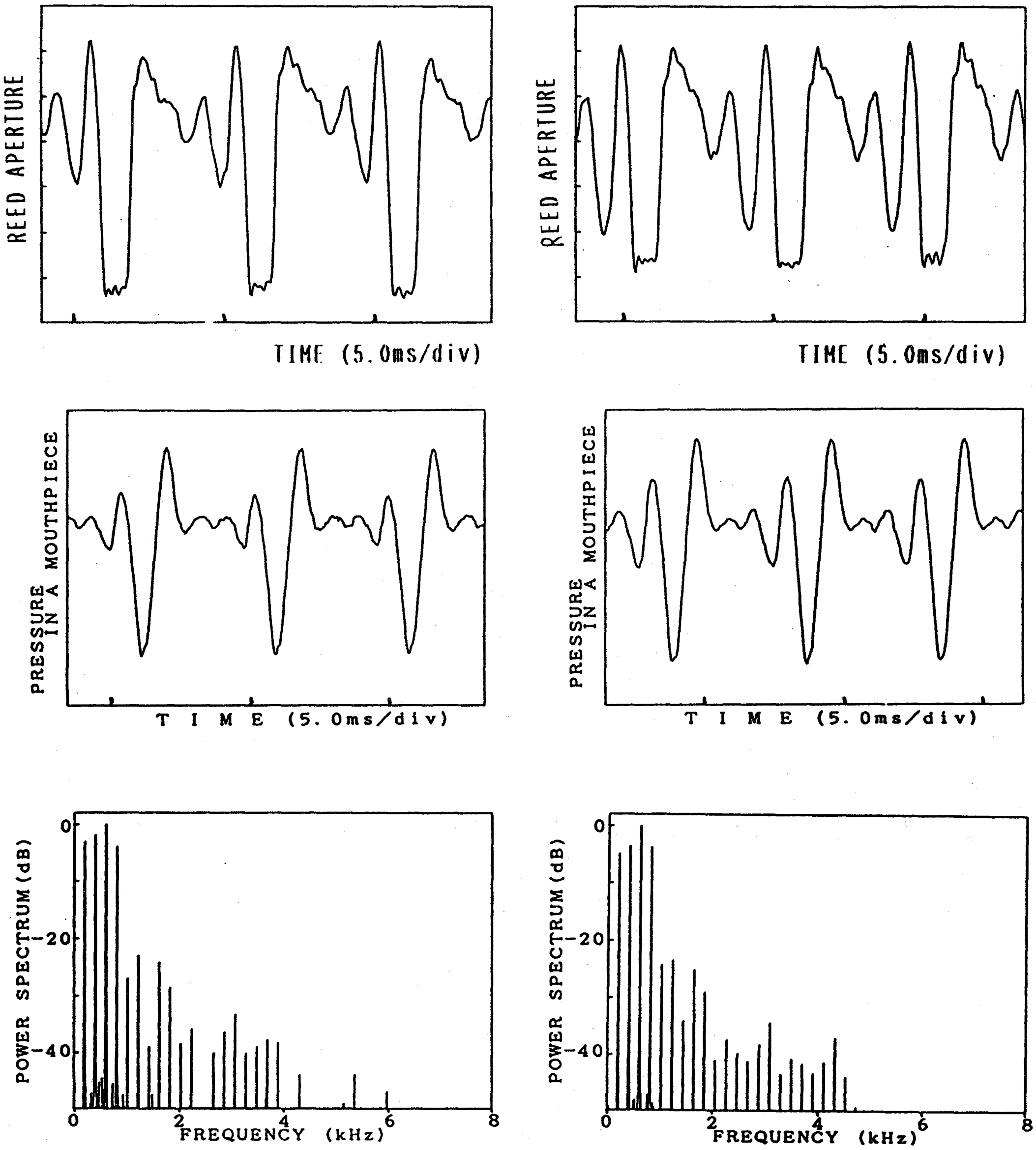
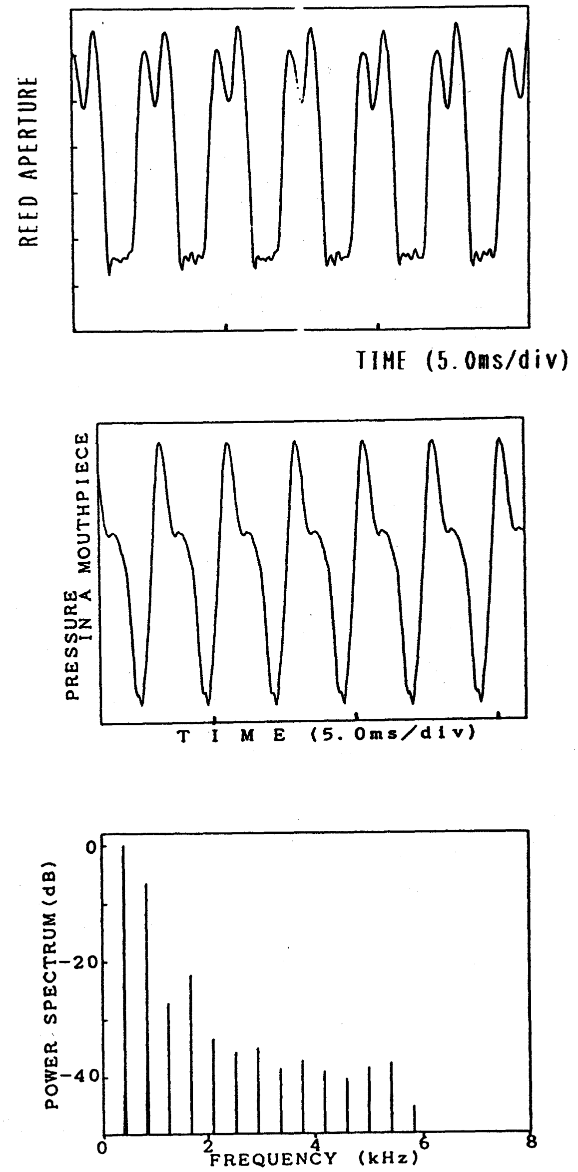


Fig.7 The transition diagram of the vibratory states shown in Fig.6.

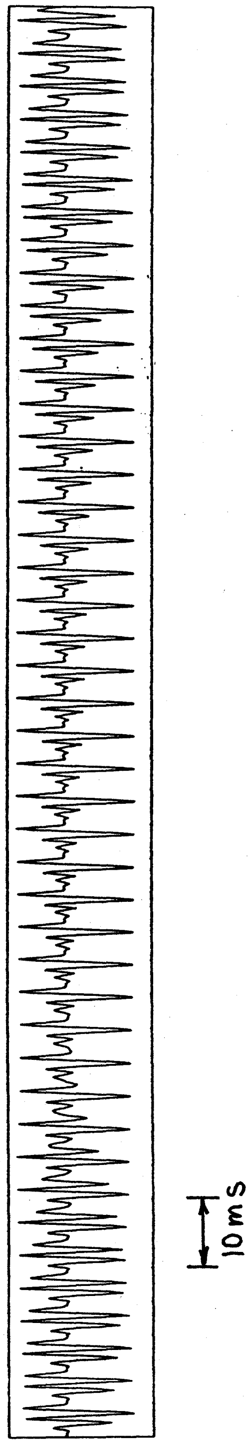


S1-1 (P=2.1 kPa) S1-1 (P=2.3 kPa)

Fig.8 y(t), p(t) and its power spectrum for the vibratory states shown in Fig.6.



S2-1 (P=3.4 kPa)



S(1-1,2-1) (P=2.6 kPa)

Fig.8 (continued.)

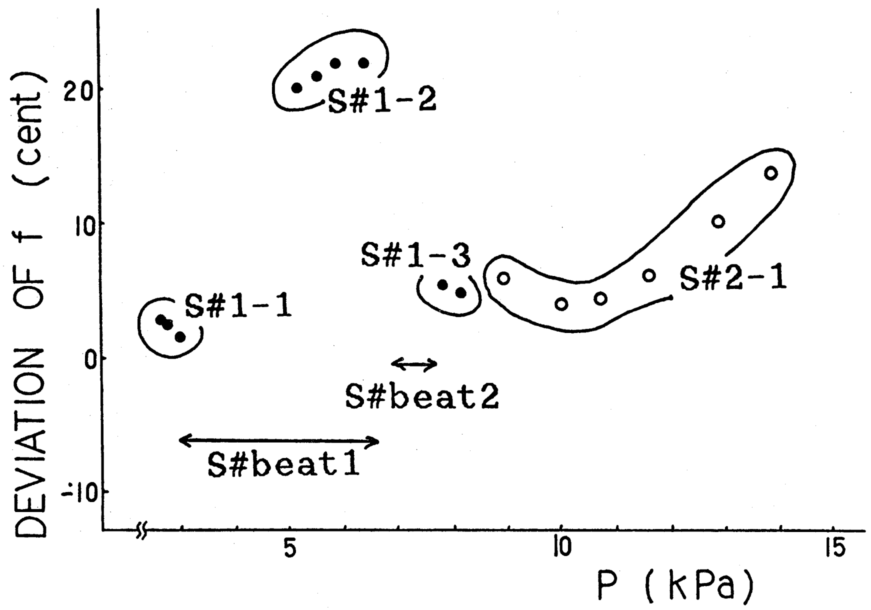


Fig.9 A distribution map of vibratory states obtained for the soprano saxophone without tone holes. The ordinate is the fundamental frequency of the emitted tone given by the interval from the nearest note of the tempered scale. The abscissa indicates the blowing pressure.

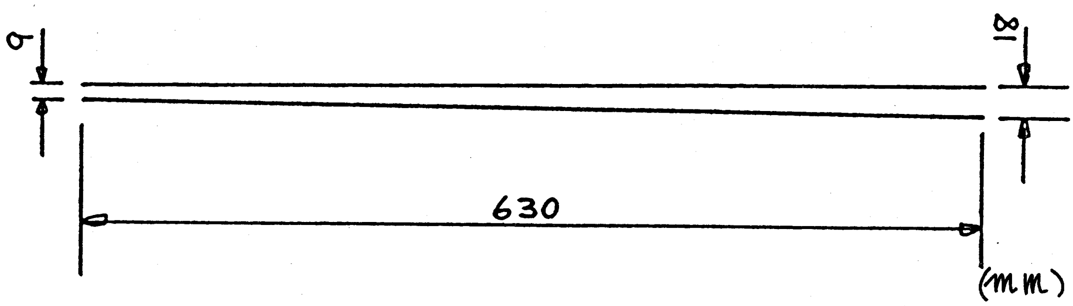
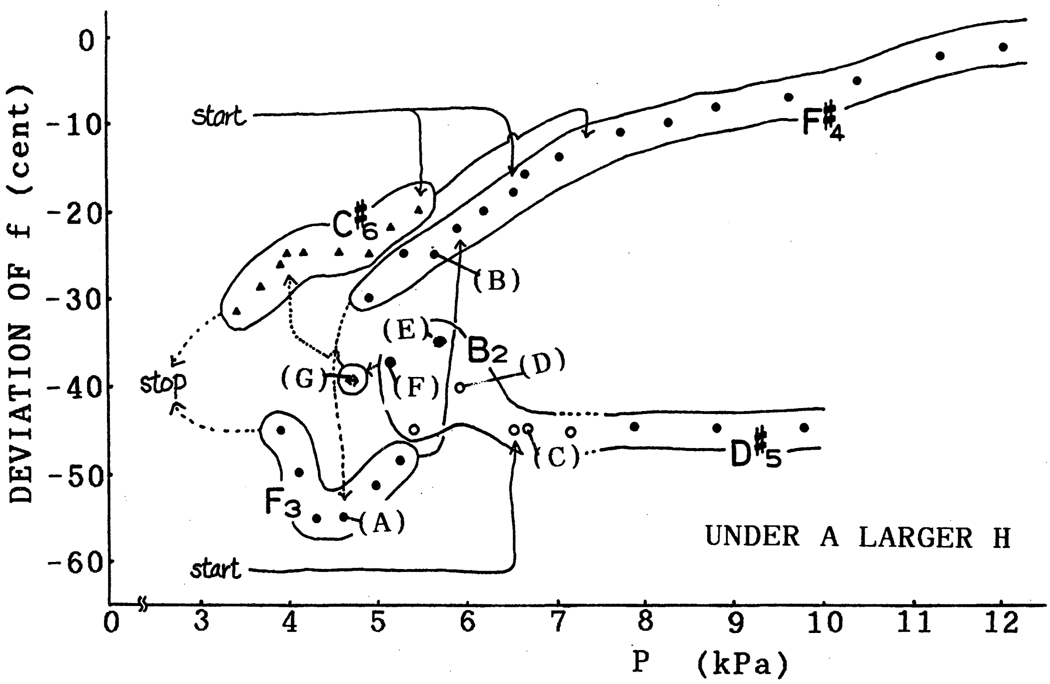


Fig.10 A conical bore. It is 630 mm long. Its apex angle is the same as that of the bassoon. It was artificially blown by using the mouthpiece of the soprano saxophone.



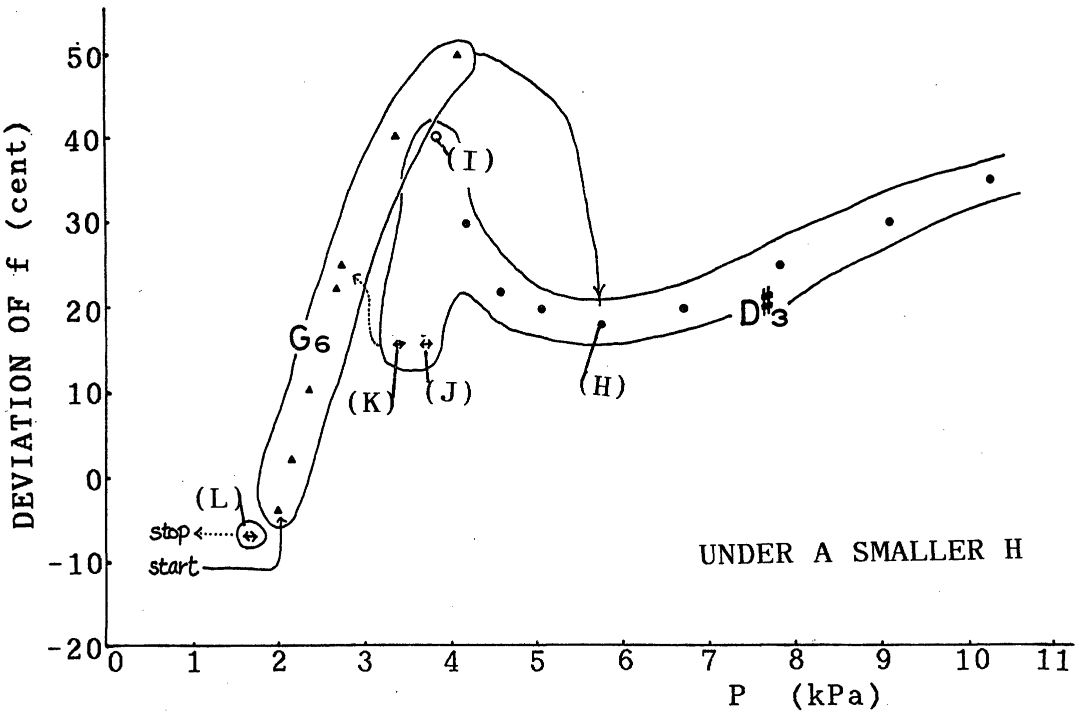
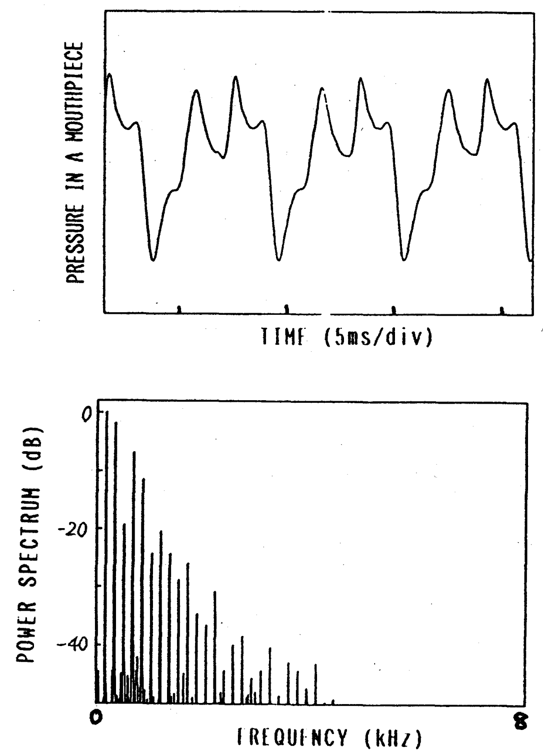
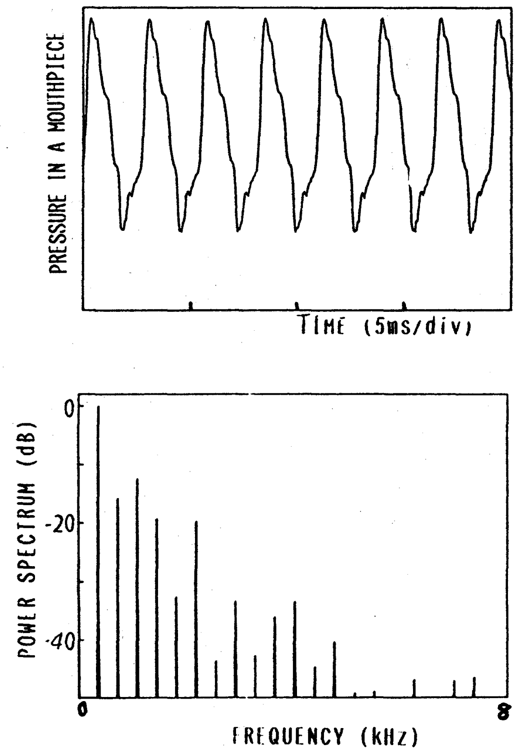


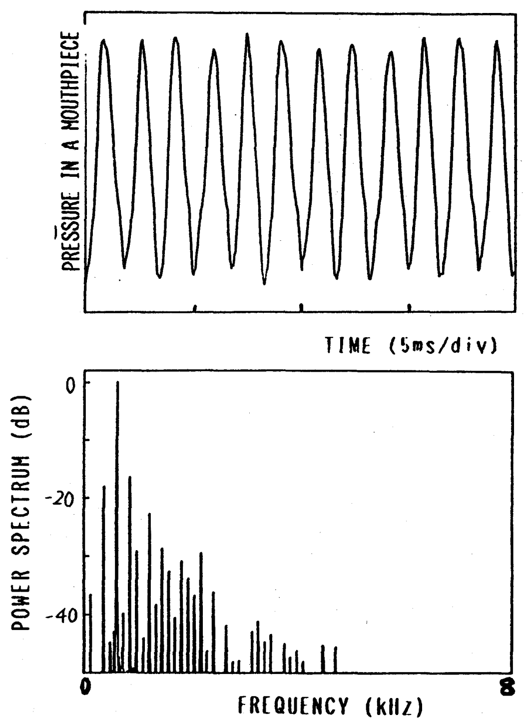
Fig.11 Two distribution maps of vibratory states obtained for the conical bore shown in Fig.10. The ordinate is the fundamental frequency of the emitted tone given by the interval from the nearest note of the tempered scale. The abscissa indicates the blowing pressure.



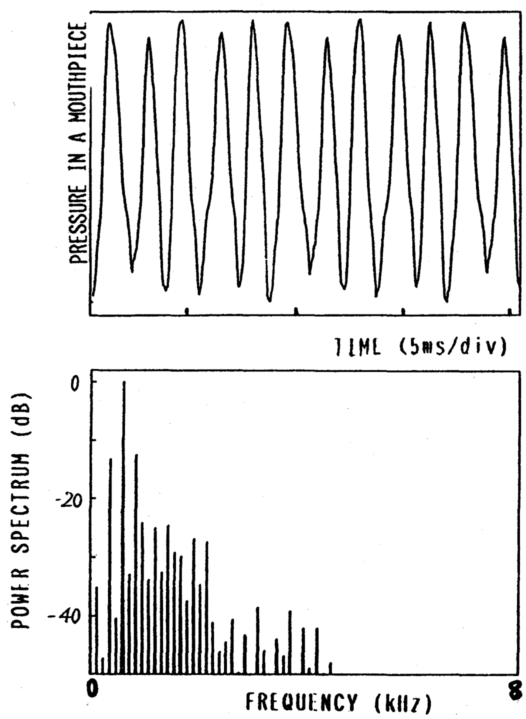
(A) P=4.6 kPa



(B) P=5.6 kPa

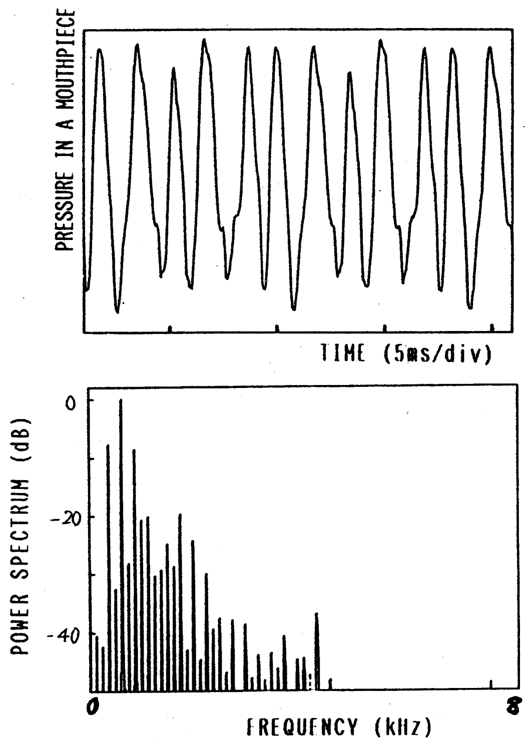


(C) P=6.7 kPa

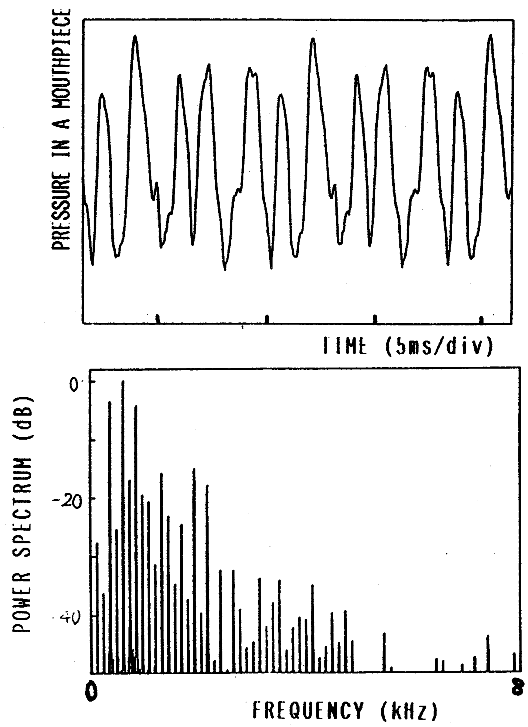


(D) P=5.9 kPa

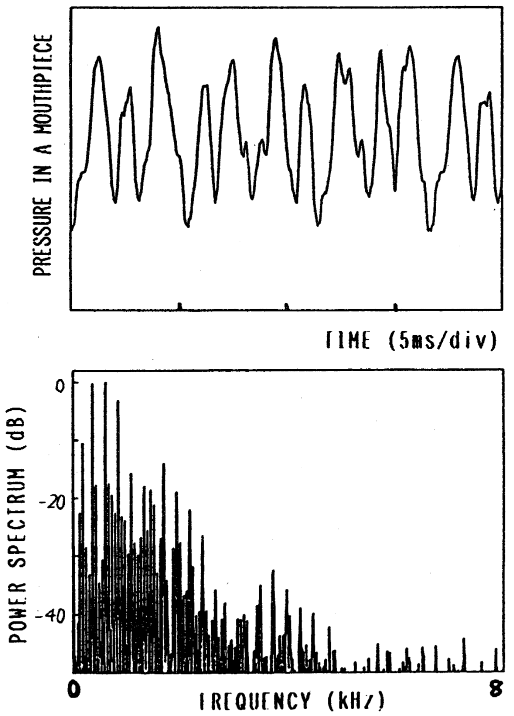
Fig.12 p(t) and its power spectrum for the vibratory states shown in Fig.11.



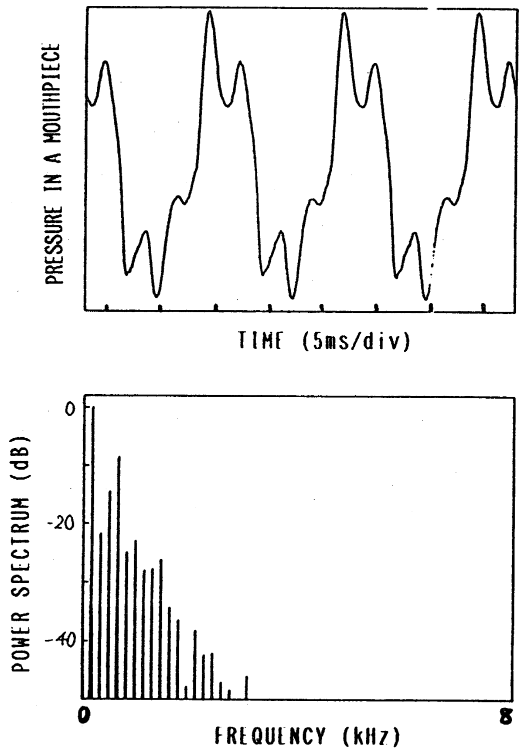
(E) P=5.7 kPa



(F) P=5.1 kPa



(G) P=4.7 kPa



(H) P=5.8 kPa

Fig.12 (Continued.)

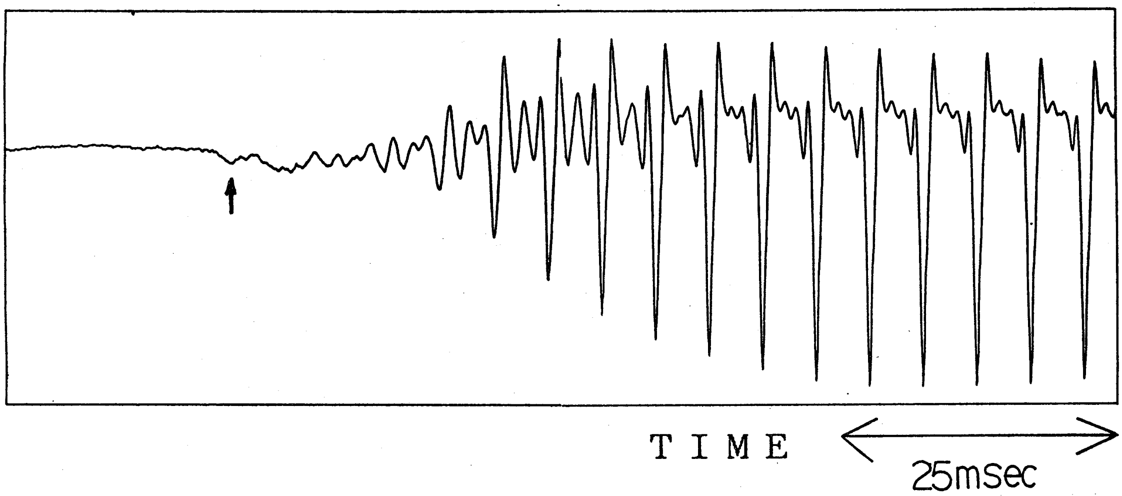


Fig.13 Reed vibrations of the soprano saxophone blown by a student player. The waveform is the output from a strain gauge pasted to the reed. A small arrow shows the tonguing. During the attack, reed vibration of higher frequencies are observed.