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THE RELATION BETWEEN BLOWING PRESSURE AND BLOWING FREQUENCY IN CLARINET PLAYING

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Different opinions on the relation between blowing pressure and blowing frequency in clarinet playing provide the background for the investigations presented in this paper. By employing mechanical blowing and a newly developed artificial embouchure, test results have been obtained which show that the correlation between blowing pressure and blowing frequency is positive for all notes in the low register of the clarinet (the chalumeau register) when all other parameters are kept constant.

I. INTRODUCTION

It is the clarinet player's unequivocal opinion that an increase in blowing pressure causes a fall in blowing frequency. From the literature on the clarinet by such authors as Benade, Worman, and Schumacher one receives the impression that variations in blowing pressure have but a slight effect on the blowing frequency. In the cases where changes do occur, these are ascribed to factors connected with the characteristics of the tube resonator, which are fixed once and for all when the tube - including the sound holes - is bored out (Benade 1976, p. 477, and Worman 1971, p. 101). These factors are then supposedly decisive for the positive or negative correlation between blowing pressure and blowing frequency.

This is contradicted by the test results obtained from experiments carried out in the Laboratory of the Institute of Phonetics at the University of Copenhagen. In fact, the results show that blowing pressure and blowing frequency are generally positively correlated. Actually, an indirect prediction of this may be deduced from the classic literature, viz. Weber's well-known lecture, reprinted in 1830.

That the conclusions of Benade (1976), Worman (1971), and Schumacher (1978) are at variance with the empirical findings presented here is probably due to their having underestimated the elasticity of the clarinet reed in their work with theoretical models of the clarinet. In their measurements of clarinet tube resonance the reed has been replaced by a compact, inelastic material.

Our experiments were arranged in such a way that the related values of blowing pressure and blowing frequency could be determined for a scale of notes in the clarinet's lowest register (the chalumeau register) as a function of time, partly by mechanical blowing, and partly with the assistance of classically trained professional clarinetists.

II. THE EXPERIMENTAL SETUP

A. EMBOUCHURE AND EQUIPMENT

An artificial embouchure has been developed in order to make possible measurements by mechanical blowing; it was mounted on a reversible wall (see figure 1). We have thus been able to collect reliable and reproduceable data and also to compare measurements for blowing and suction as well.

By removing the lead pellets and the attached bar from F (figure 1) wall, clarinet, and embouchure can - as a total system - be removed from the box, reversed and replaced. Suction is achieved when the hose (in figure 2 marked C) is at-

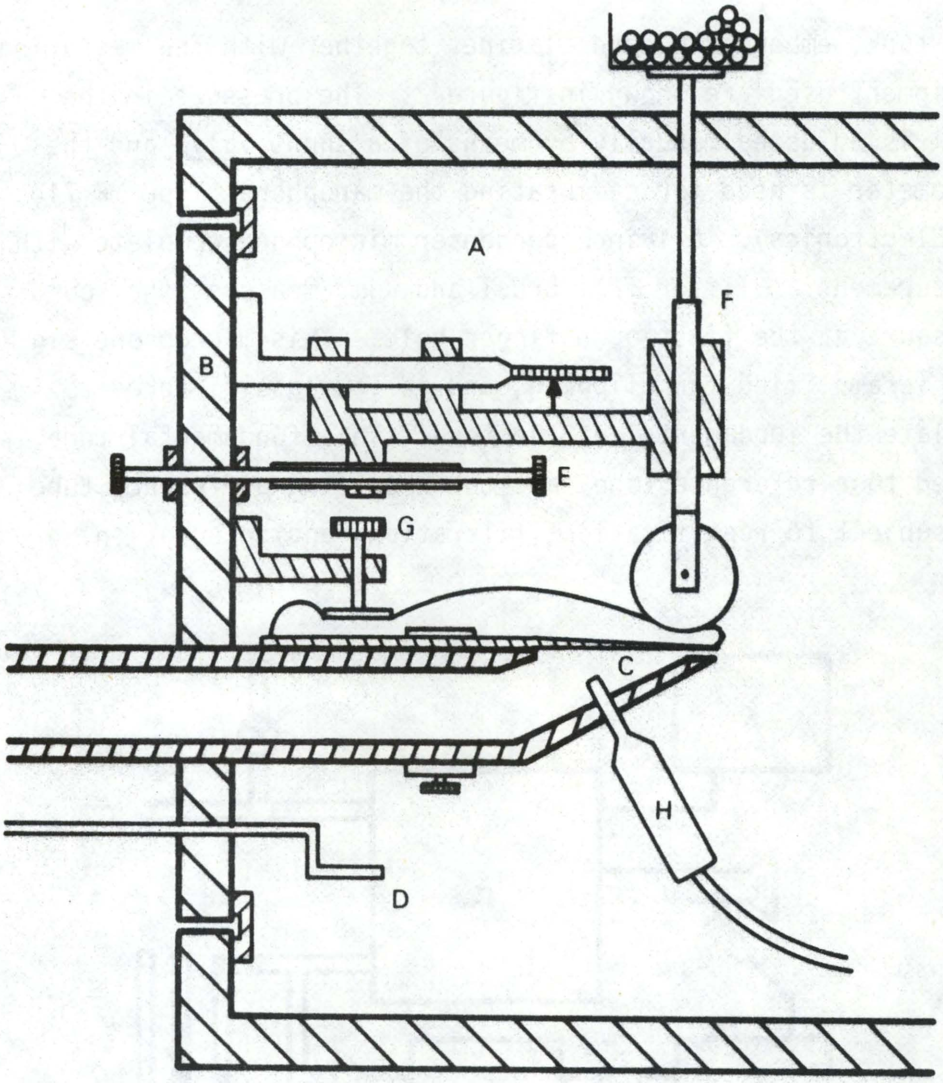

Figure 1

Schematic drawing of the artificial embouchure when mounted on the reversible wall of the air tank.
A) air-tight tank, B) reversible wall, C) mouth piece, D) remote control of speaker key used during suction, E) horizontally placed position device with adjustment screws and millimeter scale, F) lip pressure device; a container with lead pellets is placed on top of a rod which is supported by E, so that pressure is exerted on the nylon ball on top of the waterfilled balloon, G) lip damping device which regulates the water pressure in the balloon, H) quarter-inch Brüel and Kjær probe microphone.

tached to the suction unit of the vacuum cleaner.

Air tank, embouchure, and clarinet together with the measuring equipment used are shown in figure 2. The pressure in the tank is adjusted manually by means of a shunt valve and the manometer is used for calibrating the manophone (Type MF 710, FJ-Electronics). A 1-inch condenser microphone complete with measurement amplifier from Brüel and Kjær measures the sound pressure at the first open finger hole. This microphone signal is amplified for clipping, and is low-pass filtered to isolate the fundamental of the tone. This fundamental tone is added to a reference tone, and the resulting difference tone is subject to rectification, filtration, and integration.

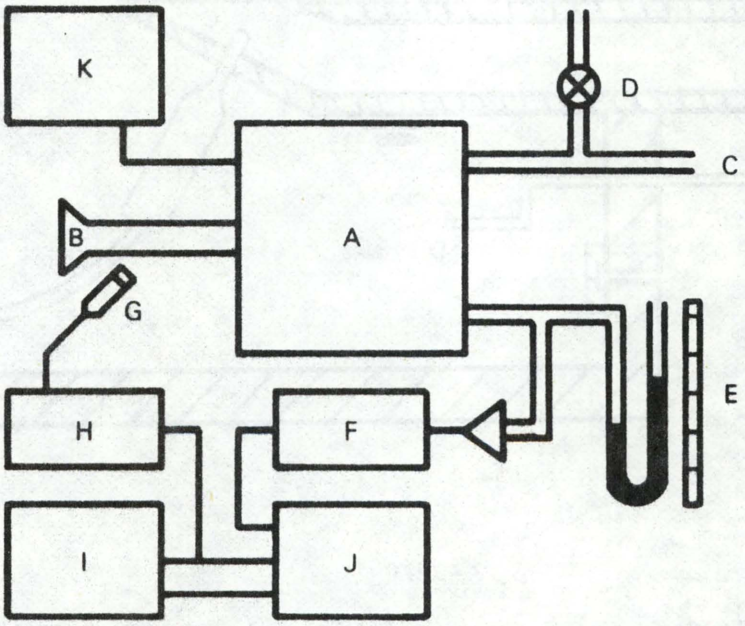

Figure 2

Schematic drawing of the experimental setup used by measuring sound pressure level (internal as well as external), blowing pressure, and blowing frequency.
A) air tank, B) clarinet, C) hose attached to an ordinary vacuum cleaner, D) shunt valve, E) Manometer, F) pressure transducer and amplifier, G) 1-inch condensator microphone, H) measuring amplifier, I) connected laboratory equipment for measuring blowing frequency, J) Mingograph (ink writer), K) spectrum analyzer.

In this way a DC-signal is obtained which - once necessary calibration has been carried out - is a measure of the deviation of the clarinet's tone from the equally tempered scale based on A_4 = 440 Hz.

The signal from the probe microphone (in figure 1 marked H) is analyzed by means of a spectrum analyzer, type 2033 from Brüel and Kjær. This apparatus makes it feasible to determine the position of the resonance peaks during blowing <u>without excitation</u> by means of the "running average" facility. In this way the internal noise signal of the mouth piece fills out the resonance peaks, and the resonance curve can be read as the resulting envelope curve.

Sound pressure from the external condenser microphone, as well as blowing pressure and blowing frequency were all registered as a function of time on a Siemens-Elema Mingograph. In experiments with "live" clarinetists, the blowing pressure was measured by inserting the manophone tube in the clarinetist's oral cavity at the corner of his mouth.

B. DEFINITION OF TERMS

A definition of key terms will facilitate the reading of the remaining pages:

P	blowing pressure; an independent variable.
P_{thr}	the threshold blowing pressure, i.e. the level where excitation begins.
P_{close}	the upper threshold blowing pressure, i.e. the level where excitation ceases.
f_{blow}	blowing frequency of the tone in question, a dependent variable.

Frequency deviations of the tempered scale's different tones are marked in cent, 100 cent equating one tempered semi-tone. The concert pitch is set to 440 Hz.

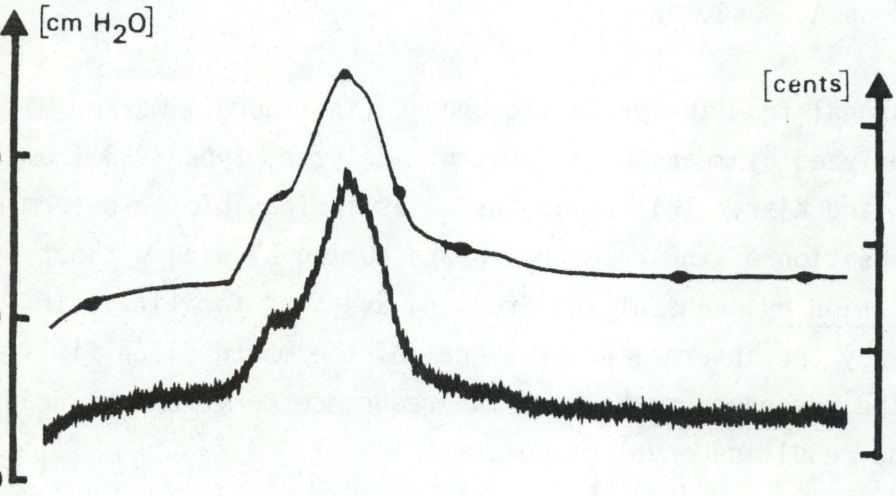

Figure 3

Mechanical blowing with artificial embouchure and constant lip pressure. The curves depict from top to bottom: blowing pressure and blowing frequency as functions of time.

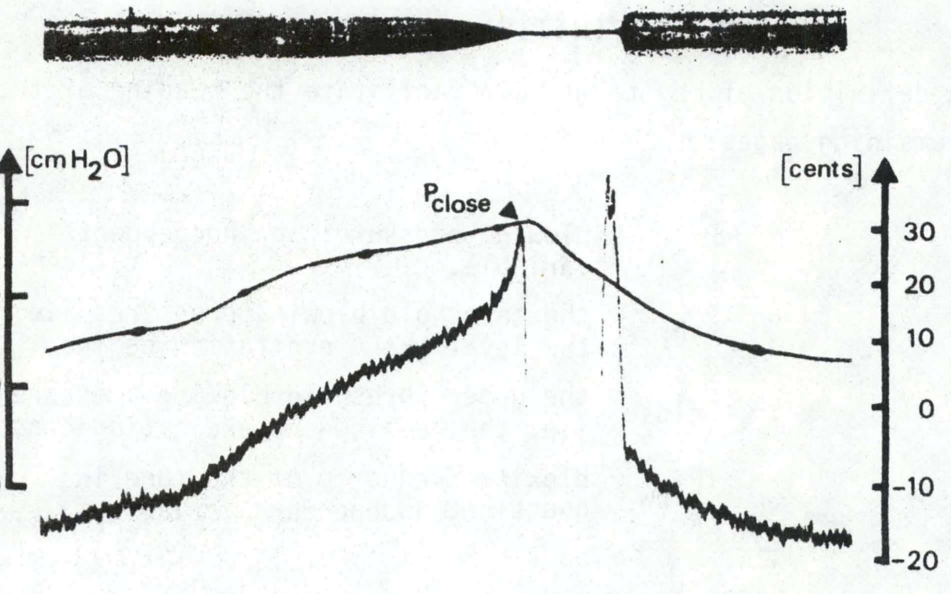

Figure 4

Mechanical blowing with artificial embouchure and constant lip pressure. The curves depict from top to bottom: sound pressure, blowing pressure, and blowing frequency as functions of time.

III. RESULTS

The characteristic correlation between P and f_{blow} appears from figures 3 and 4. Further, figure 4 provides an example of the cessation of excitation when $P = P_{close}$ and shows that oscillations are reestablished when the blowing pressure is reduced to a value somewhat below P_{close}. An equivalent hysteresis effect occurs at P_{thr}. This is a technical advantage as it makes it possible to measure f_{blow} and the first resonance frequency in turn at identical blowing pressures.

Natural clarinet playing is represented by the curves in figure 5, in which a professional performer of the classical clarinet carries out a register transition from F_3 to C_5, the only requirement being that this change be made without interruption

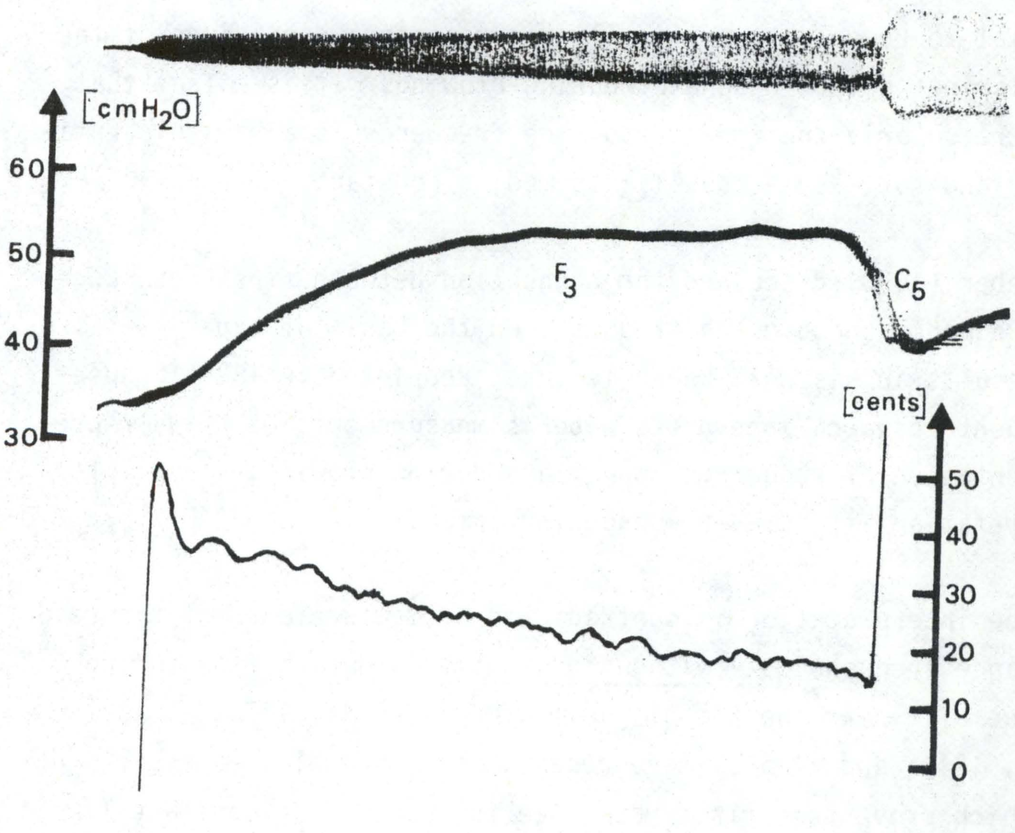

Figure 5

Professional performer of the classical clarinet. The curves depict from top to bottom: sound pressure, blowing pressure, and blowing frequency as functions of time.

of the tone production. It is interesting to note that the musician intonated a soft and relatively high tone during the initial intonation. From listening we can ascertain that the tone in question was a typical classical clarinet tone, which is characterized by a dominance of odd harmonics. During the maintenance of the tone F_3, P and f_{blow} are negatively correlated. Why do we find a negative correlation in this case, when mechanical blowing (figures 3 and 4) always shows a positive correlation? The explanation is simple: The musician may alter more than one of the embouchure parameters, whereas during the mechanical blowing only P was changed.

IV. DISCUSSION

A. THE REED CONDITIONING THE TUBE RESONANCE

In order to explain the experimental results it proves essential to reevaluate critically the resonance conditions of the clarinet's tube resonator during blowing. It is a fact that particularly the first resonance frequency is a variable entity and not, as is usually assumed, a constant.

Weber (1830) discussed the connection between first resonance frequency and blowing frequency on the basis of experimental results in his well-known lecture, reprinted in 1830. Subsequent research interprets Weber's measurements as being representative of resonance conditions during blowing. This interpretation is, however, unsubstantiated.

The interpretation is contradicted by measurements of the resonance frequencies - without excitation - during flow through the slit near the tip of the mouth-piece (Bak 1978, p. 132 and p. 134), and also by more recent, still unpublished experiments which prove that first resonance frequency - at constant lip pressure - drops drastically as pressure rises between 0 and P_{thr}. Around the threshold P_{thr}, first resonance frequency converges with the f_{blow} measured just when excitation begins.

In other words: within this pressure range the clarinet changes acoustically from a quasi-halfwave resonator to a quarter-wave resonator, and first resonance frequency is here negatively correlated to blowing pressure. This detail is vital for the understanding of the properties of the resonance tube.

In the pressure range P_{thr} to P_{close} measurements show that first resonance frequency and thus f_{blow} is positively correlated to P, and there is actually a natural explanation for this. What has till now been left out of consideration is the fact that an increasing blowing pressure forces a larger and larger part of the reed towards the curved part of the lay by the extreme tip of the mouth piece. Thus the flexibility of the reed decreases more and more just in the place where the internal sound pressure is at its highest. This has the effect of reducing the tube resonator's acoustic length, and the resonance frequencies - especially the first resonance frequency - rise. By constant blowing pressure an increase in lip pressure will, of course, have the same effect.

It is thus clear that at least two independent parameters can alter f_{blow} during the clarinetist's natural blowing. Changes in blowing pressure and lip pressure do, however, influence the dynamics and timbre of the tone in completely different ways:

1) At constant blowing pressure an increased lip pressure causes a reduction of the slit height whereby the volume flow decreases, with the result that sound pressure drops.
2) At constant lip pressure, a rise in blowing pressure produces a change of tone timbre and volume (Schumacher 1978, figs. 2 and 9), but whether this leads to a smaller or larger content of higher harmonics and whether the sound pressure rises or falls, depends entirely on the strength of the blowing pressure in relation to P_{thr} and P_{close}.

The experienced clarinet player is capable of adapting the variable parameters in such a way as to balance tone timbre and dynamics, and thus to maintain the required pitch. This is evident from figure 5, and we are now able to give a qualitative description of the missing parameter: the lip pressure.

Because the musician choses to blow softly in the beginning, lip pressure must be high if too low an intonation is to be avoided. Moreover, we know from experience that the chosen embouchure (high lip pressure and a relatively high P) will result in the typical classical clarinet tone in which the uneven harmonics - and in particular the first harmonic - are dominant. The coming change of register is determined by the first harmonic being decreased relatively to the third harmonic. To change the spectral composition of the tone, the performer has to decrease his lip pressure while at the same time increasing his blowing pressure. The change of register is now prepared and all that remains is to activate the speaker key.

B. THE CLARINETIST'S JUDGEMENT

Are clarinetists right then in maintaining that a fall in frequency - as shown in the bottom curve in figure 5 - occurs as a consequence of increased blowing pressure? The answer is no! All our conclusions so far point to the opposite. The lowering of the frequency is a result of the decreasing lip pressure. The fact is that not only a larger P but also an increase in the amount of air exhaled demands more of the performer's expiratory muscles. But whether the energy is used to increase pressure or to increase air flow he cannot possibly judge. His experience is the same. As shown by the empirical findings presented above, the blowing frequency for a given note is - contrary to common belief - positively correlated with blowing pressure. One might then ask what happens with the blowing pressure when an ascending scale of notes are played. Although this is slightly outside the scope of the present report, figure 6 is included to illustrate that on this point, too, musicians often misjudge what happens physiologically when playing the clarinet. It is a widespread assumption among clarinetists that the higher the note, the higher the blowing pressure. Figure 6 clearly shows that this is not the case.

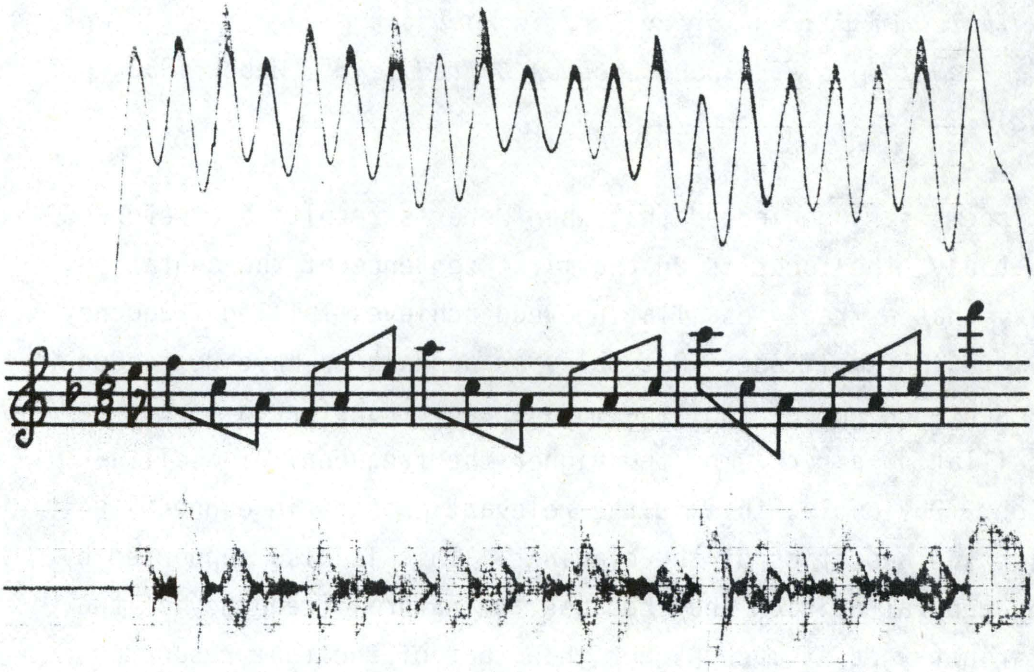

Figure 6

Fragment of Telemann's Triad in F-major played by a classically trained clarinetist. The top curve is the blowing pressure as a function of time, and the bottom curve is the sound pressure level as a function of time.

C. WEBER'S FINDINGS

Have no earlier researchers demonstrated the intimate relationship between P and f_{blow}? Apparently it has gone unnoticed that Weber is actually calling attention to this relation in his lecture: *"Ueberhaupt ist es eine Eigenthümlichkeit aller transversalschwingenden Körper, dass ihr Ton etwas tiefer bei stärkerer Schwingung, etwas höher bei schwächerer Schwingung ist. Die umgekehrte Eigenthümlichkeit haben aber alle longitudinalschwingenden Körper, und im höchsten Grade findet sie sich bei longitudinalschwingenden Luftsäulen;"* (Weber 1830, p. 402)

It seems strange indeed that when Weber's results are referred to today, the focus is on the first sentence of the quotation, viz. that a freely oscillating reed achieves falling frequency by growing amplitude. But oblivion appears to have descended on sentence number two: the more energy transferred to an oscillating air column, the higher the frequency of oscillation. Obviously, this is the relevant passage in connection with the acoustics of the clarinet. This is also supported by the general opinion that because the natural frequency of the clarinet reed is much higher than that of the tube resonator, and because much more oscillatory energy is accumulated in the air column than in the reed, it is the air column which is the driving oscillator and the reed which is the driven oscillator.

But Weber's experiments, which primarily served to clarify the blowing conditions of a freely swinging metal reed in combination with an organ pipe, cannot give an exhaustive explanation for every sequence of events during the blowing of the clarinet. For instance, the course of the frequency curve around P_{close} (figure 4) cannot be accounted for on the basis of Weber's findings.

V. FINAL COMMENTS

A modern symphony orchestra demands of a wind instrument the ability to vary a note greatly, both as concerns loudness and spectral composition, without the blowing frequency being affected.

That the clarinet is capable of meeting these demands is particularly due to the conditions investigated in this report: During playing, at least two parameters are positively correlated to f_{blow}, viz. blowing pressure and lip pressure. This provides the musician with almost inexhaustible possibilities for variation of tone and volume without getting off-key.

Similar options are not available when playing the traditional wood wind instruments from which the clarinet was originally developed. On these, only P may affect f_{blow}. They were, however, both useful and highly valued in older times when the esthetics of musical tradition differed from that of today. Furthermore, ensembles that cultivate music other than the symphonic may still employ these instruments where only one parameter determines the blowing frequency. Within this group of instruments the recorder in particular has been recognized as an excellent solo instrument under the right conditions.

However, a modern wind instrument must have at least two variable parameters which are positively correlated to the blowing frequency. The best way to realize this is perhaps to imagine a clarinet-like instrument whose blowing pressure is negatively correlated to f_{blow}, while its lip pressure is positively correlated to f_{blow} (Schumacher 1981, p. 81). It should be self-evident that such an instrument would not survive for very long, as its playing qualities would be very poor.

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