# A PEDAGOGICAL UTILISATION OF THE ACCORDION TO STUDY THE VIBRATION BEHAVIOUR OF FREE REEDS

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**ABSTRACT**

This paper is concerned primarily with an educational approach to the accordion sound generation mechanisms. Accordions are made to sound by buzzing a thin steel tongue, which is attached to one side of a metal plate containing an aperture through which the reed tongue can actually pass. The accordion utilises the free reed principle, is hand-held and is powered by bellows. The aim of this work is to present the pedagogical steps that focus on the knowledge of free reed behaviour and the pressure forces that excite the reed vibration.

## INTRODUCTION

The term Accordion is the proper generic term for all members of a complex family of free-reed aerophones. The accordion consists of a series of air-actuated free reeds tuned to notes of a musical scale and controlled by means of a keyboard. The family is divided into two preliminary halves: "Diatonic" accordions, that play different pitches when bellows are expanded or compressed and "Chromatic" accordions, that sound the same pitch in both bellows directions. The history of development of accordion family instruments shows consistent evolution from simple to complex physical construction. They vary in their machining, materials, number pitches, reed-blanks, air consumption, dynamic range, and handling and control capabilities. Nowadays, most manufacturers offer various quality grades and price ranges within their lines. In fact, Accordions are highly complex in quality assessment, based on scientific measurements of air-pressure, response characteristics, and spectral-analysis of harmonics.

This work shows how to organise, from a pedagogical point of view, the body of physical knowledge related to the free-reed behaviour and musical qualities. It is easier to enjoy and appreciate music if one understands how music is created. By learning how the accordion plays, students learn how to implement their playing technique.

## THE REEDS

The active elements of the accordion are metal reed-tongues stimulated by airflow induced by folded bellows. The reed produces the Accordions sound. The basic parts of the reed are a plate, the tongue and the rivet. One of the ends of the tongue is riveted to the plate, while the other one is free to vibrate in and out of the slot, when air pressure is supplied from the bellows. The process of making a reed could seem simple but it requires a lot of both, work and experience. In fact, different quality reeds are manufactured, depending on the amount of artisan work.

Let us examine the production steps in the manufacture of a reed. To start with, we shall consider the materials. The plates are made of aluminium and the tongues are made of steel. This choice is not casual. On the one hand, the plate mission is to support the tongue, so it would be a high number inside each accordion. As aluminium has a low-density mass (2.7 $kg/m^3$), the accordion weight is lesser using aluminium than using other metals. Generally speaking, the lighter the overall weights, the better quality of the accordion and the internal parts that have been used.

On the other hand, the reed element that moves and produces sound is the steel tongue. Steel has special features referring to hardness and ductility. These properties are related to elastic properties of the material. There have been defined some modulus to characterise elastic properties of a material. An important materials property is called the tensile elastic modulus, or Young's Modulus. To compress a rod of cross-sectional are S and length $\ell$ by an amount $d\ell$ requires a force $YS(d\ell/\ell)$, where Y is a constant called Young's modulus. For example, low alloy steels have modulus between 200 - 207 GPa, stainless steels between 190 - 200 GPa and aluminium 69 GPa. This value has an important influence on the vibration of the tongue. Materials with a high value of E are good. In accordance with this, steel is preferred rather than aluminium in the reed tongues. Besides, in order to ameliorate its Young's modulus, the steel can be heat tempered.

Once the materials have been chosen, manufacturers have to select the shape of the tongue. The material of the tongue, its length and its thickness govern its vibration speed and so the emitted pitch. As the tongue length increases the pitch decreases. But, when the tongue thickness increases the pitch also increases. To obtain the best pitch, the more appropriate profile for the reed can also be chosen. Therefore, there are many types and sizes of reeds in an accordion. Tongue is cut and ground using a special technique that avoids the steel overheating.

Simultaneously, reed plates are cut from an aluminium sheet and completed with holes for the tongues and rivets. In the next step reeds are assembled. The reed tongue is fixed to the plate with a rivet, using hammer and anvil. The reed tongue must be well centred in the plate hole to assure a good response and sound.

After the assembling, the reed is tuned using a bellow that supplies air to the reed. The sound of the reed is compared to that of a reference reed. If the sound is not satisfactory it is necessary to remove material from the reed tongue: from the tip to raise the tone and from the body to lower it. Sometimes a second tuning can be done on ordered reed sets in order to create the different typical sounds effects in the accordion (tremolo, mussette, etc.)

The reed influence in accordion sound quality is vital. Manufacturers classify the reeds in four groups as quality increases: commercials, hand-finished, hand-type and hand-made. Commercial reeds are the cheapest. They are manufactured almost entirely by machine and with worse quality of materials. Hand-finished reeds have more of handwork and a better quality. Hand-type reeds are the next quality step: they are made of superior steel and with good handwork. Hand-made reeds are the best and are used in highest quality accordions. The steel of the reed tongue is blue because it is heat tempered in strips. Tongues are hand-fitted and riveted on precision duraluminium (a light alloy of Al, Cu, Mg and Mn) plates, and individually tuned for brilliant sound. The usual accordion with four sets of treble reeds and five sets of bass reeds has no less that 448 single reed tongues of this type.

Afterwards, the hole of the reed is covered with a leather or plastic valve. Its mission is to moderate the airflow and to avoid the air passage through the hole of the reed tongue that it is not activated. The reed plates are mounted on reed blocks, which are usually made of poplar wood. A set of reeds is placed into the tone chamber (Cassotto) that gives to the instrument a rich and full sound. When the reeds are placed in the reed block and fitted into the accordion, the instrument will be fully assembled and both sides (treble and bass) will be tuned to each other to complete the process.

## THE BELLOWS

The bellows enables the accordion to offer an amazing range of expression. The air for actuating the reeds is supplied by a bellows worked by the player's arms. The air supply is either a pressure or a vacuum, depending upon whether the bellows is being compressed or expanded.

The bellows are constructed of special cardboard. All outer sides have folds bonded with special hot glue and finished with precisely pinched chrome corners.

## RELATIONSHIP OF PHYSICAL PARAMETERS TO MUSICAL QUALITIES

Four subjective qualities are frequently used to describe musical sound. They are loudness, pitch, timbre and duration. Each of these attributes depends on one or more physical and parameters that can be measured. Loudness depends mainly on sound pressure or intensity but also on the spectrum of the partials and on the physical duration. Spectrum refers to the frequencies and amplitudes of all the components in the sound. For a pure one, the pitch is determined mainly by the frequency, although the pitch may also change with sound pressure and envelope. Envelope includes the growth, the decay, and the quasi steady state. The growth or attack of a musical tone involves the time required for the tone to build up to some fraction of its ultimate value. The decay or release involves the time required for the tone to fall in intensity from one arbitrary level to some other arbitrary level. The growth and decay characteristics affect the loudness, pitch, and timbre of a tone. The quasi steady-state characteristic of a tone involves that portion of the complete sounding time in which the sound output does not vary appreciably. Timbre depends primarily on the spectrum, but it is a sort of catchall, including all those attributes that serve to distinguish sounds with the same pitch and loudness. Although closely related, the physical duration of a sound and its perceived duration are not the same. The duration of a tone is the length of time that the tone lasts or persists without a discontinuity in the sound output. The duration characteristics influence to some degree the loudness, pitch, and timbre of a tone. Table 1 relates these subjective qualities to physical parameters.

| | | | Physical Parameter | | |
|---|---|---|---|---|---|
| Subjective Quality | Pressure | Frequency | Spectrum | Duration | Envelope |
| Loudness | *ddd* | *d* | *d* | *d* | *d* |
| Pitch | *d* | *ddd* | *d* | *d* | *d* |
| Timbre | *d* | *dd* | *ddd* | *d* | *dd* |
| Duration | *d* | *d* | *d* | *ddd* | *d* |

Table 1. Dependence of subjective qualities of sound on physical parameters
*d*= weakly dependent; *dd*= moderately dependent; *ddd*= strongly dependent

## LOUDNESS

The bellows control the loudness. They force air through the reeds and are the genuine heart of the accordion. Controlling the flow of air with the bellows is used for expression and dynamics. When pressure is gradually increased/decreased to the bellows, the sound is gradually getting louder/softer. The free end of the reed-tongue vibrates in and out of the reed-slot, when air pressure is supplied from the bellows. The tongue does not vibrate faster when greater air pressure is applied, but moves further in and out, creating a greater volume.

Figure 1 shows the typical action of free reed as used on an accordion. This will vibrate only when air is passed through from the side on which the tongue is fixed. This type of reed is inward striking and if air flows from the other side, then the tongue is simply bent away from the base plate and no vibration occurs.

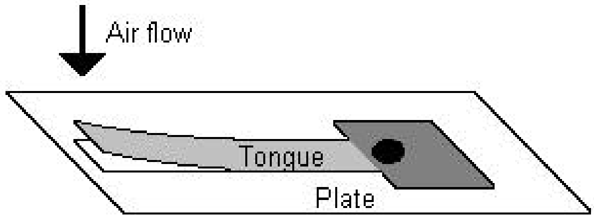


Figure 1. An inward striking reed.

Accordions can be either single or double action. The distinction is that with double action each key or button is connected to a valve, which controls two different reed-tongues. One tongue operates when the bellows are being compressed and the other tongue operates when bellows are being expanded. Both the press (compression of the bellows) and the draw (expansion of the bellows) give the same note. Since a reed-tongue will only speak when blown from one direction, this requires two similar tongues for each note, aligned in opposite directions. Figure 2 shows this configuration. With the single action two differently tuned reed-tongues are used with each key so that different notes are sounded on the press and the draw. Accordions are usually equipped with switches. The switch action makes it possible to operate several reeds from a single key.

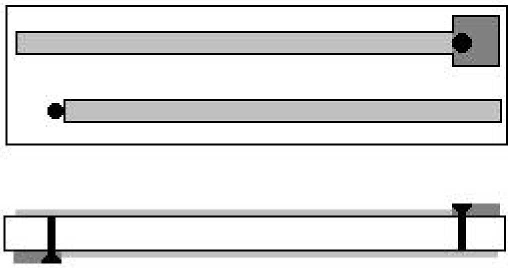

Figure 2. Two similar reed-tongues aligned in opposite directions.

Most of the interesting musical sounds lie in the range of 100Hz –3kHz and the most sensitive range of human hearing is from 1 to 3 kHz. In the case of an accordion single note and at a distance of 1 meter, it is possible a dynamic range of 40 or 50 dB without any noticeable pitch change. Due to human hearing response to acoustic pressure, it is convenient to regulate the accordion weaker intensity towards the higher frequencies.

For a given pressure, the instrument is correctly harmonised in loudness if any single note does not singularise with respect to its neighbours. Provided the blowing pressure is above the oscillation threshold, the depth of the mounting plate determines the oscillation amplitude. The sound power therefore does not vary much with blowing pressure within the normal operating range.

The grille that covers the keyboard's treble valves and mechanisms is usually "vented" to allow a louder treble sound. Sometimes, however, the grille is used as a muting mechanism.

**PITCH**

The pitch of any note is determined by the natural frequency of the reed-tongue. The reeds produce the accordion sounds and are the most vital part of an accordions sound quality. With a free reed the tongue vibrates over an aperture and is cut to exactly the same size so that it can move to and fro through the opening without being stopped by its edges. The tongue is considered to be a thin bar clamped at one end and free at the other end.

When a bar of rectangular cross-section is bent, the frequencies of the normal modes of vibration are given by

$$f_1 = \frac{0.1616\,h}{L^2}\sqrt{\frac{Y}{\rho}},\ f_2 = 6.267\,f_1,\ f_3 = 17.548 f_1, f_4 = 34.387\,f_1,\ \ldots \quad (1)$$

where L is the length, h the thickness, Y the Young's modulus, and $\rho$ the density. The above equation shows how far from harmonics are the overtones for a vibrating bar.

Its length and thickness govern the speed at which the reed vibrates. The longer and thicker the reed, the slower the rate, and consequently the lower the frequency and the pitch. It is worth noting that it is the quotient $Y/\rho$ what determines the value of the resonant frequency. For example, although the Young's modulus of a steel bar is more than three times that of an aluminium bar, the density of steel exceeds that of aluminium by almost the same factor. Thus, although a steel bar weighs about three times as much as an aluminium bar of the same size and shape, the two bars give almost the same tone. Moreover, the tongue has very little damping and vibrates at a frequency just below its natural resonance.

Comparing the frequency range of the fundamental with the entire frequency spectrum of an accordion, it can be seen that the frequency ranges of the overtones extend the frequency range by a factor of more than two octaves. Furthermore, that the low-frequency range extends to a higher frequency than that of the fundamental frequency-range. This is due to the fact that in the case of some of the lowest tones the fundamental is so weak that it can be eliminated without discerning any change in the character of the tone. The important factor in the comparison between the two ranges is the great extension of the frequency range when the harmonics are included.

## TIMBRE

Although the timbre of a reed depends on the resonant cavity and the Cassotto attenuates the higher harmonics, the timbre is primarily related to the reed. The involved parameters are the same magnitudes that modify the pitch. Thus, a modification of the pitch implies another one of the timbre.

The accordion is rich in overtones of high amplitude. The overtones of the air-actuated free reed are not produced by the different modes of vibration of the reed-tongue, because these are not multiples of the fundamental, but by the non-linear characteristics of the throttling action of the tongue upon the air stream. This action converts the steady air stream into a pulsating one of the saw-tooth type. Thus, the acoustic spectrum contains the fundamental and both odd and even harmonics.

The growth and decay times of the tones are relatively short. The bellows influence to some degree the timbre. The simultaneous action of the bellows and the fingers permits a great variety of attacks and decays that increases the hardness (fingers attack) or softness (bellows attack) of the timbre. The velocity at which a key or button is pushed or released has also a very small effect in the hardness of the attack or the decay, which is better observed in soft dynamics.

## DURATION

The bellows control the duration of sound. When a key or button is released, the corresponding sound disappears almost immediately. From the standpoint of duration of a tone the accordion is classified as a musical instrument of variable but fixed maximum duration. The maximum duration is determined by the elapsed time for a maximum excursion of the bellows. If the bellows direction is changed while pushing a key or button, the sound output will be interrupted. The bellows shake produces an effect similar to the tremolo of the bowing-string instruments. The action over the air button operates a valve that allows the bellows to open and close without the accordion making any sound. Activating the air button allows a continuous wind effect, with dynamic graduation if desired, and various rhythmical effects.

## EDUCATIONAL APPROACH

We begin our study by observing an accordion, and the sounds that the accordion emits. We investigate the conditions under which the sound quality changes. We measure the physical parameters related to musical parameters. We quantify the influence of each of the elements of the accordion in the sound. We identify the most important elements of the accordion acoustic behaviour. Using our observation as a basis, we construct a model that we can use to predict and explain the behaviour of modified reeds. We predict the characteristics of the sounds in case of the reeds are modified. We experiment with differently modified reeds and check the validity of our predictions. Figure 3 shows the main steps of the proposed approach.

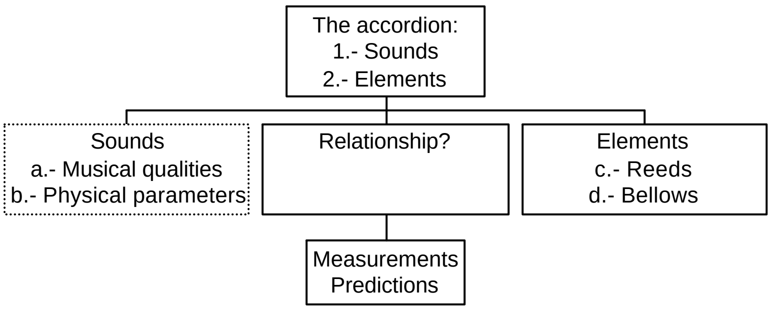


Figure 3. Schema for the study of the free reed behaviour.

## CONCLUSIONS

The laboratory-based module provides a step-by-step introduction to free reeds behaviour. Through in-depth study of the accordion acoustic mechanisms, students achieve both direct experiences with the process of science and music appreciation and creativity. The module contains narrative and experiments that require active mental engagement.

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