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# Acoustics of the Highland Bagpipe Chanter and Reed

by I. M. Firth and H. G. Sillitto

School of Physical Sciences, University of St. Andrews, St. Andrews, Fife, Scotland

## Summary

The acoustical input impedance of the chanter of the Highland Bagpipe has been measured for the notes in its scale. Spectra of played notes and of the sound produced by the reed alone have been obtained. The spectrum of the reed is shown to govern to a large extent the spectrum of played notes. The pitch of the played note is governed by the collaboration of the reed with the first impedance resonance. The  $Q$  of the first impedance resonance decreases smoothly as the scale of the chanter is ascended. Grace-note-playing, an important feature of bagpipe playing, becomes progressively easier, or faster by using notes at the top of the scale. The low  $Q$  of High  $G$  must be a contributing factor to its dominant use as a grace-note in pipe music.

## *Akustik von Pfeife und Zunge des Highland-Dudelsacks*

### Zusammenfassung

Es wurde die akustische Eingangsimpedanz der Pfeife des Highland-Dudelsacks für die Noten seiner Tonleiter gemessen. Die Spektren der gespielten Noten und des durch die Zunge alleine erzeugten Schalls wurden ermittelt. Es wird gezeigt, daß das Spektrum der Zunge das Spektrum der gespielten Noten in einem hohen Maß bestimmt. Die Tonhöhe einer gespielten Note wird durch das Zusammenwirken der Zunge mit der ersten Impedanzresonanz bestimmt. Das  $Q$  der ersten Impedanzresonanz nimmt beim Durchspielen der Pfeifen-Tonleiter stetig ab. Bei Benutzung von Noten aus dem oberen Bereich der Tonleiter wird das Spielen von Verzierungen, ein wichtiges Merkmal des Dudelsackspiels, fortschreitend leichter bzw. schneller. Das geringe  $Q$  des hohen  $G$ 's trägt wohl zu seinem vorherrschenden Gebrauch als Verzierung in der Dudelsackmusik bei.

## *Sur l'acoustique du chalumeau et de l'anche dans la cornemuse des Highlands*

### Sommaire

On a mesuré, pour les différentes notes de sa gamme, l'impédance d'entrée acoustique du chalumeau à trous de la cornemuse des Highlands, et l'on a relevé les spectres des notes sonnées et du son de l'anche seule. On montre que le spectre de l'anche régit dans une grande mesure celui des notes sonnées, dont la hauteur est régie conjointement par l'anche et par la première résonance de l'impédance. Le facteur de qualité de cette dernière diminue de façon continue lorsque l'on monte la gamme du chalumeau. Un aspect important de l'art de sonner la cornemuse est l'utilisation des «notes de grâce»: celle-ci devient progressivement plus aisée ou plus rapide pour les notes de l'extrémité aiguë de la gamme. La faible valeur du facteur  $Q$  du *Sol* aigu est sans doute l'une des raisons de son emploi dominant comme «note de grâce» dans le jeu des cornemuses.

## 1. Introduction

The form of the bagpipe which has developed in Scotland is played in many parts of the world. The scale of the Highland bagpipe does not conform to a just or equally tempered scale. A definition of a scale for the instrument has been attempted by Lenihan and McNeill [1].

The scale of the instrument is unusual and often displeasing to listeners accustomed to the equal-tempered scale of orchestral instruments. The scale of the chanter of the Highland bagpipe allows music to be played in three different pentatonic scales using only the nine notes available. The highest note of the chanter is "High  $A$ "; Low  $A$ , exactly an octave below High  $A$ , is pitched rather higher than Orchestral  $A$ , at 450 ... 460 Hz. No other interval on the scale is exactly an equally tempered tone or semitone; they are called minor tones or

major semitones. Old chanters are usually tuned lower than new: in order to obtain uniform tuning pipe bands use matched sets of chanters made by one maker to an identical pattern.

## 2. Instrument

The bagpipe chanter is a double reed instrument with eight finger holes allowing nine notes to be played. Unlike most other wind instruments it is not overblown to give extra notes in another register. It has a conical bore (1 in 20 taper) and the length of the pipe is longer than would be required to play the lowest note. The pitch of the lowest note, Low  $G$ , is determined by the length of the chanter to two cross-holes (diameter 1 cm) placed about 7 cm from the lower end of the chanter, bored at right angles to the line of the finger holes. At the bottom of a chanter a flange

Table I.  
Impedance resonances.

Note	Pitch Hz	Interval Cents	1st Hz	2nd Hz	3rd Hz	4th Hz	5th Hz	6th Hz	7th Hz	8th Hz
Low <i>G</i>	399		435	830	1268	1743	2051	2371	2828	3325
Low <i>A</i>	450	208	500	944	1467	1840	2108	2465	2821	3400
<i>B</i>	512	224	546	1055		2270	2461	2984		
<i>C</i>	570	186	601	1198	1946	2688				
<i>D</i>	620	147	640	1333	2193	3140				
<i>E</i>	688	178	706	1232	1515	2290	2540			
<i>F</i>	761	175	800	1767	2790					
<i>G</i>	840	171	900	2157	3452					
High <i>A</i>	908	135	984	2508						

often fitted. Known as the sole, and usually made of ivory or silver, it has a considerable but unknown effect on the tone of the instrument.

The bagpipe chanter used in these experiments was made by Thow of Dundee. The chanter had no sole and the reed used in playing the instruments was one belonging to H.G.S.

The pitch of individually played notes is given in Table I. A scale derived from these figures does not agree with Lenihan and McNeill [1]. The reason for the disparity is that notes were played individually in order that they could be recorded for analysis, and were not played as a part of a scale, or of music.

In experiments to measure the chanter input impedance at different notes finger holes were covered with insulating tape. The use of this medium to cover the holes did not change the spectra of played notes nor the acoustical impedance at Low *A* and was taken to be equivalent to the player's fingers over the range of the instrument.

### 3. Impedance measurements

The generator used in input impedance measurements on the chanter was an ionophone made by one of the authors. This ionophone was modelled on that used by Jansson [2]. The ionophone can be considered as a volume current source with high internal impedance of the volume velocity. The ionophone was used to excite the top (bag end) of the chanter and the input impedance is obtained by monitoring the S.P.L. at this point with a microphone.

Fig. 1 shows diagrammatically the ionophone and microphone joined to the chanter. The ionophone head was mounted in a  $\frac{1}{2}$ " diameter nylon rod. A larger nylon block had holes drilled into it to accept the ionophone, a  $\frac{1}{4}$ " B & K condenser micro-

phone and the chanter. The internal volume between ionophone, microphone and chanter was reduced by two internal collars to be nearly equal to that of the reed. One collar was a metal insert to the chanter, representing the copper staple on which the double reed is bound, and the other, made of nylon, had a set of small holes drilled opposite the microphone.

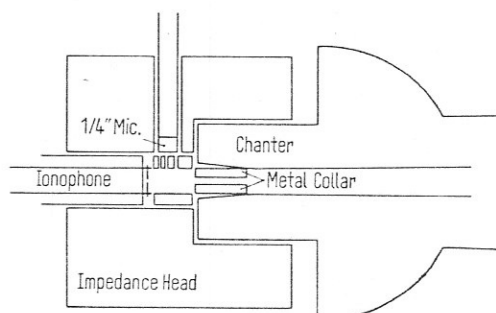


Fig. 1. Section through chanter showing the impedance head with ionophone and microphone.

The volume above the top of the chanter does not appear to be very important, but the metal collar influences the action of the chanter when joined to the impedance measuring head. When the metal insert in the chanter is the same size as the staple of the reed (8 mm long and 4 mm ID) the first impedance resonances of Low and High *A* occurred at 450 Hz, the same as the blown note, and at 818 Hz, respectively. A larger insert (14 mm long, 2.5 mm ID) was used in these experiments because it produced an interval for Low *A* to High *A* closer to an octave (500 to 984 Hz). It is obviously difficult to know whether the impedance measuring head is a good substitute for the reed but with the above adjustment it was considered adequate. It has been suggested that the motion of a double reed is responsible for purity of tuning [3].

The ionophone is modulated to produce an acoustic signal using the BFO output of a B & K Heterodyne Analyser, Type 2010, and the microphone output is filtered and averaged by the tracking filter.

#### 4. Impedance measurements

Impedance curves were obtained for all the notes in the bagpipe scale. Appropriate finger holes were covered with insulation tape. These curves are shown in Fig. 2. The input impedance to the chanter shows distinct resonance peaks up to 3.5 kHz. The first, or the first two resonances are always the greatest of the series. Above the 3.5 kHz the impedance curve shows a plateau to 6 kHz, above which it falls at about 20 dB per octave.

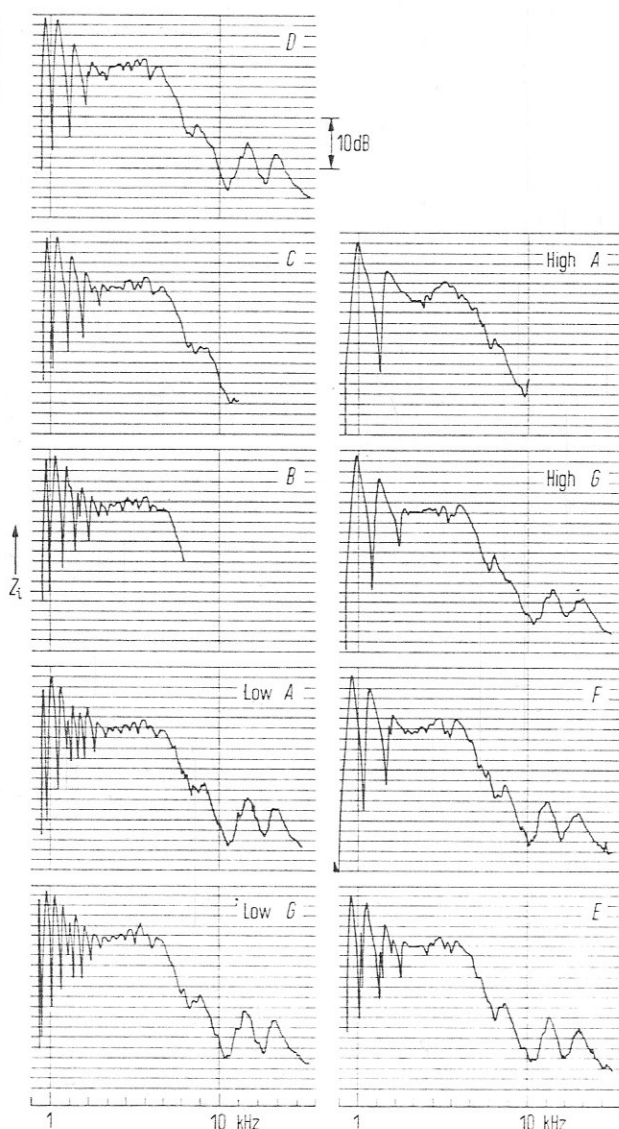


Fig. 2. Input acoustical impedance  $Z_i$  versus frequency for the notes of the chanter, low G to high A.

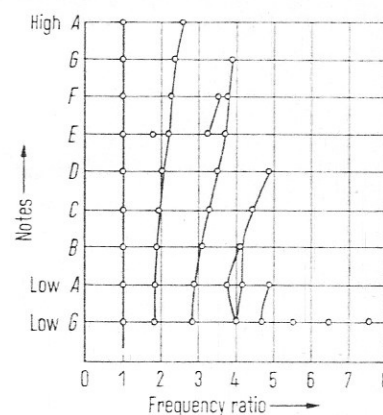


Fig. 3. Ratio of the frequency of the  $n$ th resonance of the input impedance to the frequency of the first resonance for the notes of the chanter. Resonances are not harmonic but show stretched intervals.

The frequencies of the resonances are noted in Table I and the ratios of the frequency of the  $n$ th resonance frequency of the first resonance are shown in Fig. 3 for the notes in the scale. The frequencies of the first impedance peaks are slightly sharper than the fundamental of the played notes. Resonances are not harmonically related, but show stretched intervals.

#### 5. $Q$ of impedance peaks

The  $Q$  factor of a note determines its onset time. Taking the  $Q$  of the first impedance resonance as representing that for the note when played the onset time will be related to  $2Q/\omega$ . The  $Q$ 's of the first impedance resonances of the notes of the scale are plotted in Fig. 4.  $Q$  decreases smoothly as the

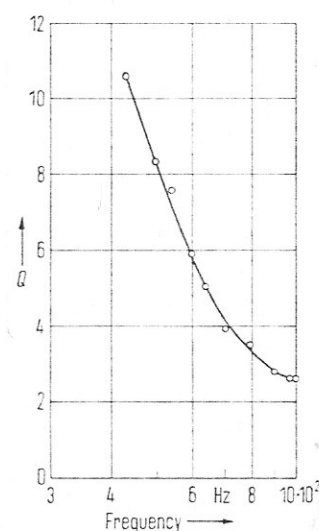


Fig. 4. Quality factor  $Q$  of the first impedance resonance of the notes of the chanter decreases smoothly as the scale is ascended.



scale is ascended:  $Q$  equals 10.5 for Low  $G$  (corresponding onset time 8 ms) and 2.5 for High  $A$  (corresponding onset time 0.9 ms).

From Fig. 4 one understands that grace-note-playing, an important adjunct to Highland bagpipe playing, becomes progressively easier, or faster to accomplish by using notes at the top of the scale. The most commonly used grace-note, and the most dominant in pipe music, is High  $G$ . High  $A$  is produced by the thumb of the left hand and is more difficult to execute rapidly. Most grace-note movements use high notes; some of those which use low notes cause difficulty even to experienced players, although this in part is due to the difficulty in moving certain fingers independently. The low  $Q$  of the impedance resonance of High  $G$  and the consequent short onset time must be a contributing factor to its dominant use as a grace-note in pipe music.

#### 6. The played notes

Each note of the chanter (with reed) was played in an anechoic chamber, tape recorded and later analysed using frequency compression techniques. Notes were transferred to the B & K Digital Event Recorder, Type 7502 and analysed using the Heterodyne Frequency Analyser, Type 2010 with an effective bandwidth of 0.3 Hz. Spectra are shown in Fig. 5, the frequencies of the notes in Table I.

The spectra adhere strictly to a harmonic series with all harmonics present. The harmonic condition is imposed by the vibrating reed; the presence of all harmonics is expected from the conical bore of the chanter.

#### 7. The spectra of the blown reed

Pipers endeavour to choose a good reed. When making a choice the reed is blown alone without the chanter: blowing hard, a smooth, high-pitched tone is heard; blowing at a reduced pressure a good reed will emit a rather harsh, high-pitched croak. Between the croak and the smooth tone there is another unstable oscillation which occurs at a lower pitch. This unstable sound is referred to here as the sub-harmonic mode because measurements of its spectra show that its fundamental oscillation is at about a half of the fundamental frequency of the smooth tone.

Even after selection the reed is usually assaulted with knife, file and sandpaper before it is actually pronounced fit to be used in a chanter. The problem is two-fold: to soften the reed so that it can be played easily; and to obtain all the notes of the scale at the correct pitch (viz, reference [3]). These

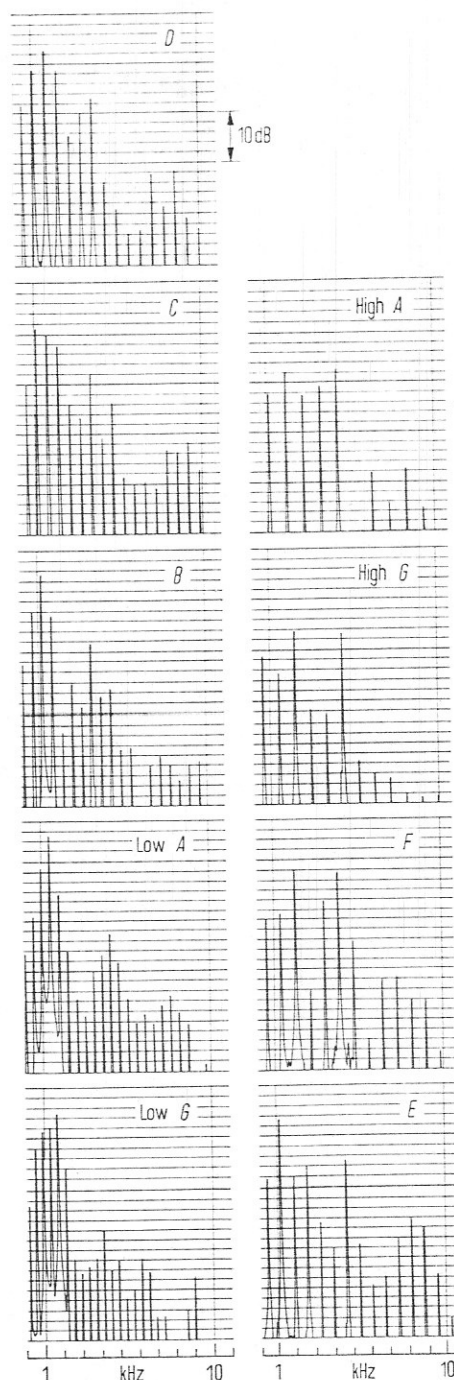


Fig. 5. Spectra of the sound output of played notes of the chanter.

have to be achieved without sacrificing tone quality. For use in a pipe band intensity is also important. For playing indoors it is possible, with care to make a reed easy to blow, sweet-toned and relatively quiet and such a reed can be played for a long time without fatigue. If a reed is made too soft, the tone quality and good pitch is lost.  $F$  is generally the first note to suffer.



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