Analysis of the timbre of Slovak folk reed aerophones using source-filter model

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Bagpipes are the only group of traditional folk reed instruments that have survived in Slovak folk culture until recent days. Unlike Scottish highland pipe, gaita, cornemuse etc., all the types of Slovak bagpipes use single reeds in both chanters and drones. Moreover the bells of the drones are partly closed with a plate (a lid) having only a small opening for air output and sound radiation. This forms a Helmholz-like resonator – acoustic filter having a strong influence on the acoustic and aesthetic properties of the sound. The ideal of the sound timbre of these pipes is “less open” (compare to open and closed vowels in speech) and, in spite of its relatively high loudness, less “aggressive” in comparison to pipes with open bells. This paper presents our first steps to study the ideal of sound timbre of the Slovak bagpipes using a source-filter all-pole model. To identify resonance frequencies/formants, we applied inverse filtering technique using discrete linear prediction. The possible relations between timbre of speech sounds (vowels) and the timbre of the sound of musical instruments are discussed.

1 Introduction

Gajdy represent a group of traditional Slovak folk reed aerophones consisting of one chanter and one drone. The chanter is equipped with one, two or three single (clarinet type) reeds made of black elder (or other) wood, cane or plastic. In this study we focus our attention on the drone, as a simpler acoustical system. It does not have fingerholes and it produces only one tone. Moreover the pitch of the drone tone is low, and therefore its signal is more suitable for modeling using linear prediction (LP). The LP derived formant frequencies are not so significantly shifted towards the position of strong harmonics in lower tones, as it is with higher pitched signals. The formant positions obtained from reed excited system should therefore be well comparable to those obtained by noise excitation. The paper describes a method to roughly estimate the resonance qualities of the bells and their influence on the drone timbre.

2 The instrument

In this first stage of the study we have focused our interest to the sound of the drone of the most frequent bagpipe in Slovakia – “trojhlasé gajdy” (three-voiced bagpipe), which has been mostly used in Central and Southern Slovakia. The double chanter of this instrument consists of a melody pipe with six fingerholes and a “small drone” with one fingerhole. A single drone is pitched two octaves below the chanter´s keynote. The measured instrument is “Trojhlasé gajdy” in A.

Fig.1 “Trojhlasé gajdy” with two spare alternative bells

3 The reed

The reed used in this study is made of plastic. It consists of a plastic cylindrical body and a tongue attached to the body by means of adjustable thread wrapping.

Fig.2 The reed of the drone in A

4 The drone

A drone is a pipe that produces one continuous accompanying tone (bourdon). (It is the long pipe laying in the horizontal position in Fig.1.) The whole drone consists of the single reed described in previous paragraph, plugged into a wooden cylindrical resonator. The reed and the resonator form an acoustically coupled system. The third part of the drone is a bell attached to the end of the resonator. Bells can have various shapes and sizes, and can be made of various materials. The bell serves as an acoustic impedance transformer and increases the effectiveness of sound radiation. But the bell also influences the frequency spectrum of the radiated sound. The majority of the bells of the Slovak bagpipes are partly closed by a lid with a function of a mute. The lid has only a small opening for air output and sound radiation. This forms a Helmholz-like resonator – acoustic filter - having strong influence on the timbre of the drone sound. Various types of bells have been used and four of them we introduce in this study.

(A) (B and C) (D) (E)

Fig.3 The bells measured in this study: (A) open cow horn bell, (B and C) open cow horn bell with a knee, (D) cow horn bell closed with lid and (E) brass bell closed with a lid

5 Method

The recordings were made in an acoustically damped sound studio. RODE K2 large diaphragm microphone with MOTU Traveller interface was used for hard disk recording. The sampling frequency was 44.1 kHz and resolution was 16 bit.

Reed-excited sounds were generated by playing the bagpipe with the chanter replaced by a cork plug. The noise excited sounds were generated by insertion of the noise-generating whistle in the position in the drone, where normally reed is placed. The whistle was blown by a player through a plastic air-duct.

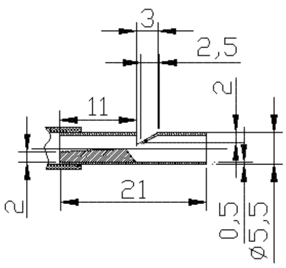
The Discrete Linear Prediction (DLP) [1] was used to compute the formant positions. Program APARAT [2] was used both for magnitude frequency characteristics and DLP inverse filter frequency characteristics computation. These characteristics are labeled on the figures as "pressure" and "tractfilt" respectively.

6 Measurements

6.1 Noise source

The design of the noise generating whistle was inspired by the Kempelen's generator of "s" sound in his speaking machine [3]. It is a whistle that operates in a mode in which only turbulent noise is produced at its edge without any significant harmonic components. Fig.4 shows the schematic drawing shows construction details of the whistle and the magnitude frequency spectrum characteristic of the generated noise.

a)



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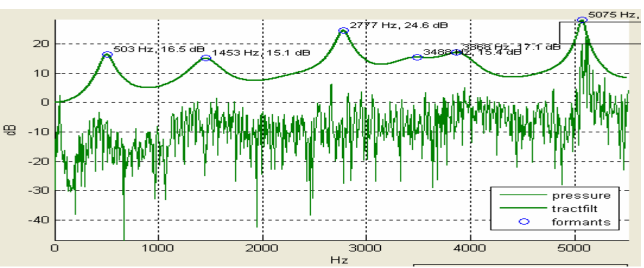


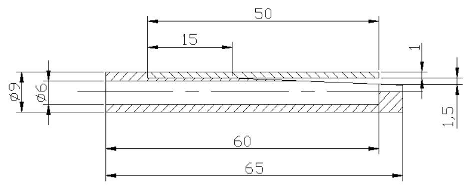
Fig.4 The noise-generating whistle: a) schematic drawing b) magnitude frequency spectrum characteristic

The frequency spectrum of the generated noise is not white, but the source guarantees excitation of all frequencies in the frequency range of our interest (i.e. from 100 to 5000 Hz).

6.2 The reed and the drone without bell

The construction details of the reed and the spectrum of its sound are shown in Fig.5. This figure also shows the spectrum of the sound of the reed excited drone without bell, and spectrum of the drone when excited by noise.

a)



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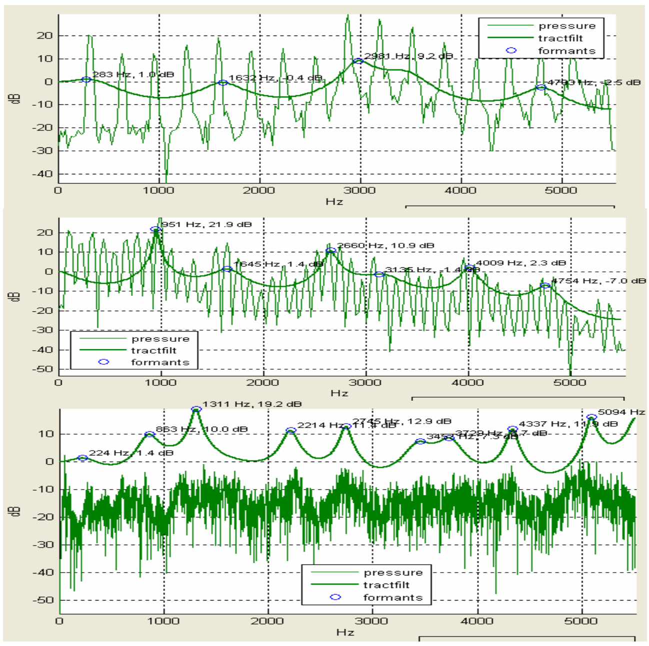

Fig.5 The reed a) schematic drawing, b) magnitude frequency spectra of the reed sound (up), the drone without bell reed excited (middle), and noise excited (down)

6.3 Open cow horn bell (A)

The simplest type of bell is the one made of a cow horn by cutting its end (see its schematic drawing in Fig.6).

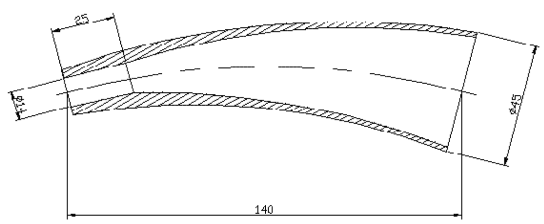

Fig.6 Open cow horn - schematic drawing

This bell is attached directly to the resonator without using any kind of knee. This type of bell has been used rarely in Slovakia. It can be found only on some simple, "primitive" instruments and children instruments. The measured characteristics are shown in Fig.7.

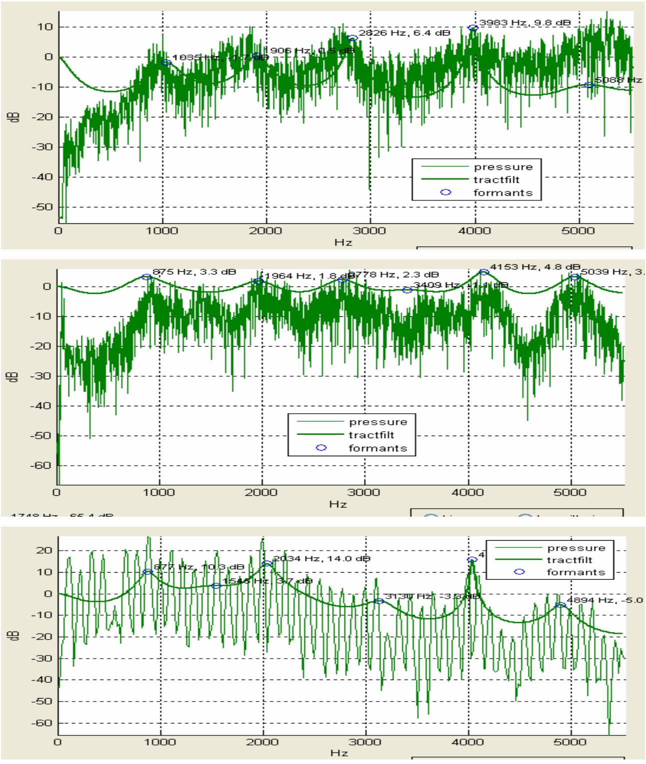

Fig.7 Open cow horn bell (A): The magnitude frequency characteristics (MFCHs) and DLP derived formant positions (FPs) of noise excited bell (up), noise excited drone with the bell (middle) and reed excited drone with the bell (down)

The measurements show, that the first resonance (F1) is less significant than in other bells. The bell frequency characteristic falls down from F1 towards lower frequencies very steeply.

6.4 Open cow horn bell with a wooden knee (B – open direct channel, and C – closed direct channel)

The open cow horn connected to a wooden knee was used in Slovakia mainly in Pohronie region around the town of Heľpa. Nowadays it is much more used by Hungarian bagpipers.

The studied bell has two outputs of the air channel. One of them leads to the cow horn and the second one goes through the straight part of the wooden knee. This opening can be closed by beeswax and so this bell offers two modes of function - with this direct channel open and closed.

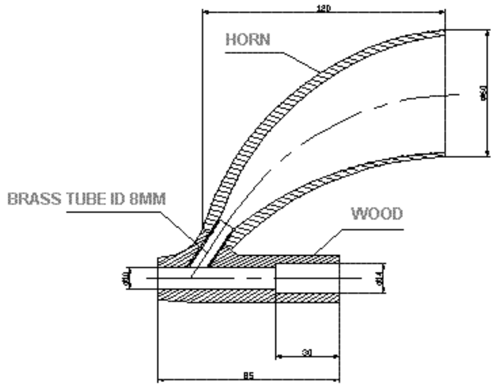

Fig.8 Open cow horn with a wooden knee - schematic drawing

When the straight part of the air channel is open, it causes that some frequencies of the radiated sound are less influenced by the cow horn. It causes an antiresonance at about 750 Hz (see Fig.9) which is not observable in the spectra of the sound of the bell with closed straight channel output (Fig.10).

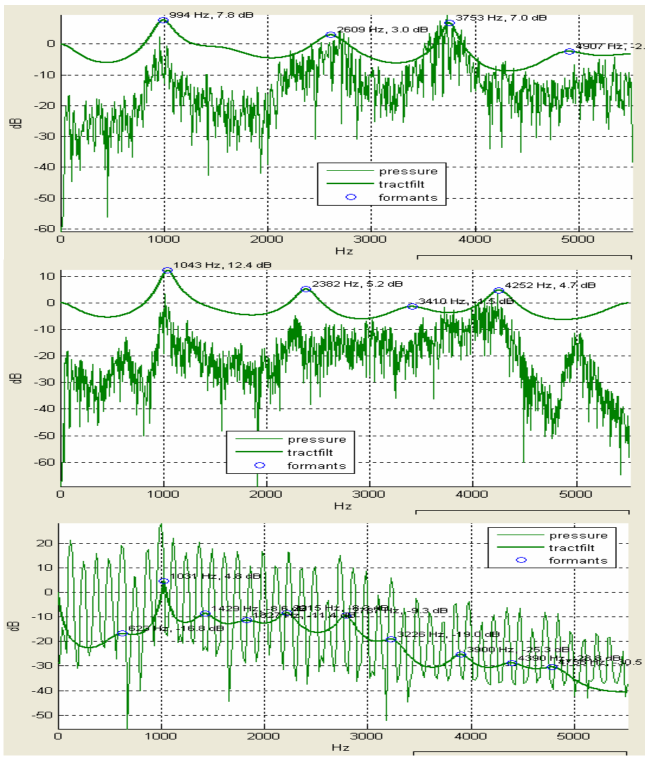

Fig.9 Open cow horn with a wooden knee (B) - schematic drawing

Similarly to the previous bell, the position of the first resonance is relatively high in pitch (at about 1 kHz), but it is more dominant.

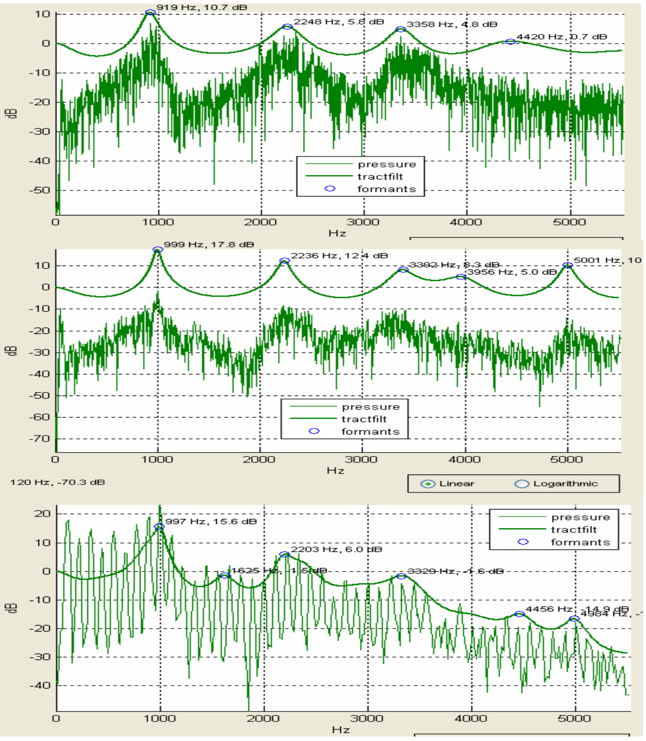

Fig.10 Open cow horn bell with a wooden knee (C): MFCHs and FPs of noise excited bell (up), noise excited drone with the bell (middle), and reed excited drone with the bell (down)

The small formant at 1500 Hz is caused by the both reed and wooden drone pipe – the resonator (Fig.5). It is not present in the noise excited horn spectrum.

6.5 Cow horn bell with a lid (D)

The cow horn with a lid belongs probably to the older types of bells. Typically it had a single/channel wooden knee. The cow horn knee as the one on the measured bell (see Fig.11), was less frequent. The cow horns often used to be extended by brass to reach higher volume of the bell and lower the resonance frequency.

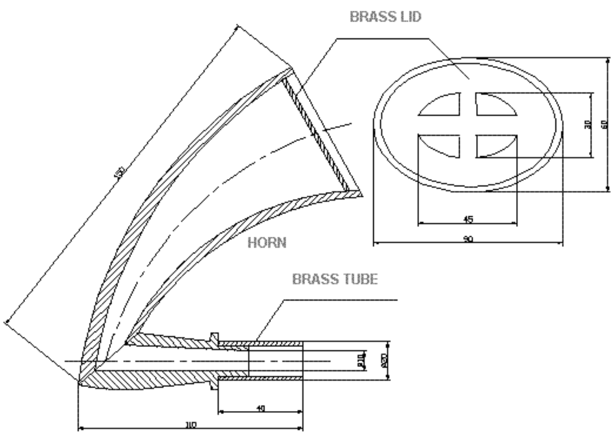

Fig.11 Cow horn bell with a lid - schematic drawing

The spectra of the sound of the drone equipped with this horn are shown in Fig.12.

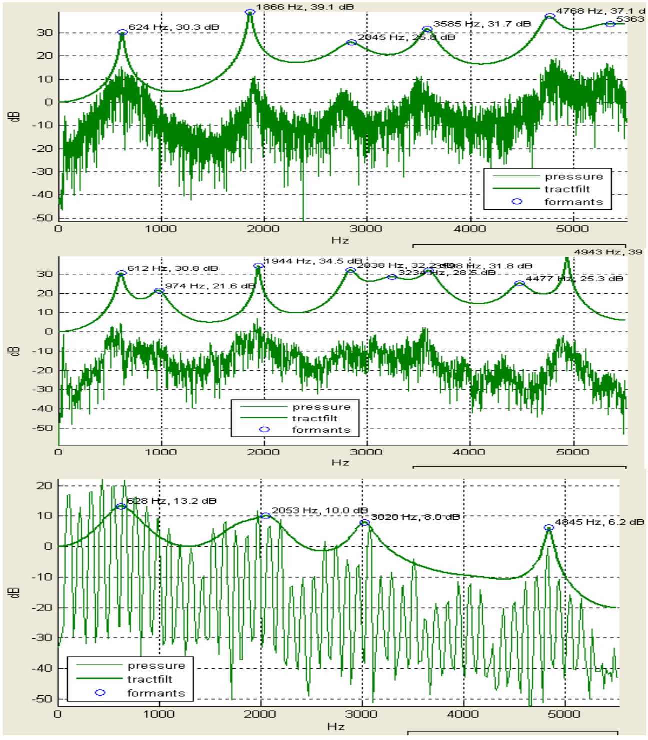

Fig.12 Cow horn with a lid (D): MFCHS and FPs of noise excited bell (up), noise excited drone with the bell (middle), and reed excited drone with the bell (down)

The sound of a drone with this bell is pleasant and cultivated but still loud enough to fulfill the bourdon function well.

The measurements show a strong resonance much lower (at about 630 Hz) than the F1 in open bells. It corresponds to our earlier findings [4], that the bell of the Slovak bagpipes with a lid amplifies frequencies of the third octave above the F0 (i.e. fourth to eighth harmonic). This is the range the melody chanter is tuned to.

6.6 Brass bell with a lid

The brass bells (Fig.13) have been very popular in Slovakia since brass became available material for common people, i.e. since the beginning of the 20th century.

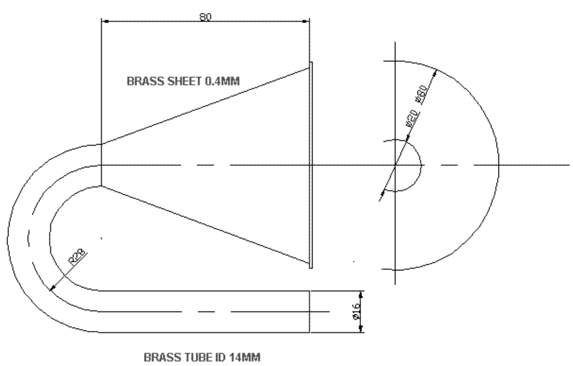

Fig.13 Cow horn bell with a lid - schematic drawing

The authors have heard from the old bagpipers that there was at least one manufactory where the brass bells were made. Other parts of bagpipes have never been produced in mass production in Slovakia.

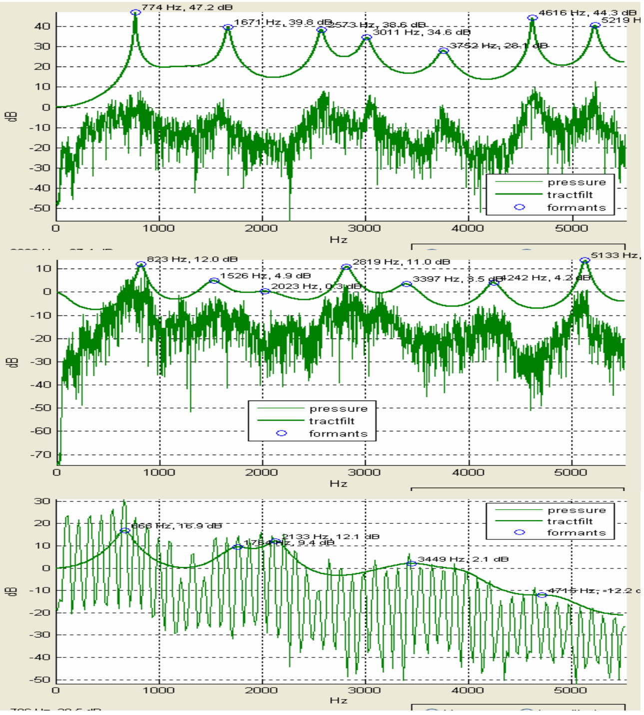

Fig.14 Brass bell with a lid (E): MFCHs and FPs of noise excited bell (up), noise excited drone with the bell (middle), and reed excited drone with the bell (down)

The first formant is markedly dominant and its center frequency is at about 770 Hz. The sound of the drone is slightly louder than the one with previous type of bell (D).

7 Discussion

The sound of a drone with straight open cow horn (A) is very loud, which could be an advantage but the bagpipers do not like its timbre and they say it sounds open like "e" vowel. In general in the second half of the twentieth century more Slovak bagpipers used bells with a lid. We therefore think there was a tendency towards less strong, less aggressive, darker and more cultivated sound of bagpipes. The comparison with the timbre of speech is not easy, nor unambiguous. The open bells in general do not have such low formants as F1 in vowels, which is (together with F2) the most important formant for vowel identification.

Formants of Slovak vowels [Hz]					Fromants of bells [Hz]				
a	o	e	i	u	(A)	(B)	(C)	(D)	(E)
681	481	452	285	386	900	1000	1000	630	780
1315	1084	1718	1900	967	1900	2700	2260	1900	1600
2290	2194	2365	2656	2059	2700	3700	3300	2600	2600

Table 1 Center formant frequencies of the Slovak vowels and formants of the measured drones with bells

Some cow horn bells with a lid and brass bells with a lid could be tuned to have the first two formants similar to those of the vowel "a" or "o", but any effort of makers of players to do so has not been proved.

The other fact is that for this kind of comparison we would need to use formants of female and male sung vowels.

Anyway the method we have used allows an instrument maker to check the resonance frequencies of his bells and it opens a possibility to make copies of the well playing bells even if the material (cow horn) is of different shape.

The basic ways to change resonance frequencies in bells with lid are change of bell volume and change of the open area (outlet) of the lid. Some of the bagpipe makers in Slovakia have even developed lids with variable outlet areas. This gives the player a possibility not only to change the timbre of the sound of the drone (which was the main subject of this study), but also to change slightly the pitch and the acoustic impedance of the bell which influences the stability of the reed vibration.

8 Conclusion

The presented study was focused on the determination of the resonance characteristics of bagpipe drones and their parts. The resonance frequencies were obtained by modelling the sound using a source-filter all-pole model. The Discrete Linear Prediction was used for computation of formant positions. Noise excitation and reed signal (pulse train) excitation were used alternatively to bring a deeper knowledge on the timbre of the sound with and without the influence of the coupled reed-drone acoustic system. The measurements have confirmed practical usability of the proposed method for further research on folk reed aerophones.

Acknowledgments

The instrument measured in this work with bells (A), (B), (C) and (E) was made by Juraj Dufek, the bell (D) was made by Anton Vranka.

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References

[1] El-Jaroudi A., Makhoul J., Discrete All-Pole Modeling, *IEEE Transactions on Signal Processing*, Vol. 39, No. 2, , pp. 411-423 (1991)

[2] Alku P., Bäckström T., Vilkman E., Normalized amplitude quotient for parametrization of the glottal flow, *J. Acoust. Soc. Am.*, vol. 112, no. 2, , pp. 701-710 (2002)

[3] von Kempelen W., Mechanismus der menschlichen Sprache, Wien, §220, (1791)

[4] Rusko M., Daržágín S., Basic Research on Acoustic Characteristics of Slovak Folk Reed Aerophones, in: Malm K., (editor), Studia instrumentorum musicae popularis XI, Musikmuseet Stockholm, pp. 127-131 (1995)