

The mystery of pipe acoustics

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Introduction

Students at school are not given a lot of information about sound formation in pipes. Explanation is reduced to the description of the standing sound wave in the pipe and importance of the sharp edge, which is struck by the airflow. The aim of this article is to answer in more detail three fundamental questions about the sound formation in pipes:

1. Why is the area around the edge so important and how exactly does a clear and continuous tone arise?
2. How can we influence a tone height by the force of blowing or by covering the end hole?
3. Why does the fujara have three holes and why are pipes with six holes also popular?

1. Formation of a continuous tone in a pipe

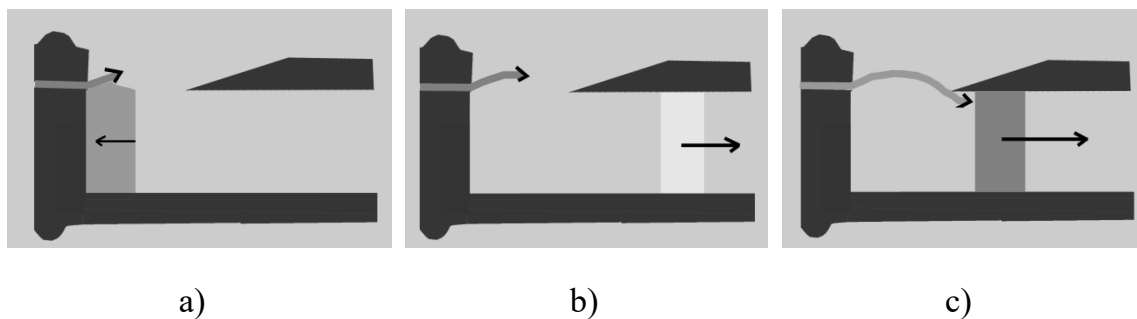
Tone in a pipe arises because of the periodic reflection of pressure wave at the ends of the pipe. Unlike the reflection from the covered end, in case of the reflection from the open end (or from the end with a window) the wave reflects in anti-phase and part of it leaves the pipe. To get a continuous tone, we must constantly supply energy to the reflecting wave, just like we supply energy to a swing by pushing it.

Unlike the swing where our reflexes are faster than its motion, the sound wave motion is too quick for our reflexes, which means that blowing air into the pipe has to be automated. Device that is called fipple or even, said poetically, soul of the pipe serves for this purpose (pic. 1). Its basic element is a thin channel, through which we blow air towards the sharp edge. At this edge the airflow deflects upwards and downwards simultaneously forming vortices. After the deflection the system tries to reach equilibrium, so the airflow will return back to the straight direction. However, the airflow usually passes over to the opposite side of the edge because of inertia. Direction of the airflow's deflection thus spontaneously and periodically changes and we can easily affect it, for example, by pressure in the pipe.



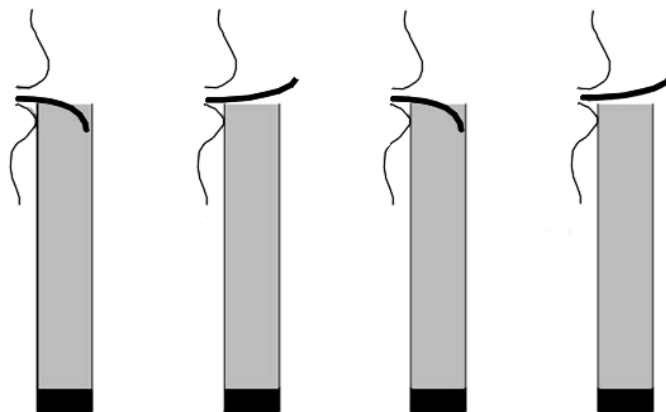
Picture 1 – On the left: section view of a recorder's fipple. On the right: blowing air through the channel to the sharp edge and forming vortices.

Mechanism of supplying energy in the fipple is represented in the picture 2. When the compressed part of a pressure wave approaches the fipple (pic. 2a), the increase of pressure causes the deviation of airflow from the pipe outwards. The airflow directed outwards gradually changes its direction and then it returns to equilibrium (pic. 2b). Meanwhile the pressure wave has reflected from the end of the pipe at the fipple. The fipple has a hole (window), that is why we can consider the end of the pipe at the fipple open (wave reflects in anti-phase). Thinned air then propagates through the pipe from the fipple and one half of the period later thickened air follows. At that time (pic. 2c), the deviated airflow has reached the edge and it is now moving from the exterior into the pipe. Hence it slips under the edge and during forming the vortex it blows into the leaving compressed air, thereby increasing its density. For the sake of clarity, the vortices are not shown in picture 2. Similar process also takes place when thinned air approaches the fipple, but in this case the airflow deviates in the opposite direction and vortex forms at the external side of the edge (thereby the thinned air expands).



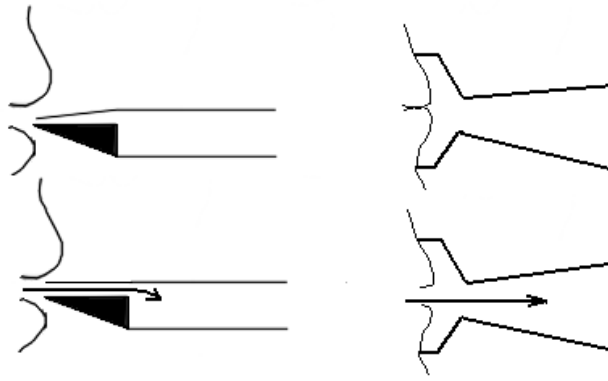
Picture 2 – Mechanism of supplying energy to the pressure wave

Similar mechanism (vortices) is used in the pan flute as well (picture 3), which is obviously the simplest type of pipes.



Picture 3 – Mechanism of supplying energy to the pressure wave in the pan flute

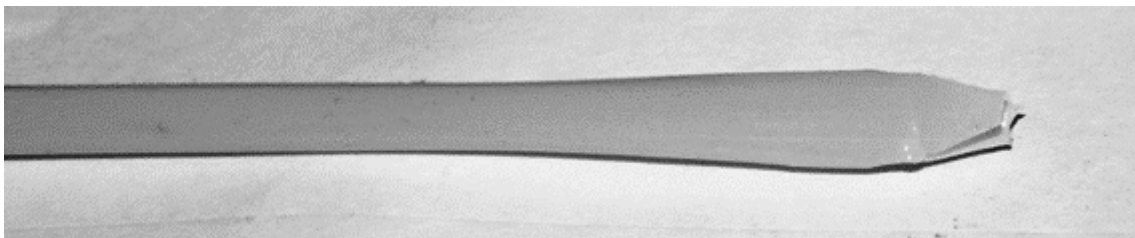
Another frequently used way to supply energy is closing and opening of the air inlet. In a clarinet or saxophone there is a reed that serves for this purpose, but, for example, in case of a trumpet we use our lips, see picture 4. Coming thinned and thickened air opens and closes the reed or increases and decreases a slip between the lips respectively. Thereby air blows into the pipe at the proper time.



Picture 4 – Mechanism of supplying energy to the pressure wave in the clarinet (left) and in the trumpet (right)

The above mentioned mechanisms can be easily demonstrated. To make one pan flute, we need just a thin tube and a piece of modelling clay. The piece of clay will serve as a plug for the one side of the tube. By moving this plug using a small wooden piston we regulate length of the tube. When the plug reaches the right position (tone height), we fix its position by pressing it from both sides. Suitable plastic tubes and round wooden sticks can be found, for example, in a building materials store.

The idea of the reed can be demonstrated with a piece of dandelion stem. When we squeeze one end of the stem, it will crack and make two reeds close to each other. Or we can also use a plastic drinking straw. We cut one end at a slant from the sides, thereby we create two reeds (picture 5). Finally, we press the reeds together with our teeth, and the pipe is finished.



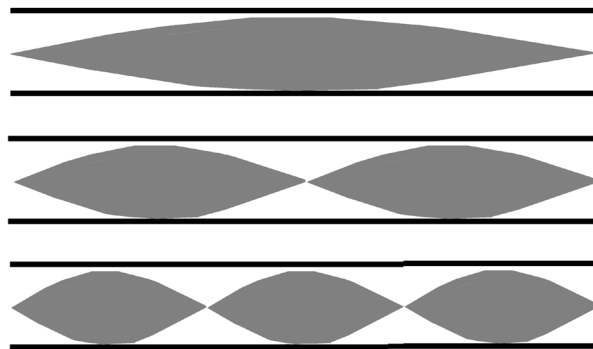
Picture 5 – Reed pipe from a plastic straw

We set the tone height by shortening the straw to a proper length.

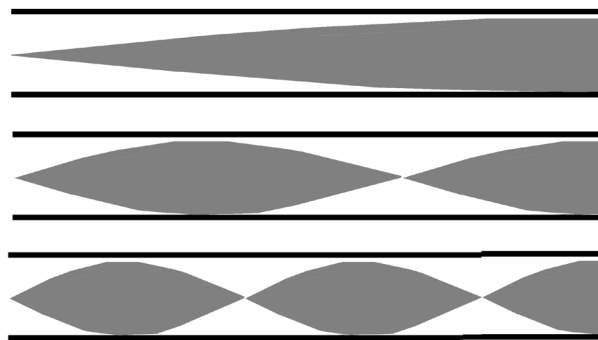
Making a pipe with a fipple is more complicated, you can read about it in [1]. To show the supplying of energy by lips, we need a long pipe, whose length is around 1 m and diameter is 3 – 4 cm (for instance, vacuum cleaner pipe or waste pipe). Then we will get an instrument similar to the Australian didgeridoo. To achieve the same tone colour as a didgeridoo has, we will need a thicker pipe (about 5 cm), whose diameter at one end needs to be made smaller. Australian Aborigines use wax to make the diameter smaller, but in the case of a plastic pipe we can just heat it and shape while it is still soft.

2. Changing tone height with the force of blowing

In the previous section we have explained the formation of a continuous tone because of the processes that take place when maximum or minimum of the pressure wave reaches the edge of the pipe or fipple. In fact, the pressure is changing from the maximum to the minimum and back continuously. Waves are ceaselessly propagating from one end of the pipe to the other, therefore standing waves are created in the pipe. Thus, depending on the tone frequency, there can be a whole series of maxima and minima of pressure. The only limitation is that we cannot change pressure at the open end of the pipe (air can freely leave the pipe or enter it), so the minimal changes of pressure have to be there. Conversely, at the closed end air cannot get away, therefore pressure changes reach their maximum (pictures 6-7).



Picture 6 – Distribution of pressure changes in the pipe that has both ends open



Picture 7 – Distribution of pressure changes in the pipe that has one end closed

How is it possible that standing waves of different frequencies can arise in the pipe of constant length? How does the pipe choose which frequency will arise? It will be the frequency of the wave that has received the greatest amount of energy, during the reflection in the fipple, from the airflow from the channel. As we know, optimally, the time during which the deflected airflow covers the distance between the channel and the edge is equal to one half of the oscillations' period. If we blow into the channel slightly, the airflow's velocity will be low, therefore a low frequency will accept more energy, for example, like in the upper part of the picture 6. If we blow harder, for instance, with twice greater pressure, velocity of the airflow will be two times greater, therefore a higher frequency will be intensified (middle part of the picture 6). If we go

on increasing the force of blowing, greater multiples of the lowest frequency will arise gradually.

Ability to change the tone height by the force of blowing is limited. For example, two frequencies, which correspond to the situation shown at the top and at the middle of the picture 6, are in a ratio of 1:2, which is the same tone, just shifted by one octave (e.g. C1-C2). Hence the tone in the middle of the picture 6 (e.g. C2) is considered as the fundamental tone of the pipe. If we blow even harder, we will get the situation shown at the bottom of the picture 6, which corresponds to the frequency ratio 2:3 (with respect to the fundamental tone), and this ratio corresponds to the interval of a perfect fifth (e.g. C2-G2). As long as we close one end of the pipe, we will obtain another ratio. We will obtain a great amount of tones by blowing harder into the pipe, not all tones of the scale though. Nevertheless, some simple emotional melodies can be played even on the pipe without holes, for example, *koncovka*.

3. Changing tone height with holes

To play other tones than those that can be played on a *koncovka*, we need pipes of different lengths. Length of the pipe can be shortened by boring holes in the pipe. Then we can open and close the right hole with our fingers (picture 8).



Picture 8 – Section view of a three-hole pipe

We already know that we can obtain the perfect fifth (e.g. for C2 it is G2) by blowing harder into the pipe, which means that we do not have another 3 tones: D2, E2 and F2. But if we bore 3 holes in the right places on the pipe, we will be able to play 4 tones while blowing slightly: C2 (all holes are closed), D2 (the bottom hole is opened), E2 (two bottom holes are opened) and F2 (all holes are opened). Then we close all the holes again and blow harder. Thereby, we will get higher multiple tone G2. Opening the holes again, we will play other higher tones. To find the right location of the holes, you can use an aid [2].

Another possibility, which enables to tune up more precisely even higher tones by the holes' location, is boring six holes. When we close all the holes, we will play the fundamental tone (e.g. C2). Then, by opening other holes, we can play other tones D2-E2-F2-G2-A2-H2. Finally, we close all the holes and blow more strongly, thereby we play C3. Then we open the holes gradually again, to play even higher tones.

Conclusion

Understanding of how pipes work should belong to the general education, especially when pipes and *fujara* belong to our cultural heritage. Making simple pipes also could be an interesting activity for students.

References

- [1] Kundracik F.: *Tlakové vlny a ich rezonančné zosilnenie. Ako vlastne hrá koncovka a fujara?* Fyzikálne listy XVII (2012), č. 2-3, s. 11-18. ISSN 1337-7795.
- [2] <http://www.drp.fmph.uniba.sk/~kundracik/fujara.xls>