The research of musical instruments has not been only recognition of new findings but also looking back from time to time. This contribution that follows up our measurement of cylindrical air column resonance mode frequencies in 2002 presents also the looking back. The purpose of the measurement was a specification of well-known simple empiric relations for a size of length correction as a difference between a mechanical length of the cylindrical tube and so-called air column acoustic length in this tube. The measurements were performed by the BIAS system received from our Viennese friends.

On this picture we can see one of the tube measurement results of a length corresponding to one quarter of a wave length. Then the results of measurement inspired us to revise a calculation of the length correction used, above all, by organ makers. I asked Prof. Merhaut, a mentor and friend of mine, to revise the calculation and already the first results showed a very good matching with measured values. Regrettably, Prof. Merhaut died last year, so Pavel Dlask, our new colleague, whom I would like to introduce to you, undertook his work.

The results of measurement led us to the first methodical remark that definitely does not bring any new facts and may be summarized in the next five points.

1. The influence on pipe tone is observed very often in distance larger than 0.3 D from the pipe end.
2. The known formulas don’t respect the tube length and the frequency too.
3. The influence of tube dimensions on resonance mode inharmonics is unclear.
4. It’s impossible directly to calculate the acoustical length and open-end correction too.
5. The acoustical length is non existent, only there is the true resonance frequency value.

The „acoustical“ length of wind musical instruments, what is it? The best known image bears on the organ pipe: The length of oscillating air column is longer then length of tube and determines the 1. harmonic frequency of sounding tone.

Why?

Because the equalization of acoustic pressure inside and outside of the tube is gradual. Is it true???

Some known formulas for open-end correction

\[ \Delta L = \begin{cases} 0.3D \text{ (by Levine & Schwinger)} \\ 0.41D \text{ (by Rayleigh)} \\ 0.29D \text{ (by Blaikley)} \\ 0.33D \text{ (by Boehm & Bate)} \end{cases} \]

etc.

Some methodical „revision“ remarks on measurements of air column oscillations

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1. remark

The „acoustical“ length of wind musical instruments, what is it? The best known image bears on the organ pipe: The length of oscillating air column is longer then length of tube and determines the 1. harmonic frequency of sounding tone.

Why?

Because the equalization of acoustic pressure inside and outside of the tube is gradual. Is it true???
Now we are going to follow up the 5th point and look again at the result of measurement. As you can see, the length correction measured values, more precisely the difference between the calculated and measured resonance frequency do not depend on a tube diameter linearly. It is well known that this fact is related to an influence of radiation impedance on the open tube end and losses inside the tube. However, in which parts of the curve these losses do apply more than the radiation impedance and vice versa? The answer must be sought firstly in a type of considered radiation impedance and secondly in a sound velocity determined by a temperature, humidity, pressure and air chemical composition. The sound velocity is changed with losses inside the tube and so it depends not only on climatic conditions but also on the frequency and tube diameter.

On this picture we can see an instances of the narrowest and the shortest measured tube. The difference between the calculated and measured resonance frequency for the first five modes, naturally odd modes, rely to a radiation impedance in form of a pulsative sphere, then in form of a vibrating piston in an infinite wall and, finally, when a radiation impedance is not considered. It all applies once for an ideal gas and for the second time for air with values along the measuring.

If we merely increase the tube diameter only the differences between the mentioned type of calculation on single resonance modes increase.
Now we will perform a similar calculation for air without a speculation about the influence of the radiation impedance. We will get relations that are very close to the already mentioned experiential relations but at the same time very different from the results of measurement.

Finally, we will perform a calculation for the radiation impedance in form of a plane piston vibrating in an infinite wall. Here even a difference polarity between the short tube calculated and measured resonance frequency will vary.
The next pictures bring the same although otherwise sequenced results.

The influence of temperature and air humidity on the mentioned results is shown on this picture.

Now there is the most important thing. Let us compare the measured and calculated values of the length correction. These lines correspond merely to the influence of the radiation impedance but these curves include also correction of sound velocity respectively according to Thomas Moore’s publication in Acta Acoustica this year. Considering the radiation impedance in form of a plane piston source vibrating in an infinite wall, the accordance with the results of measurement is very good. The differences that might be thought to be measurement errors also rely, among others, to uneven distribution of air temperature inside the tube. (The tubes have been made from duralloy.)

The second remark may be summarized in the following points:

1. The radiation impedance in form of a vibrating piston in an infinite wall is preferential for a calculation of the cylindrical air column resonance frequencies.

2. The calculation must cover the influence of all the losses that occur inside the tube.
Let us make two additional remarks. The first one also refers to a notorious fact that the higher resonance modes frequency positions are not harmonically distributed. On this picture we can see a frequency deviation of the ninth resonance mode for various tube diameters. Leaving out the radiation impedance influence, the deviation will be zero. In case of radiation impedance as a pulsative sphere or a plane piston source in an infinite wall the inharmonicities increase with increasing of the tube diameter. However, correcting the sound velocity will essentially change the dependence of inharmonicity sizes. This calculated relation does not differentiate the considered type of radiation impedance very much and matches the values measured in 2002.

The last remark is devoted to cylindrical tube air column transversal oscillations, more precisely oscillations oriented outside the tube axis. Practically, we met these oscillations already over 15 years ago during a development of pulse methods for measurement of wind instrument input impedance. On this picture, the results of measurement of four clarinets with all side holes closed are being compared. These holes themselves already facilitate a creation of a marked transversal resonance mode. Frequency position of the mode coheres with the inside tube diameter of the clarinet, the shape of the mode coheres with the variable depth, diameter and position of side holes of the clarinet.

The next picture presents the results of measurement of these transversal modes for two positions of the BIAS measuring modes. At axial head position merely a slight undulation occurs, at off - axial head position these modes are very marked. The existence of transversal modes may be proved by a calculation of tube resonance modes for three-dimensional solution in cylindrical coordinates.
The result of calculation basically matches the results of measurement.

The mentioned remarks are interesting for us, above all, from a view of organ pipes sound timbre and thereby the whole organ sound research. Although the cylindrical organ pipe presents the simplest wind instrument, we do not get ahead very much with a simple solution of the Webster’s equation for ideal gas, let alone in case of wood and brass instruments.

Nevertheless, We hope that our small looking back would have been inspiring for the research of these instruments, too.

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References


Cremer O. (1993): The variation of the specific heat ratio and the speed of sound in air with temperature, pressure, humidity, and CO₂ concentration, J. Acoust. Soc. Am. 93 (5), 2510-2516