Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Assessment of chest impedance in relation to Phonocardiography

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PACS: 43.58Bh, 43.80Sh

ABSTRACT

Weak sounds originating from the heart, coronary arteries, or the lungs can be used to perform a non-invasive diagnosis of a certain diseases. However, the sounds of interest can be difficult or even impossible to pick up due to loss of signal when the sound is transmitted through the tissue and from the surface of the skin to the transducer. If the impedance of the skin is known, it may be possible to optimize the transducer to achieve an improved signal for a certain frequency range, while attenuating disturbing noise. Further, from a classical stethoscope it is known, that the sound picked up by the stethoscope can be influenced by changing the pressure on the chest piece of the stethoscope. A high pressure will stretch the skin similar to a drum skin, and attenuate lower frequencies, while lighter pressure will broaden the frequency range. By using an impedance tube (also known as standing wave tube), it is possible to measure the impedance of the surface of the skin and at the same time investigate the influence of different pressures and diameters of a transducer. The impedance tube is made specifically with the purpose of measuring chest impedances in the frequency range from 50 Hz to 5 kHz. An MLS sequence is used as the excitation signal, and based on the measured impulse responses; the impedance of the surface is calculated. The diameters used for the setup are in the same range as diameters of normal stethoscopes, and the force applied to the tube ranges from close to zero to pressures in the range normally used for auscultation. The study involves the measurement of the chest impedance on several people at locations on the chest, where auscultation of the heart is normally carried out. Knowledge of the chest impedance is aimed at use in optimal selection of transducer (e.g. microphone, force transducer or accelerometer), sensitivity and dynamic range, frequency range, coupling area, coupler geometry etc. for a system to pick up chest sounds. Especially the weak sounds of the heart, e.g. the murmur sound originating from coronary arteries or the fetal heart sounds, are of interest.

INTRODUCTION

The sounds from a beating heart are mainly consisting of the closing of the atrioventricular and semilunar valves with silent periods in between called the systolic and diastolic periods. During the diastolic period, the heart is in a relaxed state allowing blood flow through the coronary arteries. This blood flow is causing a weak turbulent noise (a murmur sound)(Dock, Zoneraic.S 1967), which in comparison to the sound of the closing heart valves is approximately 60 dB lower. If there is a build up of plaque inside the coronary arteries, the turbulence of the blood flow will increase and consequently also increase the level of the noise.

The weak murmur sound can be difficult of even impossible to pick up using a classical stethoscope with a bell shaped air filled coupler. By thinking acoustical principles into the principle of using an air filled coupler it may be possible to optimize the coupler within a certain frequency range for picking up weak sounds not only from the heart or coronary arteries, but e.g. also fetal hearts.

When focusing on optimizing a transducer for picking up weak sounds from the heart, murmur sounds from the coronary arteries or lung sounds, knowledge about the impedance of the skin and tissue is essential to achieve an improved signal for a certain frequency range and at the same time attenuate disturbing noise.

The classical stethoscope is mainly picking up sound from just below 100 Hz to slightly above 1 kHz, though sounds outside this range may provide additional information when performing an auscultation. Consequently, the frequency range of the impedance measurements has been extended outside the range of a stethoscope. Previous studies (Suzuki, Nakayama 1998) have indicated that only little or no information is available in the heart sound at higher frequencies, hence extending the upper limit of the frequency range to 5 kHz is sufficient. The lower frequency limit is determined partly by the frequency that will be of interest and partly by what is practically achievable due to the length of the impedance tube. Thus a lower frequency limit of 50 Hz has been chosen.

With the coupler positioned on the chest, the acoustic coupling between the chest and coupler can be described by an equivalent impedance analogy diagram using Thevenings Theorem.

On Figure 1 the sound from the heart is equivalent to a signal generator and the impedance of the tissue is indicated by Z_{Torso} while the impedance of the coupler is shown as $Z_{Coupler}$ which also includes the compliance of the air inside the coupler, if the coupler is similar to the stethoscope type bell.

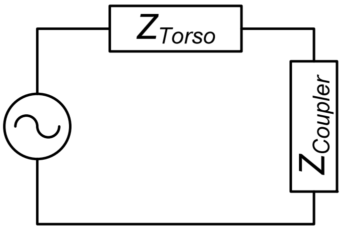

Figure 1 - Thevenin equivalent impedance circuit.

If the impedance $Z_{Coupler}$ is much larger than the impedance of the torso, the attachment of the coupler for measuring heart sounds equals an open circuit measurement in the equivalent diagram.

The impedance of the coupler will be influenced by the pressure applied to the coupler. A high pressure will stretch the skin similar to a drum skin, and attenuate lower frequencies while a lighter pressure will broaden the frequency range.

MEASUREMENT SYSTEM AND EQUIPMENT

The chest impedances were measured using two measuring tubes (standing wave tubes) with four fixed microphone positions. The two measuring tubes were differing in the internal diameter of the tubes in order to measure the influence of the diameter in respect to the impedance. After constructing the first tube, initial measurements revealed the small changes of the positions of the microphones could improve the performance of the tube (se tube dimension in Table 1). The tube is made of aluminium with a recess for each microphone (Sennheiser KE-4-211) and a fittings made of nylon are keeping the microphones in place. The MLS sound is generated by a loudspeaker (Vifa M19MD-39-08).

At the open end of the tube, another recess makes it possible to attach different terminations of the tube for calibration and measuring purposes.

	Tube 1	Tube 2
D	20 mm	30 mm
Δl_{12}	30 mm	30 mm
Δl_{13}	140 mm	140 mm
Δl_{14}	700 mm	600 mm
l_{end}	7 mm	10 mm
L	750 mm	660 mm

Table 1 - Dimensions of impedance tubes

When calculating reflectance and impedance any combination of the four microphones can be used within certain frequency limits. The upper frequency limits is determined by the wavelength, thus the distance between the microphones must be shorter than the half wavelength. The lower limit is determined by the precision of the measuring equipment (ISO 10534-2 1998). By using microphone one as reference, the largest frequency range is achieved while using microphone two only provide information at lower frequencies, thus using microphone two as reference is mostly serving as a double check of the calculations. Table 2 is showing the frequency range for each pair of microphones.

	Tube 1	Tube 2
Mic 1-2	1125 - 5000 Hz	1150 - 5000 Hz
Mic 1-3	215 - 1125 Hz	225 - 1150 Hz
Mic 1-4	50 - 215 Hz	60 - 225 Hz
Mic 2-3	220 - 1230 Hz	225 - 1280 Hz
Mic 2-4	50 - 220 Hz	60 - 225 Hz

Table 2 - Frequency intervals for microphones

Based on the measured sound pressures at each microphone position, the reflectance is calculated from Eq. 1 (Blauert, Xiang 2008):

$$r = \frac{(p_1/p_2) - e^{-jkl_\Delta}}{e^{+jkl_\Delta} - (p_1/p_2)} e^{+2jkl_2} \qquad \text{Eq. 1}$$

where $p_1$and p_2 are the sound pressures measured at respectively the microphone closest to the open end and the microphone in question. l_Δ is the distance between the two microphones while l_2 is the distance from the open end of the tube to the microphone in question. k is the wave number. From equation Eq. 2, the termination impedance is determined as:

$$Z = \rho_0 c \frac{r+1}{r-1} \qquad \text{Eq. 2}$$

Verification of impedance tube

To verify the measuring tube, the impedance is calculated in two situations with a closed end termination and an open ending, where the tube is radiating into air. For the first situation a closed end termination with a length of 60 mm is attached to the end of the tube. Resonance and antiresonance will occur when $\cot(kL) = 0$, where L is the distance between the position of the end where the termination is attached (where the tube is driven) and the closed end of the termination. By comparing the calculated and measured impedances, the frequency characteristic and level of the impedance can be verified. Figure 3 shows the measured and calculated impedances with the close end termination attached to the tube:

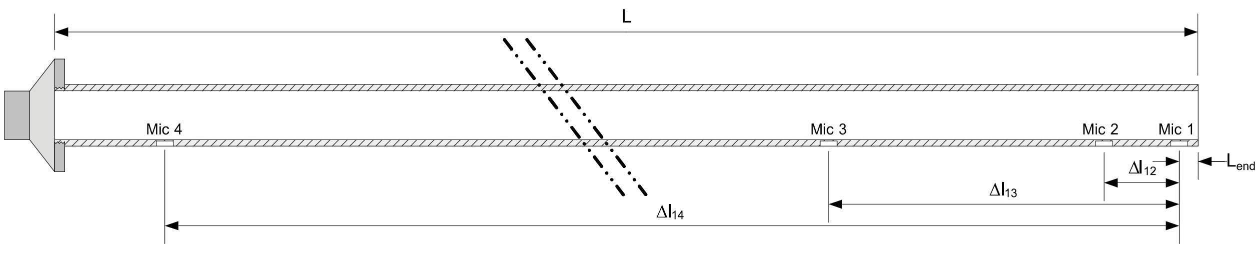

Figure 2 - Sketch of tube and the positions of the microphones

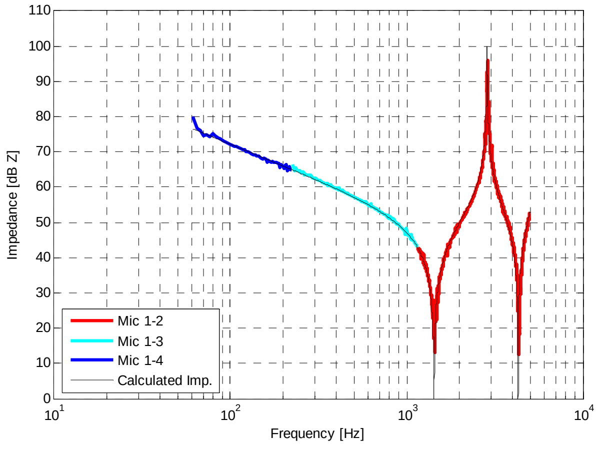

Figure 3 - Impedance response of closed end termination.

The impedance as also measured for an open tube ending radiating into air. The tube can be considered as an open pipe with no flange; hence the impedance should increase as a function of the frequency as seen on the Figure 4.

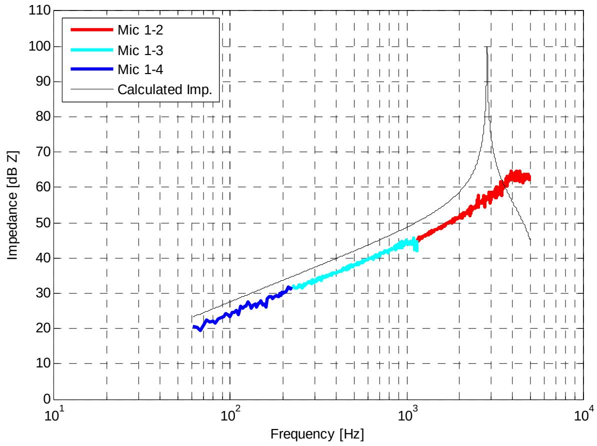

Figure 4 - Impedance response where the tube is radiating into free air. The deviation between calculated and measured responses is related to an approximation of the soft termination

The deviation between the calculated and measured impedances for the open tube shown on Figure 4, is caused by an approximation where the open end is considered as a soft termination with a reflectance that equals $r = -1$.

When carrying out the impedance measurements an extension of 40 mm is added to the open end of the tubes, to ensure that the sound pressure measured at the first microphone position is not disturbed by diffraction of the sound close to the opening of the tube.

MLS sequence for impedance measurements

The excitation signal used for measuring the sound pressure at the four microphone positions was a Maximum Length Sequence (MLS)(Vanderkooy 1994). The MLS was a 14^{th} order sequence with 20 averages used for pre-averaging of the signals. The recording and playback system is based on a pc with a multichannel soundcard (Søren Krarup Olesen et al. 2000).

Before the measurements were carried out, the sensitivity of the microphones were measured.

MEASUREMENT PROCEDURE

The measurements of the chest impedance were carried out on a subject lying in a supine position with the arms resting along the torso and on the stomach. This position was chosen since the chest muscles are relaxed hence not interfering with the measurements. The impedance tubes are hanged up in a support similar to a gyroscope, which makes it possible to angle the impedance tubes and achieve an angle perpendicular to the chest. The gyroscope setup was connected to a rod which was supported in middle. By placing a counter weight on the opposite side of the support, the pressure of the impedance tube could be adjusted by moving the counter weight (Figure 5).

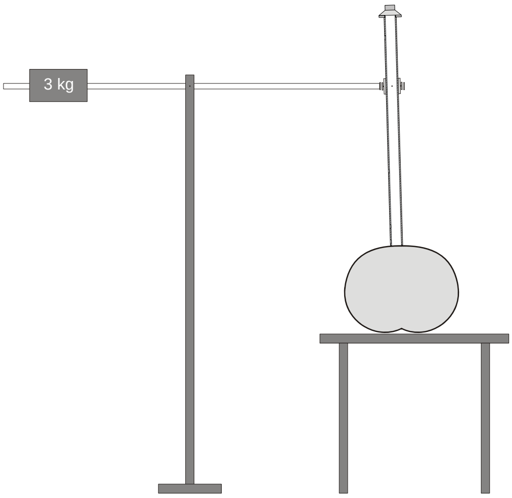

Figure 5 - Drawing of setup with counterweight for adjusting the pressure of the impedance tubes.

Before the measurements were carried out, a scale was used to define the positions of the counterweight in relation to the force or pressure of the impedance tube. When defining these positions of the counterweight the impedance tubes were in a vertical position. When the angle of the impedance tube is changed from vertical to an angle perpendicular to the chest, the pressure will also change slightly, however this small change is not considered to be significant and will not influence the measurements.

The maximum force or pressure is determined by the length of the rod between the support of the stand and the impedance tube, and the weight of the impedance tube. The lower weight limit could in theory be close to zero gram, however due to the torque required to move the weight of the system up and down (when the subject is breathing) and resistance in the joints, a pressure less than 50 gram, would not be sufficient and cause leakages when is breathing out and the chest is mowing down. This also yields a source of error, since the actual pressure applied to the chest will change significantly in relation to the static pressure. The error is reduced when the force applied to the chest is increased. However to minimize the error, the subjects were asked to stop breathing while the measurements were carried out.

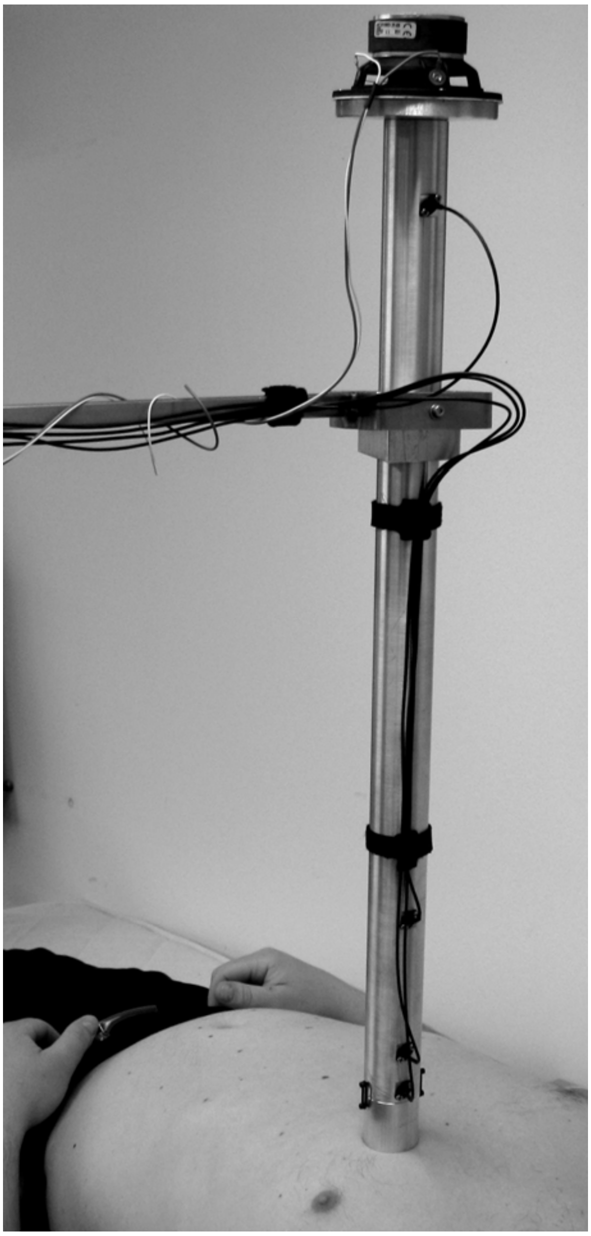

Figure 6 - Picture showing the setup when measurements of chest impedances are carried out.

The impedance tubes were positioned at the fourth intercostal, approximately three centimetres from the edge of sternum. This position is commonly used for auscultation of heart sounds.

Three subjects, all males, were participating in the test and before the measurements on each subject were conducted, the impedance tubes were checked by measuring the know impedance from a rigid termination of the tube.

Beside the measurement of the chest impedance, the subjects had also the impedance of the thigh measured, in order to have a reference, where less sound internally from the body were present, and at the same time measure on tissue, which to some degree is comparable to the tissue of the chest.

IMPEDANCES OF THE CHEST

The first part of the measurement, different pressures of the impedance tube is compared. In Figure 7 Figure 7- Chest impedance measured with large impedance tube.the impedances are shown for three different weights using the large impedance tube. At low frequencies up to 200 Hz, a high pressure is increasing the impedance of the skin, while at higher frequencies beyond 500 Hz, it magnitude has increased for at light pressure.

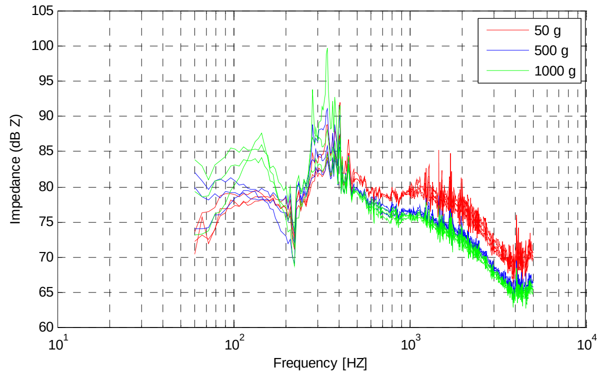

Figure 7- Chest impedance measured with large impedance tube.

The impedance measurement of the thigh on Figure 8 shows the similar pattern, though for one subject the impedance curve makes a jump at slightly above 1 kHz. This jump cannot be of biological origin.

The figures related to different pressure for the small impedance tube, is similar to the figure shown on Figure 7 and Figure 8, hence this figure has been left out.

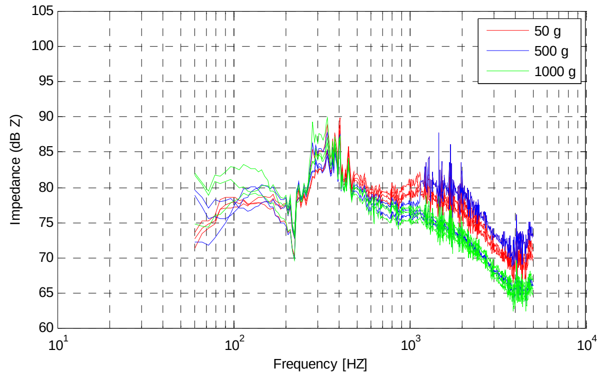

Figure 8 - Impedance measured on the thigh using the large impedance tube

Comparison between the small and the large impedance tube on Figure 9 show that for low and high frequencies the magnitude of the impedance is largest for the small tube.

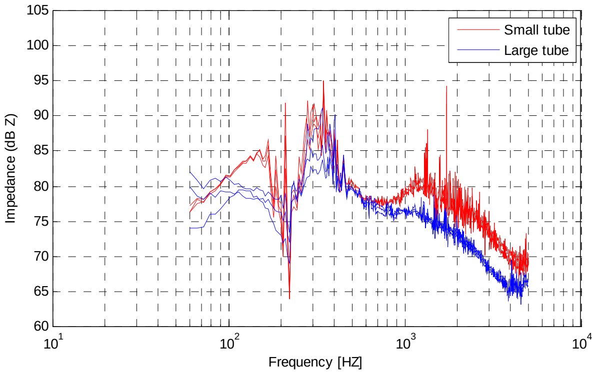

Figure 9 - Comparison between the large and small impedance tubes.

SUMMARY

In order to calibrate and verify that the impedance tubes are capable of measuring the impedance at a given surface, the impedances were measured for a rigid end termination and an open end termination. In both cases the measured impedances were according to the calculated impedances, and only for the open termination a small deviation was present. This deviation was caused by a rough approximation in the calculation of the reflection of an open pipe.

The measurements of the chest impedances on three subjects indicated a difference between the impedances when different diameters and different weights were used. Initial results are promising but more measurements will be needed before we can use the knowledge of the chest impedance to ensure optimal system performance when recording chest sounds.

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