การพัฒนาระบบท่ออิมพิแดนซ์สำหรับการศึกษาการดูดกลืนคลื่นเสียงตกกระทบแนวฉากของวัสดุ

Development of Impedance Tube System for Normal Incident Sound Absorption Measurement of Materials

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บทคัดย่อ

ระบบท่ออิมพิแดนซ์ตามมาตรฐาน ASTM-C384 ได้ถูกพัฒนาขึ้นเพื่อใช้ในการศึกษาการดูดกลืนคลื่นเสียงตกกระทบแนวฉากของวัสดุ ซึ่งประกอบไปด้วยไมโครโฟน ท่ออิมพิแดนซ์ เครื่องกำเนิดสัญญาณ ชุดขับเคลื่อนเชิงเส้นและเครื่องขยายสัญญาณแบบล็อกอิน โปรแกรม LabView และคอมพิวเตอร์ถูกนำมาใช้ในการควบคุมอัตโนมัติของระบบขับเคลื่อนไมโครโฟน การปรับเปลี่ยนความถี่และการเก็บข้อมูล ผลการทดลองการตอบสนองต่อความถี่เสียงของท่ออิมพิแดนซ์พบว่ามีความถี่กำทอนที่สอดคล้องกับทฤษฎีซึ่งสามารถใช้ในการหาค่าอัตราเร็วเสียงในอากาศเทียบเคียงกับทฤษฎีได้อย่างถูกต้อง ระบบท่ออิมพิแดนซ์ยังถูกใช้ในการวัดรูปแบบของคลื่นนิ่งที่เกิดในท่อ และใช้หาสัมประสิทธิ์การดูดกลืนคลื่นของวัสดุตัวอย่าง 4 ชนิดได้แก่ โฟมสังเคราะห์ แผ่นอะครีลิคทึบ แผ่นอะครีลิคมีลายทะลุเป็นรูปดาว และแผ่นไม้ปาล์ม การทดลองพบว่าสัมประสิทธิ์การดูดกลืนคลื่นเสียงของวัสดุทั้งสี่ชนิดในช่วงความถี่ 300-2000 เฮิรตซ์มีค่าแตกต่างกันแต่มีค่าเฉลี่ยคงที่ไม่ขึ้นกับความถี่ ในการทดลองยังพบว่าแผ่นอะครีลิคทึบจะมีสัมประสิทธิ์การดูดกลืนคลื่นเสียงต่ำกว่า 0.0025 ซึ่งต่ำสุดในชุดตัวอย่างทดสอบ ในทางกลับกันแผ่นไม้ปาล์มมีสัมประสิทธิ์การดูดกลืนคลื่นสูงสุดประมาณ 0.1 ซึ่งค่าที่วัดได้เหล่านี้สามารถเทียบเคียงได้กับค่ามาตรฐานที่ใช้กันในทางอุตสาหกรรม

คำสำคัญ: ระบบท่ออิมพิแดนซ์, ค่าสัมประสิทธิ์การดูดกลืนคลื่นเสียง

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Abstract

An impedance-tube apparatus was constructed complying with the requirement of ASTM-C384-04 for measuring normal incident sound absorption of materials. The system comprises of microphone, impedance tube, function generator, linear traveling stage and lock-in amplifier. Computerization with LabView software was developed to automate the microphone movement, frequency sweep and data acquisition. The frequency response of the tube was investigated for sound speed determination. The measurement and simulation of standing wave pattern were studied. The sound absorption coefficients as a function of frequency for synthetic foam, flat acrylic disc, 3-mm star-patterned acrylic and palm wood panelwereobtainedwithin 300-2000 Hz.They are approximately independent of the frequency. The flat acrylic disc possesses has minimum absorption coefficient of less than 0.025 while for the palm panel hasmaximum around 0.1. The sound absorptions of these can be approximated to be constant, comparable to common reflectors.

Keywords: Impedance tube, Sound absorption coefficient.

1. Introduction.

Nowadays, sound absorption materials are essential components for most industries, hospitals, conference hall and vehicles. They help reducing noise, e.g., those resulting within a room and those coming from external surroundings. Sound absorption materials are mostly porous and soft, such as foams (Subramonian, Remy & Schroer, 2004) and textiles (Lee & Joo, 2004). However, a variety of biomass materials such asTea-leaf-fiber (Ersoy & Küçük, 2009) and betung bamboo(Karlinasari, *et al*., 2011) are exploited. Generally, such materials are formed of panels or boards because of their light weight and easy to attached. In 2003, the composite boards of some materials (rice straw, fiber and plywood) were developed to study of acoustic absorption (Yang, Kim & Kim, 2003). When an incident sound wave travel to the material, the sound is absorbed or converted into heat by friction of moving air molecules in porous structure of materials.The absorption thus depends on its frequency and the material properties such as porosity, pore size and air-flow resistance etc. (Wang, 2007) There are two typical methods used to determine the sound absorption, reverberation room and impedance tube methods (Jaaniten, 2011). The reverberation room is mainly used to classify acoustic quantity for both architects and musicians by investigating the rising and falling time of the reverberant sound field in a room. This method is complex and expensive since it requires the materials which cover the surfaces of the room under analysis. The impedance tube (also called standing wave tube) or ASTM-C384-04 standard testing method (ASTM, 2004) is less complex than the reverberant room technique.It is easy to build with accurate measurement but it stilled high cost incommercial.In this research, we aim to develop the budget impedance tube complying the ASTM-C384-04 for measuring the sound absorption of panel type materials. In the testing,a measurement of position of the wave field as a function of sound frequency with reference to the surface of the specimen is required. The normal incident sound absorption(α)can be determined from the standing wave ratio (*SWR*) by

$$\alpha = 1 - \left|\frac{SWR-1}{SWR+1}\right|^2 \qquad (1)$$

2. The Development of an Impedance Tube

Constructions. The experimental setup is shown in figure 1. The impedance tube used in this work is constructed in accordance to the American Society for Testing and Materials(ASTM C384-04, 2004). It is made of one-meter polyvinylchloride tube, 100 mm inside diameter with a wall thickness of 5 mm. The testing frequency range is limited by the tube geometry. In this case, it is limited by 300-2000 Hz. The testing disk-shape samples of 113 mm diameter are tightly placed against 20-mm thick cylinder polished stainless steel, located opposite the loudspeaker side. The microphone, B&K Type 4961, is mounted onto one end of a thin metal hollow cylinder that is axially inserted through the impedance tube. The other end of the cylinder is connected to a 15-cm translational stage (LTS-150 Thorlabs) providing horizontal motion to the microphone with 1-mm resolution per step.

The loudspeaker is sinusoidally driven by an Agilent 33220A function generator at 2 $V_{p\text{-}p}$. Acoustic signals from the microphone in the tube are recorded by a computerized lock-in amplifier (SR830) allowing high signal-to-noise ratio measurement. The average microphone noise in the tube is measured to be in the microvolt level within the frequency range of the impedance tube while the measured acoustic signal is over 100 mV. Moreover, the acoustic signal from the microphone is also observed on an oscilloscope. LabView software is used to automate the microphone movement, frequency sweep, and data acquisition.

Initially, the microphone is positioned at the sample surface and then pulled away from the surface through the speaker by the translational stage.

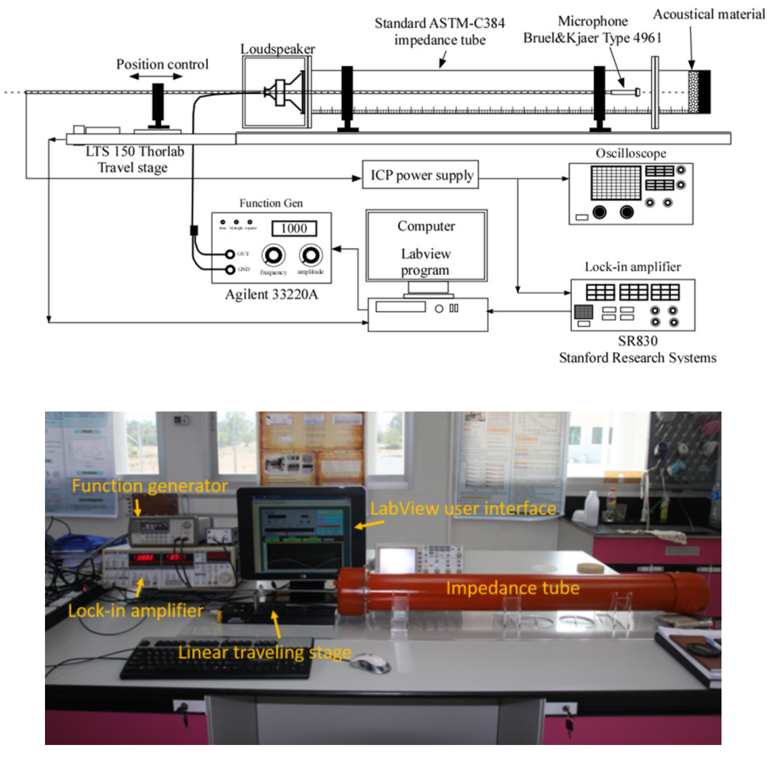
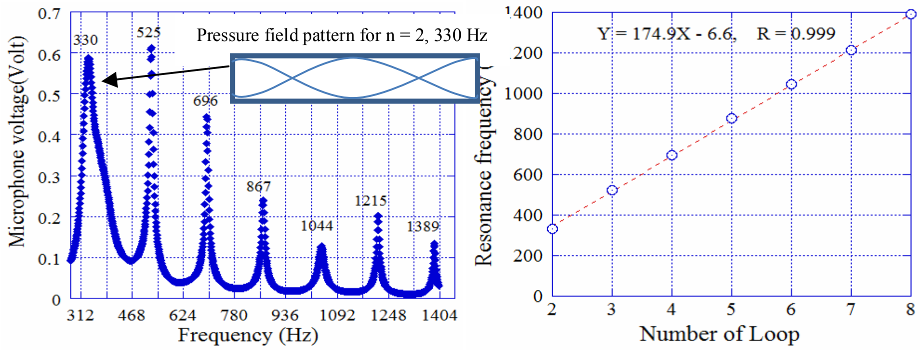


Figure 1. Experimental setup.

Characterizations. The frequency response of the tube is studied firstly. The sound frequency is applied ranging from 300-1400 Hz. The microphone voltage corresponded to the sound pressure is measured as a function of the frequency. The experiment shown that resonances met at 330, 525, ..., and 1358 Hz. Which resonances are corresponded to the nature properties of the closed end tube with $\frac{nc}{2L}$ field pattern. Then n = 2, 3, 4, ..., and 8,is the number of resonant loops, c is sound speed and L is length of the tube. The relation of the resonance frequencies with respect to n is illustrated in figure 2b). From this graph, the sound speed can be found that is 350 m/ssatisfied to the theoretical value. The standing wave patterns with only stainless steel backing plate are then measured at which resonances. An example for 865 Hz, shown in figure 3 is displayed the maxima and minima of 0.32 Volt and 0.0018 Volt, respectively. The *SWR* can be obtained for 177.7and the absorption coefficient is about 0.02.



a) b)

Figure 2. Tube characterizations, a) frequency response and b) plotting of resonance frequency with respect to the number of loop.

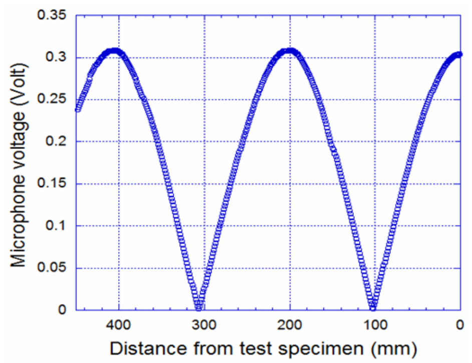
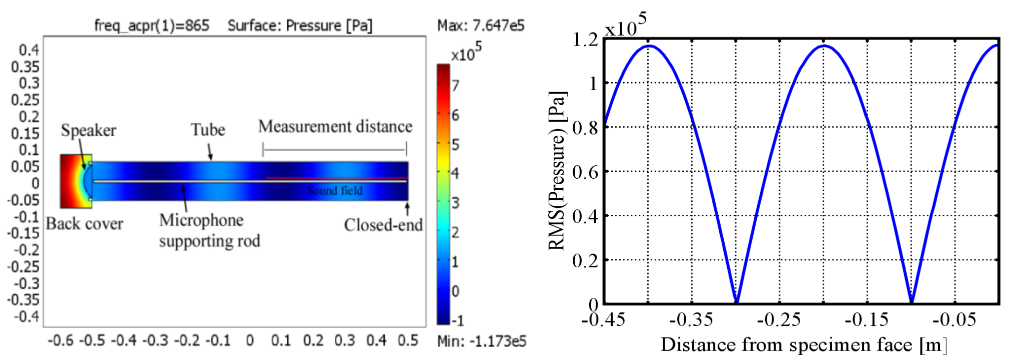


Figure 3. Standing wave pattern of empty tube with stainless steel backing plate for 865 Hz.



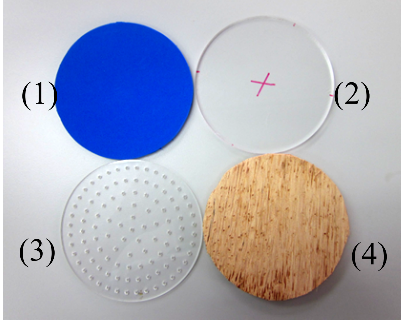
a) b)

Figure 4. Simulations,a) model configurations and b) simulated standing wave pattern for 865 Hz, 350 m/s.

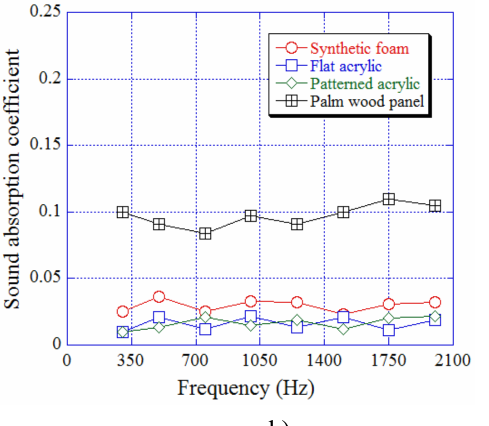
Moreover, the sound field in the tube is also studied by using Comsol Multiphysics 3.5a software from USA. The tube geometry is set to be identical with the experiment as shown in figure 4a). For 865 Hz and 350 m/s sound conditions, the root mean square of the sound pressure in the sound hard boundary wall is illustrated in figure 4a). The wave pressure as a function of the distance from the closed-end to 450 mm is pointed out, displayed in figure 4b). The calculations show good agreement with the measurement result.

3. Experiments

The absorption experiments are performed for four different samples, synthetic foam, flat acrylic disc, 3-mm star-patterned acrylic and palm wood panel. Configurations of these samples are shown in figure 5a). The tests are done within the frequency range. Fig. 5b) shows the absorption coefficients of these samples. They are approximately independent of the frequency since fluctuations are relatively small. The flat acrylic disc possesses absorption coefficient of less than 0.025. The 3-mm star-patterned acrylic has quite the same order of absorption compared to that of the flat disc. The absorption coefficient of the synthetic foam is around 0.035 while for the palm panel is around 0.1.



a)



b)

Figure 5. The testing of absorption, a) four type of samples: (1) synthetic foam, (2) flat acrylic, (3) 3-mm star-patterned acrylic,(3) palm wood panel and b) plotting of the absorption relating on applied frequency.

4. Conclusions

From the experimental results, the frequency response and sound speed in the tube are corresponded to the closed-end tube phenomena. The impedance tube apparatus constructed complying with the requirement of ASTM-C384-04 is validated by the simulation and is able to undergo normal incident sound absorption measurement. Within 300-2000 Hz, the sound absorptions of the smooth samples can be approximated to be constant, comparable to common reflectors (The Engineering Tool box, 2015). The absorption value for the acrylic disc is smallest, while that of the palm wood panel is highest.

5. Acknowledgements

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