（様式課程博士３）

学 位 論 文 の 要 旨

専　攻　名	環境工学	ふりがな 氏　名	なずり びん ちぇ でぃん NAZLI BIN CHE DIN　印
学位論文題目	Measurement method with a pressure-velocity sensor for measuring surface normal impedance of materials using ensemble averaging (アンサンブル平均と音圧 - 速度センサーを利用した材のノーマルインピーダンス測定法に関する研究)		

With the rapid progress of computer technology, numerical simulations based on wave equations such as finite element method (FEM) and boundary element method (BEM) have become powerful tools for conducting acoustical investigations and carrying out design processes. Although the boundary conditions of such simulations are generally modeled using surface impedance, insufficient impedance databases may have been supplied to date. What is problematic is that in many rooms and environmental acoustic problems within the lower frequency range, roughly less than 1000 Hz, wave-based considerations are required, whereas various *in-situ* impedance measurements frequently encounter difficulties because of the wave characteristics of the sound.

To overcome the situation, numerous *in-situ* measurement techniques have been proposed. Different aspects of methods taking into account e.g. type of sound incident, the concept of locally reacting, geometrical procedures and etc. to develop the great interest in being able to measure the absorption characteristics of material *in-situ*. Generally, most of these methods are based on the assumption of plane wave approximation. It can be concluded that most of the *in-situ* measurement techniques are still remain the problem: e.g (i) low frequency restriction, (ii) measurement of weakly absorbing materials, (iii) complicated equipment used *in-situ*, (iv) practicality of the relative positioning of a sound source, microphone and sample, etc.

From these reasons, Takahashi, Otsuru *et al.* proposed the method of surface normal impedance at random incidences using a two-microphone technique and ambient noise for obtaining absorption characteristics of porous materials at field incidence. Several measurements were conducted in various environments to measure the normal surface impedance of glass wool and rock wool. The results showed good repeatability and wide applicability. However, adequate consideration of the geometrical configuration was not given on the level of detail of a practical measurement.

Meanwhile, with the development of the particle-velocity sensor i.e. Microflown, alternative measurement techniques become possible for direct measurements of impedance and other related particle velocity quantities. The small pressure-velocity sensor (pu-sensor) enables measurement of the pressure and particle velocity practically at almost identical points only a few millimeters from the sample surface. The pu-sensor offers the development and refinement of the two-microphone technique to obtain the surface normal impedance at random incidence.

Further along with abovementioned, Chapter One is an introduction and purpose in this research project. Past and present literatures among the relevant studies are briefly reviewed and discussed related issues to be considered in dealing with the *in-situ* measurement. The discussion involves the capability of each technique, limitation of geometrical configuration, as well as the integration between theory and corresponding measurement.

（注）和文 2,000 字又は英文 800 語以内　　続紙　有■　無□

In Chapter Two, the pertinent concepts of ensemble averaged surface normal impedance and a basic technique to measure it using a pu-sensor are discussed. A series of simulations using the boundary element method (BEM) and corresponding measurements are conducted to examine the validity and superiority of the concept and technique to conventional ones such as a reflection method. Several simulations of glass wool both at normal and at random incidences demonstrated that the ensemble averaging decreases the interference effect cause mainly by the specimen's edges. In addition, consideration of isotropy and anisotropy of glass wool in the BEM simulation at random incidence are described. The expected value of surface normal impedance of the glass wool is remarkably improved with anisotropy consideration when comparing with those measurement results.

Chapter Three discusses the investigation if different geometrical configurations such as the sensor height and the sample size for measuring the acoustics behavior of absorptive material. A series of BEM simulations is conducted to examine the effects on the resulting absorption characteristics. Corresponding measurements are conducted to determine the validity of the proposed method. The resulting absorption characteristics both simulations and measurements demonstrate the accuracy and general utility of the proposed method for various application.

Chapter Four there are three parts to be discussed, first part is discussed the comparison between the two type of sensors to obtain the absorption characteristics of the materials. Then, the second part describe the plausibility of the proposed method in terms of sound absorption characteristics when comparing with the conventional method i.e. impedance tube method. Lastly, the trial application with selected materials with reliable specimen size was carried out to impress the ubiquitous examination of material's absorption characteristics at different sound fields such as in architectural spaces.

Chapter Five conclude the overall research project in this thesis. It then provides recommendation for the project improvement as well as for future research.

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学位論文審査結果の要旨

専　　攻	環境工学　専攻	氏　　名	Nazli Bin Che Din
論　文　題　目	Measurement method with a pressure-velocity sensor for measuring surface normal impedance of materials using ensemble averaging（アンサンブル平均と音圧-粒子速度センサーを利用した材のノーマルインピーダンス測定法に関する研究）		
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審査結果の要旨（1000 字以内）

本論文は、室内音響や騒音対策など建築環境の波動音響的な検討の際に不可欠な材のノーマルインピーダンスの新たな測定手法を提案したもので、以下の６章で構成される。

第１章では、本論文に関連する既往の諸研究の総括と研究の背景、目的、意義を述べた。

第２章では、まずアンサンブル平均を利用する新たな測定概念を定義し、基本的測定系を示した。続いて、境界要素法解析と検証実験の両面から、基本的測定系の再現性・安定性を検討した。それらの結果から、Allard らに代表される既往の手法に比べ、提案手法が材周辺や室内壁面等からの反射波・回折波の影響をより効率的に除去し、高い再現性のもとで分散の小さいノーマルインピーダンスの測定を可能とすることを明らかにした。なお、先行する Takahashi らの研究では２本の近接マイクロホン間の差分を用い粒子速度を近似していた。これに対し本研究では、近年 de Bree らにより実用化された音圧-粒子速度センサーを用いることで、理論モデルにより近似な測定系を実現している点が特徴的である。

第３章では、基本的測定系を応用する際に重要な測定系の幾何学的関係を検討した。検討の対象は、(1) 試料寸法、(2) 試料形状、(3) センサーと試料間距離、(4) 音源と試料間距離、(5) 音源から試料面への入射角、である。一連の境界要素解析と検証実験を実施した結果、0.5 m 以上の寸法の材について、かつ、センサー位置が試料上方 13 mm 以内であれば、ほぼ同一の吸音特性が得られることなどが知見として得られ、それらを整理して提案手法活用のための指針とした。

第４章では、高吸音から低吸音まで網羅する数種の材を対象に、提案手法で測定したノーマルインピーダンスを、ISO 1053-2、並びに、JIS A 1405 で規定され標準的とみなせる管内法による測定値と比較した。その結果、提案手法による測定値が再現性や安定性に優れ、測定値がその定義に従いランダム入射時のノーマル方向インピーダンスの時空的な平均値となっていることを確認した。

第５章では以上を総括し結論を述べ、今後の方向性を第６章に記した。

以上、本論文は新規性・有効性の観点から学術・技術的に有意義である。最終試験における質問に対する回答も的確で、学位論文として相応しいものと認められる。