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A correction method of tube attenuation in impedance-tube two-microphone-position method for absorption coefficient

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ABSTRACT

A correction method for the tube attenuation is given in ISO 10534 (Determination of sound absorption coefficient and impedance in impedance tubes). However, it can be noticed in experiments that this method yields a systematic error in the absorption coefficient. The error is as a sinusoidal function of frequency, whose magnitude is a few percent of the absorption coefficient and whose frequency period corresponds to the wave length of two times the distance between the test piece surface and the microphone location for the reflection factor measurement.

Investigation of the cause for this phenomenon was carried out based on the Kirchhoff acoustic dissipation theory of the viscous and thermal boundary layer for wide tubes. Consequently it was found that the ISO correction method regards only the irreversible component and disregards the reversible component of the tube attenuation.

A determination technique of the attenuation constant as a function of position is developed and implemented. The effectiveness of the position-dependent attenuation-constant in the two-microphone-position reflection-factor determination and in the tube-attenuation correction was evaluated by conducting BEM numerical simulations and experimental tests.

1 INTRODUCTION

The impedance tube method [1, 2] has been used widely for acoustic property measurements of materials. Especially the standing wave method (ISO 10534-Part 1, [1]) has been primarily used for the absorption coefficients. The absolute values of the reflection factors were primarily of concern and a few percent errors in the results were accepted. Recently the two-microphone-position transfer-function method for reflection-factor measurements (ISO 10534-Part 2, [2]) has become widespread instead. The surface impedances of test pieces become required. The phase measurement also becomes important and the requirement for the degrees of accuracy of measurements is becoming rigorous.

The objective of the study is to figure out the attenuation constant as a function of the tube longitudinal position and to improve the accuracy of the two-microphone-position method for reflection-factor measurements and of the tube-attenuation correction. The attenuation constant

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for a one-dimensional traveling wave has been assumed to be independent on the longitudinal position in the tube [3]. That may be acceptable when only a traveling wave in one direction presents in the tube. But can that be still acceptable when both incident and reflected waves present and make a standing wave field where the sound pressure and the particle velocity depend on the position.

In this study, first, the position dependence of the attenuation constant in connection with the tube-wall acoustic-dissipation of the viscous and thermal boundary layer is investigated theoretically. Secondly, a determination technique of the attenuation constant as a function of position is developed and implemented. Finally the effectiveness of the position-dependent attenuation-constant in the two-microphone-position reflection-factor determination methods and in the tube-attenuation correction methods was evaluated. The investigations were made primarily by conducting numerical simulations with a Boundary Element Method (BEM) code (implemented by our own [4]) and partially by conducting experimental tests.

2 EXPRESSION OF ONE-DIMENSIONAL WAVE IN A IMPEDANCE TUBE

Figure 1 shows the experimental test arrangement for the impedance tube method used in the investigation. Assuming one-dimensional wave field in the impedance tube, the sound pressure p_x and particle velocity u_x, the incident and reflected wave pressures p_x^- and p_x^+, and the incident and reflected wave velocities u_x^- and u_x^+, and reflection factor r_x at a position x are related as

$$p_x = p_x^- + p_x^+ ,\ u_x = u_x^+ - u_x^- \tag{1a,b}$$

$$p_x^{\pm} = p_0^{\pm} \exp[\mp j\phi_{0,x}] \tag{2}$$

$$u_x^{\pm} = p_x^{\pm} / \rho v_{\mathrm{ph}} ,\ r_x = p_x^+ / p_x^- \tag{3,4}$$

where ρ denotes the density of the air.

2.1 Expression by Position Dependant Attenuation Constant

When the attenuation constant α_{w} depends on the position (but is assumed to be independent on the traveling wave direction), $\phi_{0,x}$ in the above expression (2) may be represented as

$$\phi_{0,x} = \int_0^x k dx ,\ k = \omega / v_{\mathrm{ph}} - j\alpha_{\mathrm{w}} ,\ v_{\mathrm{ph}} = c - c^2\alpha_{\mathrm{w}} / \omega \tag{5a,b,c}$$

where c is the sound speed of the air in the tube of $\alpha_{\mathrm{w}} = 0$, and v_{ph} is the phase speed of the sound.

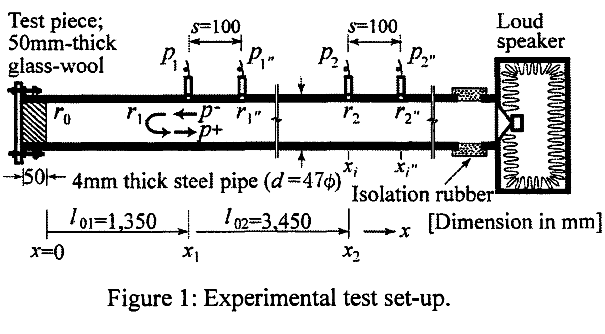


Figure 1: Experimental test set-up.

2.2 Expression for Position Independent Attenuation Constant

When the attenuation constant does not depend on the position, denoting the position independent attenuation constant as $\bar{\alpha}_{\mathrm{w}}$, $\phi_{0,x}$ in equation (2) may be written as

$$\phi_{0,x} = \bar{\phi}_{0,x} = \bar{k}x,\ \bar{k} = \omega / \bar{v}_{\mathrm{ph}} - j\bar{\alpha}_{\mathrm{w}},\ \bar{v}_{\mathrm{ph}} = c - c^2\bar{\alpha}_{\mathrm{w}} / \omega \tag{6a,b,c}$$

$$\bar{\alpha}_{\mathrm{w}} = \left[R_{\mathrm{v}} + R_{\mathrm{h}}\right] L_{\mathrm{P}} / (2\rho v_{\mathrm{ph}} S_{\mathrm{D}}) \tag{7a}$$

$$R_{\mathrm{v}} = \sqrt{\frac{\rho\omega\mu}{2}},\ R_{\mathrm{h}} = \frac{\gamma - 1}{\sqrt{\mu c_p / \kappa}} R_{\mathrm{v}} \tag{7b,c}$$

where S_{D} and L_{P} are respectively the cross sectional area and the perimeter length of the tube. ω is the angular frequency. μ, κ, c_p and γ are respectively the viscosity, the thermal conductivity, the specific-heat coefficient at constant pressure and the specific-heat ratio of the air.

Incidentally $\bar{\alpha}_{\mathrm{w}}^{\mathrm{ISO}}$ is given in ISO 10534 [1] for $\bar{\alpha}_{\mathrm{w}}$ of Eq. (7a) as

$$\bar{\alpha}_{\mathrm{w}}^{\mathrm{ISO}} = 1.94 \times 10^{-2} \sqrt{\omega / 2\pi} L_{\mathrm{P}} / (2cS_{\mathrm{D}}) \tag{8}$$

where the length should be taken in meter. After this $v_{\mathrm{ph}} = c$ will be used for simplicity.

3 ATTENUATION CONSTANT AND TUBE WALL DISSIPATION FACTOR

Figure 1 shows the experimental test arrangement for the impedance tube method used in the investigation. Denoting the sound power of the incident wave at a section x by P_x^-, and denoting the acoustical power dissipation and the dissipation factor of the tube wall between the test piece surface x_0 and the section x (the length l_{0x}) by P_{0x} and δ_{0x}, respectively, we have the following relationships

$$\delta_{0x} = P_{0x} / P_x^-,\ P_x^- = (S_D / \rho c) \mid p_x^- \mid^2 / 2 \tag{9a,b}$$

The acoustic admittance for the visco-thermal boundary layer β_{w} is given [5] by

$$\beta_{\mathrm{w}} = (1 + j)\left[\frac{R_{\mathrm{h}}}{c} - \frac{cR_{\mathrm{v}}}{\omega^2} \nabla_{\mathrm{T}}^2\right] \tag{10}$$

where ∇_{T}^2 denotes the Laplacian taken tangentially to the wall. Applying this expression, the sound intensity I_{w} outward normal to the wall at x can be derived as Eq. (11) and the unit-tube-length acoustic-dissipation factor δ_x is given by Eq. (12) .

$$I_{\mathrm{w},x} = I_{\mathrm{w},x}^{(\mathrm{h})} + I_{\mathrm{w},x}^{(\mathrm{v,irrev})} + I_{\mathrm{w},x}^{(\mathrm{v,rev})} \tag{11a}$$

$$I_{\mathrm{w},x}^{(\mathrm{h})} = \frac{R_{\mathrm{h}} |p_x|^2}{2\rho^2 c^2},\ I_{\mathrm{w},x}^{(\mathrm{v,irrev})} = \frac{R_{\mathrm{v}} \mid u_x \mid^2}{2},\ I_{\mathrm{w},x}^{(\mathrm{v,rev})} = \frac{-R_{\mathrm{v}}}{\rho\omega} \mathrm{Re}\left\{(1 - j)\frac{d}{dx}\frac{p_x^* u_x}{2}\right\} \tag{11b,c,d}$$

$$\delta_x = \frac{d\delta_{0x}}{dx} = \frac{d}{dx}\frac{P_{0x}}{P_x^-} = \frac{L_P I_{w,x}}{P_x^-} \tag{12}$$

On the other hand, denoting the net sound power towards the test piece from the sound source at section x and $x+dx$, respectively, as P_x and P_{x+dx}, the difference dP_{0x} can be reduced to Eq. (13) and we have a relationships as Eq. (14) .

$$dP_{0x} = P_{x+dx} - P_x = P_x^- \left\{(e^{2\alpha_w dx} - |r_x|^2 e^{-2\alpha_w dx}) - (1-|r_x|^2)\right\} = 2P_x^- \alpha_w dx(1+|r_x|^2) \tag{13}$$

$$\alpha_w = \delta_x / 2(1+|r_x|^2) \tag{14}$$

4 OBSERVATION METHODS OF REFLECTION FACTOR

Following two methods are used in this paper. The standing wave method (SWM) of ISO 10534-Part 1 [1] is not used here. The tube-attenuation correction is important there since SWM requires at least one wave length.

4.1 One Point Pressure and Velocity Method

We conduct numerical simulations by using a BEM. That gives directly the particle velocity u_i as well as the sound pressure p_i at an arbitral observation position x_i. Denoting the reflection factor for this by $r_i^{(\mathrm{1Pos})}$, we have the relationships as

$$r_i^{(\mathrm{1Pos})} = (p_i + \rho c u_i)/(p_i - \rho c u_i) . \tag{15}$$

4.2 Two Point Pressure Method (Two-Microphone Position Method, Transfer Function Method)

The two-microphone position method observes the transfer function between the pressure p_i at an observation point x_i and the pressure $p_{i''}$ at another observation point $x_{i''} = x_i + s$ as Eq. (16). Using the transfer function, the reflection factor by this method, $r_i^{(\alpha_w^{(s)}=\alpha_w)}$, can be determined by Eq. (17) .

$$H_{ii''} = p_{i''} / p_i \tag{16}$$

$$r_i^{(\alpha_w^{(s)}=\alpha_w)} = (e^{+j\phi_i^{(s)}} - H_{ii''})/(H_{ii''} - e^{-j\phi_i^{(s)}}) \tag{17}$$

where $r_i^{(\alpha_w^{(s)}=\alpha_w)}$ represents the reflection factor when $\alpha_w^{(s)} = \alpha_w$ is taken for the attenuation constant $\alpha_w^{(s)}$ for the tube of length s between the two-microphone positions, i.e.,

$$\phi_i^{(s)} = \int_{x_i}^{x_i+s} k dx = \int_{x_i}^{x_i+s} \left\{\frac{\omega}{v_{\mathrm{ph}}} - j\alpha_w\right\} dx \tag{18a}$$

On the other hand, $r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)}$ represents the reflection factor when $\alpha_w^{(s)} = \bar{\alpha}_w$ is employed, i.e.,

$$\phi_i^{(s)} = \bar{\phi}^{(s)} = \bar{k}s \tag{18b}$$

ISO 10534-Part 2 gives $\alpha_{\mathrm{w}}^{(\mathrm{s})}=0$ for the attenuation constant $\alpha_{\mathrm{w}}^{(\mathrm{s})}$, i.e.,

$$\phi_i^{(s)}=\bar{\phi}_{\mathrm{ISO}}^{(s)}=(\omega/c)s \tag{18c}$$

$r_i^{(\alpha_{\mathrm{w}}^{(s)}=0)}$ denotes the reflection factor determined by the two-microphone method with $\alpha_{\mathrm{w}}^{(\mathrm{s})}=0$.

5 CORRECTION METHODS FOR TUBE ATTENUATION

The reflection factor r_0 and the absorption coefficient α_0 at the test piece surface x_0 are , respectively, defined by

$$r_0=p_0^+/p_0^-,\ \alpha_0=1-|r_0|^2 \tag{19a,b}$$

For the tube of length l_{0i} between x_0 and x_i, as to the method of the tube-attenuation correction, r_0/r_i, from the reflection factor r_i at the observation position x_i to that r_0 at the test-piece surface x_0, following three attenuation-constant assumptions, (a) $\alpha_{\mathrm{w}}^{(0,i)}=\alpha_{\mathrm{w}}$, (b) $\alpha_{\mathrm{w}}^{(0,i)}=\bar{\alpha}_{\mathrm{w}}$, and (c) $\alpha_{\mathrm{w}}^{(0,i)}=\bar{\alpha}_{\mathrm{w}}^{\mathrm{ISO}}$, can be appropriate depending on the accuracy demand, i.e.,

$$r_0/r_i=\exp[2j\phi_{0i}]=\exp\int_0^{x_i}2j(\omega/v_{\mathrm{ph}})dx\cdot\exp\int_0^{x_i}2\alpha_{\mathrm{w}}dx \tag{20a}$$

$$r_0/r_i=\exp[2j\bar{\phi}_{0i}]=\exp(2j(\omega/\bar{v}_{\mathrm{ph}})l_{0i})\cdot\exp(2\bar{\alpha}_{\mathrm{w}}l_{0i}) \tag{20b}$$

$$r_0/r_i=\exp[2j\bar{\phi}_{0i}^{\mathrm{ISO}}]=\exp(2j(\omega/\bar{v}_{\mathrm{ph}}^{\mathrm{ISO}})l_{0i})\cdot\exp(2\bar{\alpha}_{\mathrm{w}}^{\mathrm{ISO}}l_{0i}) \tag{20c}$$

6 DETERMINATION METHOD FOR POSITION DEPENDENT ATTENUATION CONSTANT

The position-dependant attenuation-constant α_{w} along the tube section between the microphone positions x_i and $x_{i''}$ (of distance s) and/or that along the tube section between the microphone position x_i and test piece surface position x_0 (of distance l_{0i}) must be known to carry out the Eq. (18a) and/or Eq. (20a). The determination method devised here for α_{w} along the tube section between x_i and $x_{i'}$(of distance $l_{ii'}$), with known sound pressure p_i and reflection factor r_i at an observation position x_i, is as follows; Subdivide the tube section between x_i and $x_{i'}$ into N sections, denoting the small length for section n ($n=1,2,\cdots,N$) by l_n, we implement the integration by its approximation as $\int_{x_i}^{x_{i'}}\alpha_{\mathrm{w}}dx=\sum_{n=1}^{N}\alpha_{\mathrm{w}}^{(n)}l_n$.

As to a section n (between $x_a^{(n)}$ and $x_b^{(n)}$), by using the pressure $p_a^{(n)}=p_b^{(n-1)}$ and reflection factor $r_a^{(n)}=r_b^{(n-1)}$ at the interface of the test piece side of the section $n-1$ and by using Eqs. (1), (2), (3) and (4) assuming appropriate $\alpha_{\mathrm{w}}^{(n)}$ first, we have the pressure and particle velocity distribution in the section n. Using these distribution and Eqs.(11) and (12), we obtain the wall acoustic dissipation factor δ_x. With δ_x and Eq. (14) we can improve the value of $\alpha_{\mathrm{w}}^{(n)}$. We have convergence in this manner for $\alpha_{\mathrm{w}}^{(n)}$, as well as the sound pressure $p_b^{(n)}$ and the reflection factor

$r_b^{(n)}$ at the interface of the test piece side of the section n. These $p_b^{(n)}$ and $r_b^{(n)}$ is to be used for the determination of the unknowns in the next section $n+1$.

Conducting above procedure for every $n=1,2,\cdots,N$ in turn from the sound pressure p_i and the reflection factor r_i at the observation position x_i, we can obtain $\alpha_{\mathrm{w}}^{(n)}$ and $r_b^{(n-1)}=r_a^{(n)}$ for all the sub-divided sections $n=1,2,\cdots,N$, and the reflection factor $r_{i'}$ at the test piece side position $x_{i'}$. For the subdivided section length, $l_n=1\mathrm{mm}$ and $l_n=10\mathrm{mm}$ were taken in the determination of $\alpha_{\mathrm{w}}^{(\mathrm{s})}$ and $\alpha_{\mathrm{w}}^{(0,i)}$, respectively, in the applied results given in the succeeding section

7 DISCRIPTION OF NUMERICAL SIMULATION BY A BEM

Numerical simulations by using a BEM with visco-thermal boundary layer processing routine (implemented by our own) were carried out to comprehend fundamental nature of the attenuation constant and reflection factor free from experimental error in a tube. To save computer complexity a two-dimensional model was employed for the circular tube. The height of rectangular duct (with unit width) of the equivalent diameter of 47mm is 24mm. Since in the two-dimensional simulation the resistances for the height side walls are disregarded, the results for the tube wall acoustic dissipations have been corrected by (1,000+24)/1,000.

For the boundary elements, quadratic elements were used and the sizes were mostly 1.6mm. Eq. (10) was applied to the boundary condition of the tube walls.

8 RESULTS OF NUMERICAL SIMULATIONS

Figure 2 shows the results of the numerical simulations when the termination is rigid, $s=100\mathrm{mm}$, $x_i=1,400\mathrm{mm}$ and the frequency is 210 Hz.

8.1 Tube Wall Acoustic Dissipation factor

Figure 2(a) shows the components of the tube-wall acoustic-dissipation factor per unit tube length, δ_x. The contribution of the reversible component $\delta_x^{(\mathrm{v,rev})}$ is important. Figure 2(b) shows the unit-tube-length acoustic-dissipation factor, δ_x, and the tube-wall acoustic-dissipation factor, δ_{0x}, of the pipe section l_{0x}. It should be noticed that δ_x has its maxima at the pressure antinodes.

8.2 Position Dependency of Attenuation Constant and Reflection Factor

Figure 2(c) and (d) show the results obtained by the determination method for position dependant attenuation constant mentioned in section 6.

The reflection factor r_x determined from that at observation position, r_i, to that at the test piece surface, r_0, shifts according to the reflection factor r_i. The accuracy of the reflection factor r_i directly governs the accuracy of r_x and r_0. The determination method for the reflection factor r_i is affected by the observation methods and the observation positions, and must be improved. A reflection-factor update-routine was implemented but has not obtained better results so far.

In contrast, the attenuation constant α_{w} is little affected by the reflection observation methods and the observation positions. The correlation between this α_{w} and δ_x of Figure 2(b) is excellent. This implies that Eq. (14) is effective to determine α_{w}.

8.3 Optimum Attenuation Constant for Two-Microphone-Position Reflection-Factor Observation

Figure 2(e) shows the difference of the reflection factors observed by the two-microphone position methods, $r_i^{(\alpha_w^{(s)}=\alpha_w)}$, $r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)}$ and $r_i^{(\alpha_w^{(s)}=0)}$. The observation positions were taken at every 100mm along the tube section from x_0 to $x_i = 1,400\text{mm}$. The error in the reflection factors, $r_i^{(\alpha_w^{(s)}=\alpha_w)}$, $r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)}$ and $r_i^{(\alpha_w^{(s)}=0)}$ are approximately within $\pm 0.7\%$, $\pm 0.5\%$ and $\pm 0.2\%$, respectively, in comparison with the exact value of the reflection factor $r_i^{(\text{Exact})}$. The error has its minima around the tube section at $\alpha_w = 0$, and then at frequencies $f_n^{\min} = c(2n-1)/(4l_{0i})$ for $n = 1, 2, \cdots$.

8.4 Optimum Attenuation Constants for Test-Piece Reflection-Factor Estimation

Figure 2(f) shows the test piece reflection factor estimation, r_0, from the two-microphone position reflection factors, $r_i^{(\alpha_w^{(s)}=\alpha_w)}$, $r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)}$ and $r_i^{(\alpha_w^{(s)}=0)}$, through the corrections for the pipe wall attenuations, $r_0 / r_i = \exp[2j\phi_{0i}]$, $r_0 / r_i = \exp[2j\bar{\phi}_{0i}]$ and $r_0 / r_i = \exp[2j\bar{\phi}_{0i}^{\text{ISO}}]$.

8.4.1 Correction for Tube Attenuation by Position-Dependent Attenuation Constant

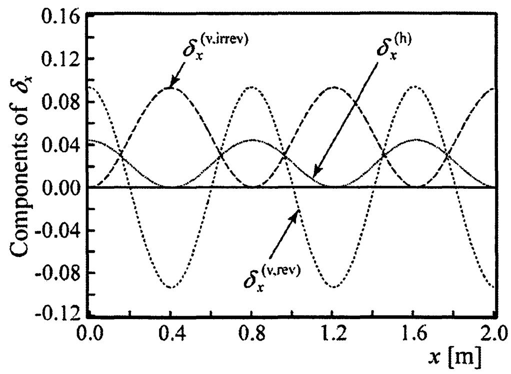
When the tube-attenuation correction by Eq. (20a), $r_0 / r_i = \exp[2j\phi_{0i}]$, is used, the accuracy of the test-piece reflection-factor estimation r_0, depends directly on the accuracy of the reflection-factor observation r_i. The accuracy of the one-position reflection-factor observation $r_i^{(\text{1Pos})}$, and then $r_x = r_{i=1.400}^{(\text{1Pos})} \exp[2j\phi_{0i}]$ and r_0 should be extremely high while the accuracy of the two-position reflection-factor observation $r_{i=1.400}^{(\alpha_w^{(s)}=\alpha_w)}$, and then $r_x = r_{i=1.400}^{(\alpha_w^{(s)}=\alpha_w)} \exp[2j\phi_{0i}]$ and r_0 are rather poor.

We have not accurate enough two-position reflection-factor observation method to utilize this correction of Eq. (20a), we rather recommend to use $r_0 = r_i^{(\alpha_w^{(s)}=0)} \exp[2j\phi_{0i}]$ for second best.

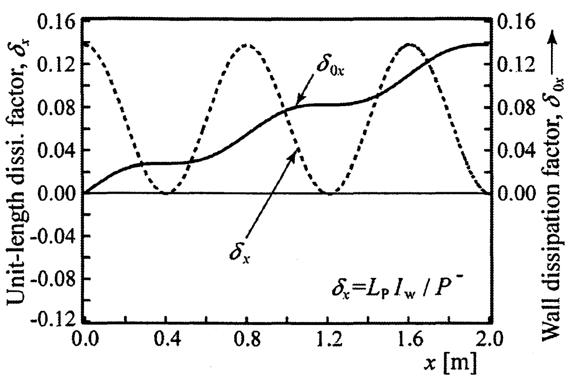
8.4.2 Correction for Tube Attenuation by Spatially Averaged Attenuation Constant

When the tube-attenuation correction by Eq. (20b), $r_0 / r_i = \exp[2j\bar{\phi}_{0i}]$, is used, the accuracy of the test-piece reflection-factor estimation r_0, seems to be excellent. This is because the reflection-factor at the observation position, $r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)}$, falls on the line of the correction $r_x = r_0 \exp[-2j\bar{\phi}_{0i}]$, even at observation position where $r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)}$ does not agree to its exact reflection factor, $r_i^{(\text{Exact})}$. If this is generally true, this correction method, i.e., $r_0 = r_i^{(\alpha_w^{(s)}=\bar{\alpha}_w)} \exp[2j\bar{\phi}_{0i}]$ may be most practical one. Farther investigation must be made to confirm this simulation results.

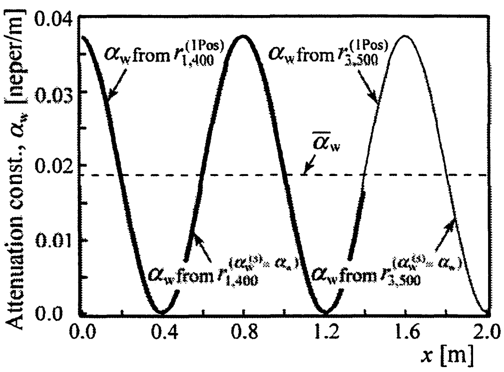
The accuracy of the reflection factor by the tube attenuation correction according to ISO 10534, $r_0 = r_i^{(\alpha_w^{(s)}=0)} \exp[2j\bar{\phi}_{0i}^{\text{ISO}}]$ can be poor when the microphone position were taken very far from the test piece surface and the circumstance differs from the standard conditions.



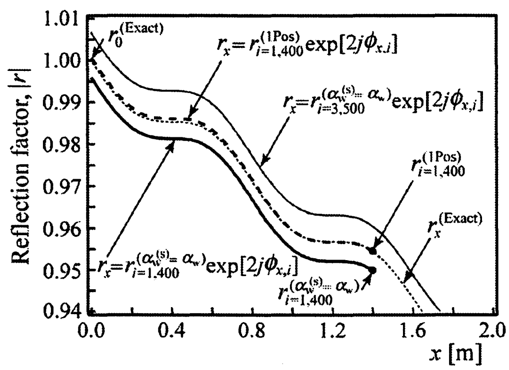
(a) Components of tube-wall acoustic-dissipation factor.



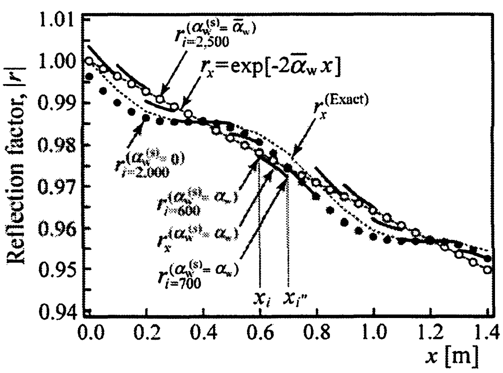
(b) Tube-wall acoustic-dissipation factor determined.



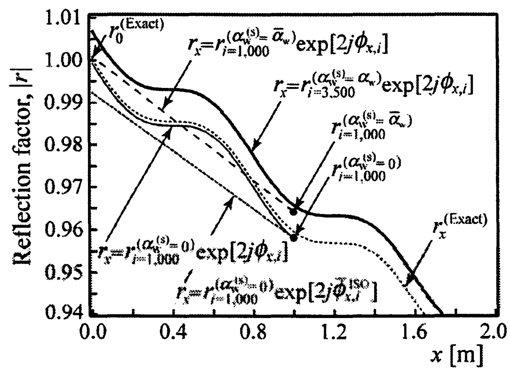
(c) Attenuation constants determined.



(d) Reflection factors determined.



(e) Reflection factors observed by 2Pos. methods.



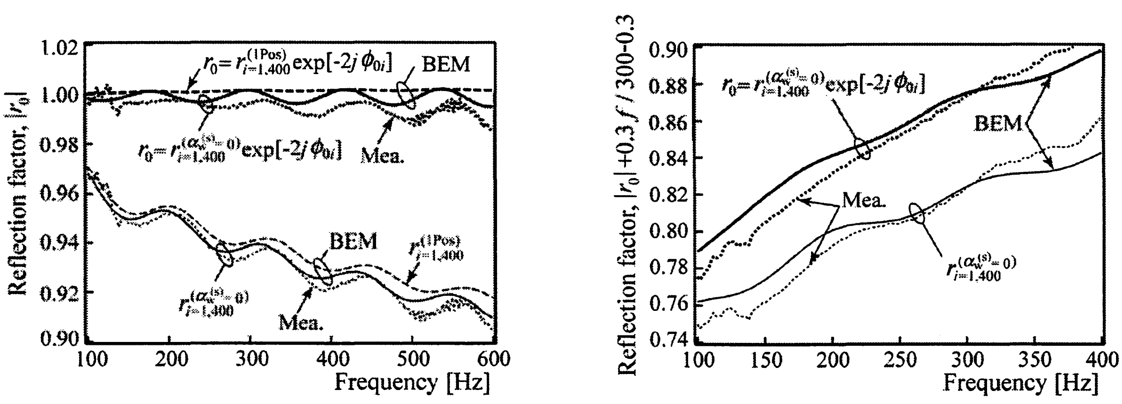
(f) Dependence of test-piece reflection factor on correction methods.

Figure 2: Results of numerical simulation for rigid end at 210Hz when $s = 100\mathrm{mm}$ and $x_i = 1,400\mathrm{mm}$.

9 CONFIRMATION OF NUMERICAL SIMULATIONS BY EXPERIMENTS

Figure 3 shows the comparison of the numerical simulations and experiments for test-piece acoustic-reflection factors. Figure 3(a) is for the rigid end. The test-piece reflection factor must be unity, $r_0^{(\text{Exact})} = 1$. At the observation position $x_i = 1{,}400\text{mm}$, the reflection factors by the BEM simulation and by the experiment agree excellent. That confirms the effectiveness of the numerical modeling and its implementations.

Figure 3(b) is for the test piece of a fiber-glass of 50mm thick lined directly to the rigid end. Delany and Bazley model was used for the simulation of the fiber-glass region. Although the agreement of the reflection factors by the BEM simulation and the experiment is poor, (caused by difference in the reflection factor at the test piece surface originated from insufficient modeling for the fiber-grass region), the periods of the peaks and dips of the reflection factors at the observation position agrees to the predicted one $f_{n+1}^{\min} - f_n^{\min} = c/(2l_{0i})$ caused by the uneven tube-wall attenuation.



(a) Rigid end.

(b) a 50mm-thick fiber-glass lined directly to the rigid end.

Figure 3: Comparison of numerical simulations and experiments for test-piece acoustic-reflection factors.

10 CONCLUSIONS

For the tube-attenuation correction and the two-microphone-position reflection-factor observation, the position dependence of the attenuation constant of the incident and reflected waves was investigated by numerical simulations and experiments. Findings are as follows:

(1) An expression between the unit-tube-length acoustic-dissipation factor and the traveling-wave attenuation-constant has been derived and confirmed.

(2) The unit-tube-length acoustic-dissipation and the traveling-wave attenuation-constant strongly depend on the longitudinal position of the tube. They have minima and maxima at pressure node and anti-node, respectively.

(3) For the traveling-wave attenuation-constant in the microphone-position reflection-factor observations, use of zero attenuation constant gives relatively accurate results.

(4) In the test-piece-surface reflection-factor observations, use of the spatially-averaged attenuation constant for both the microphone-position reflection-factor observations and the tube-attenuation corrections can be a practical method.

(5) An iterative determination method for the traveling-wave attenuation-constant and the reflection-factor from two-microphone-position pressures has been derived and implemented. Excellent results were obtained for the traveling-wave attenuation-constant determination. However for the reflection-factor determination the expected accuracy has not attained so far, and the computer codes for the determination process must be reviewed.

11 ACKNOWLEDGEMENTS

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