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ON SUBSTRUCTURE BOUNDARY ELEMENT TECHNIQUES TO ANALYZE ACOUSTIC PROPERTIES OF AIR-DUCT COMPONENTS

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INTRODUCTION

A direct BEM (boundary element method) has been employed combining with the substructure techniques to analyze duct acoustic fields which contain thin plates and porous materials. The results by this BEM have been compared with those by experimental, FEM (finite element method) and theoretical for silencers and duct open ends.

NUMERICAL METHOD

In this method, acoustic field are divided into subregions by introducing intersurfaces. A linear equation system is constructed by discretizing Helmholtz integral formula governing an individual subregion, employing plane quadrilateral constant boundary element and Gaussian quadrature formulae to perform numerical integrations over boundary elements including singular elements. A set of simultaneous equation is reconstructed, reduced and solved linking the subregions one after another.

![Diagram](image)

**Fig.1** 2D expansion chamber
APPLICATION TO ACOUSTIC FIELDS WITH THIN OBSTACLES

2D expansion chamber with thin plates

Silencers with inner projections have been studied. Typical substructurized BEM model and results are shown in fig.1. This BEM using constant boundary elements agrees well with FEM using quadratic quadrilateral elements. The discrepancy between these numerical and experimental in the higher frequency range is caused by incomplete hard wall construction in the experiment. The results implies that this substructurization enables to analyze acoustic field with thin obstacle for which singularity arises when direct BEM is used without subdivision.

3D open end of circular and rectangular duct

Reflection at open end with a finite projection from a wall to semi-infinite field has been studied. Typical results are shown in fig.2 to 4. The equivalent diameter of
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To calculate the free field Green's functions in the integral formula, effective sound velocity $c_e$ or wave number $k_e = \omega / c_e = \omega / c_{\text{ep}} - j \delta_e$ in the porous material [3] must be explicitly given. Where, $j = \sqrt{-1}$, $\omega$ denotes angular frequency, $c_{\text{ep}}$ phase velocity, and $\delta_e$ attenuation constant.

Furthermore, to satisfy the equation of continuity $q / q_e = - \rho / \rho_e$ at the intersurface between air and the material, effective density $\rho_e$ in the material must be known. Where, $q$ denotes pressure gradient in the outward normal to the surface. Symbols with and without subscript (e) indicate quantities for porous material and for air respectively.
Method to determine the properties

To determine \( c_e \) and \( \rho_e \), reflection factor \( r \) at the air adjacent to the material surface is measured employing the two microphon method as shown in fig.5. The following eq.(2) is employed for this method instead of normal impedance \( z_n \) by eq.(1) for conventional:

\[
\frac{\rho_e c_e}{\rho c} = \frac{z_n^*}{(1+\exp(-2jkeL))/(1+\exp(-2jkeL))}
\]

Supposing that a set of materials tested have the same properties, \( \rho_e c_e / \rho c \) has constant value independent of the length; accordingly measuring \( r \) or \( z_n \) for two test pieces with different length \( L \), one can determine \( ke \) or \( c_e \) and \( \rho_e \) solving eqs.(2).

The properties of the material used

The measured properties are shown in fig.6. All the test pieces were cut from a lump of porous polyurethane foam (26.9kg/m\(^3\)), nevertheless there is difference in the determined properties with the lot of the length pair because of difficulty of keeping uniformity in inserting test pieces.

Numerical results for a silencer with porous materials

The expansion chamber studied and the results are shown in fig.7. Using 2D BEM and the mean values \( c_{em} \), \( \delta_{em} \) and \( \rho_{em} \) except max. and min. at every frequency, the validity of this method by means of eqs.(2).

CONCLUSIONS

The effectiveness of the substructurized direct BEM employed has been confirmed by comparing with experimental, FEM and theoretical for duct open ends and for silencers with thin plates and porous materials.

REFERENCES