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ON THE ACTIVE CONTROL OF TRAFFIC INDUCED NOISE IN A VIADUCT USING PIEZOCERAMIC ACTUATORS

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1. Introduction

The traffic-induced noise, both high frequency as well as low frequency noise, is a serious environmental problem as it is found to cause socially as well as medically (stress, psychological effects, etc.) unwanted effects on the occupants of the nearby areas[1]. Therefore, the study of the phenomena and its control has become a matter of concern to many people these days.

Since only certain vibration modes of the structure which are well coupled with the radiated field or the acoustic modes contribute more to the radiation pressure, the acoustic pressure can be controlled by controlling only the coupled modes of the structure[2),3]. It should be noted that the structural modes contributing the most to the acoustic radiation may not necessarily be the dominant mode of vibration as perceived from the view point of vibration control of structure. In the case of vibration control of structure, only the first few modes are considered dominant and are controlled. The uncontrolled modes, generally higher modes, may not be dominant but they may contribute to the radiation of noise. Our control scheme is motivated by this fact and is described below.

2. Control Scheme/Strategy

Generally two major types of control schemes are applied for the control of the acoustic field – (*a*) Active Noise Cancellation (ANC) involving the active cancellation of the acoustic field by means of an "anti-noise" created by an exact mirror-image of the "disturbance", and (*b*) Active Structural-Acoustic Control (ASAC) which involves the use of shakers or piezoceramic patches to modify the vibration of the structure, thereby altering the way it radiates noise. While owing to the complexity of the sound transmission and the involvement of large area (volume) the first option is ineffective in the present case of the noise induced by traffic in a viaduct; the second alternative is also not effective in this case of sound radiated from a massive structure like bridge girder since it will involve control of comparatively higher vibrational modes. Control of higher modes of massive structures is both technically as well as economically infeasible.

In this light, we propose to introduce a method of control by introducing a noise barrier with piezoceramic actuators[4] fitted on it, as shown in Fig. 1. The use of such flexible active noise barriers will be beneficial in that it would provide a mean to control or manipulate the radiated field or the acoustic modes by controlling or modifying the modes of such barriers which are well coupled with the acoustic field. In our formulation, both the structural degree of freedom and a velocity potential defined in the acoustic field are treated as the control variables. The velocity potential in the acoustic field is modified by applying control forces on the active noise barrier.

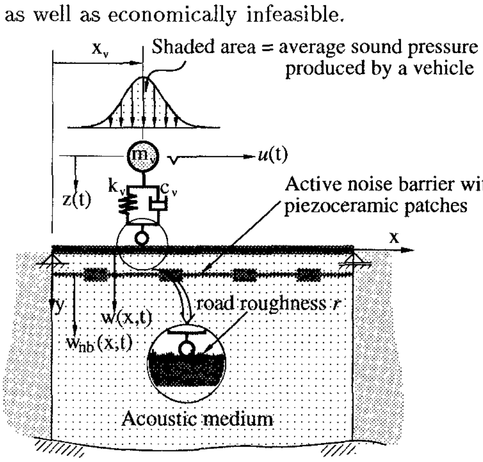

Fig. 1 Model and control scheme for the traffic induced noise in a viaduct.

3. Mathematical Formulation of the Problem

In order to take the advantage of the modern control theory (e.g. LQ control, pole-allocation or Sliding Mode Control, etc.) in the design of the active sound control system, a time domain state-space approach is adopted here. Assuming that both the pressure fluctuation in the acoustic field and the vibration of the girder is of small amplitudes, the equation of motion of the whole system, but without the active noise barrier, is first derived as

For Acoustic medium : $\phi_{tt} = c^2 \nabla^2 \phi$ ······ (1)

For Bridge : $\frac{\partial^2}{\partial x^2}\left[EI\frac{\partial^2 w}{\partial x^2}\right] + c_b\frac{\partial w}{\partial t} + \rho_b\frac{\partial w^2}{\partial t^2} = -\rho_f\phi_t[x, w(x,t), t] + P(t)\delta(x_v - x) + R(t)\delta(x_v - x)$ · (2)

For Vehicle : $m_v\ddot{z} = -k_v z + k_v w - c_v\dot{z} + c_v\dot{w} + (c_v\dot{r} + k_v r)$ ······ (3)

where $P(t) = m_v g + c_v(\dot{z} - \dot{w} - \dot{r}) + k_v(z - w - r)$, $R(t)$ is the pressure caused by the noise created by a typical vehicle, ρ is the mass density of the respective media, c is the velocity of sound, ϕ is the velocity potential defined as, fluid velocity $v(x,y,t) = -\nabla\phi(x,y,t)$ and acoustic pressure $p(x,y,t) = \rho_f\phi_t(x,y,t)$ and δ is the Dirac–delta function. Subscripts b, v and f stand for beam, vehicle and acoustic medium, respectively, whereas the subscript t represents partial derivative with respect to time. Except for the interface between the girder and the fluid, all other boundaries are assumed to be of rigid type (i.e. $\nabla\phi\cdot\mathbf{n} = 0$, $\mathbf{n}$ is an outward normal). The boundary condition at the interface between bridge and the acoustic medium is expressed as $w_t = -\partial\phi(x,0,t)/\partial y$.

Equations (1) and (2) represent an infinite dimensional system. For any approximation test function ψ defined in the acoustic medium (Ω) and γ defined in the girder (Γ), a variational or weak form for the structure–fluid system is derived as

$$\int_\Omega \frac{\rho_f}{c^2}\phi_{tt}\psi d\Omega + \int_\Gamma \rho_b w_{tt}\gamma d\Gamma = k_v\gamma(x_v)z - \int_\Omega \rho_f\nabla\phi\cdot\nabla\psi d\Omega - k_v\gamma(x_v)w - \int_\Gamma \frac{\partial^2\gamma}{\partial x^2}\left(EI\frac{\partial^2 w}{\partial x^2}\right)d\Gamma$$
$$+c_v\gamma(x_v)\dot{z} - \int_\Gamma \rho_f\phi_t\gamma d\Gamma - c_v\gamma(x_v)\dot{w} - \int_\Gamma c_b w_t\gamma d\Gamma + \int_\Gamma \rho_f w_t\psi d\Gamma$$
$$+\int_\Gamma R(t)\delta(x_v - x)\gamma d\Gamma + m_v g\gamma(x_v) - c_v\dot{r}\gamma(x_v) - k_v r\gamma(x_v) \quad \cdots\cdots (4)$$

It is clear from Eqs. (3) and (4), depending upon the choice of the approximation function either modal analysis or Galerkin's method or Finite Element method can be applied to approximate the infinite dimensional problem into a finite dimensional one. Choosing $\mathbf{z} = \{z, w, \phi, \dot{z}, \dot{w}, \dot{\phi}\}$ as state–variables, Eqs. (3) and (4) can be cast in the following state–space form.

$\dot{\mathbf{z}} = \mathbf{Az} + \mathbf{Ef}$ ······ (5)

where $\mathbf{A}, \mathbf{E}$ and $\mathbf{f}$ are obtained from Eqs. (3) and (4).

For the controlled case, a system of equations for the controller with piezoceramic actuators is derived parallel to the equations derived above. In this case the forcing terms $R(t)$ and $P(t)$ are replaced by a single term representing the sound pressure at the level of the noise barrier. However, an extra term representing the action of the piezoceramic patches are introduced in the equation of motion for the noise barrier which is also modelled as a beam. The control action of the piezoceramic actuators are derived to be[4)]

$$\frac{\partial^2}{\partial x^2}\left(EI\frac{K^B d_{31}}{\mathcal{T}}\sum_{i=1}^{s} u_i\left[H(x-\alpha_{i1}) - H(x-\alpha_{i2})\right]\right), \quad \cdots\cdots (6)$$

where d_{31} is the piezoelectric strain constant, $\mathcal{T}$ is the thickness of the piezoceramic patch, u_i is the voltage applied to the ith patch, K^B is a constant which depends on the geometry and material of the piezoceramic patch, s is the total number of patches, α_{i1} and α_{i2} represent the location of the two ends of the patch measured along the x–axis, and H is the Heaviside function.

This additional term consequently results in an additional term in the right hand side of Eq. (4). Therefore, the final equation of motion in the state–space form for the controlled case is derived in the form of $\dot{\mathbf{z}} = \mathbf{Az} + \mathbf{Bu} + \mathbf{Ef}$. The elements of $\mathbf{A}, \mathbf{E}$ and $\mathbf{f}$ in this case are different than in Eq. (5) as the state variables are now given by $\mathbf{z} = \{w_{nb}, \phi, \dot{w}_{nb}, \dot{\phi}\}$, where the subscript nb stands for noise barrier.

The present research is going on and the final simulation results discussing the effeciveness of this control scheme will be presented in the presentation.

References

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