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Reduction of Sound Radiation by Using Force Radiation Modes: Effect of a Rigid Wall Near a Vibrating Object

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http://docs.lib.purdue.edu/herrick/69

Reduction of Sound Radiation by Using Force Radiation Modes: Effect of a Rigid Wall Near a Vibrating Object

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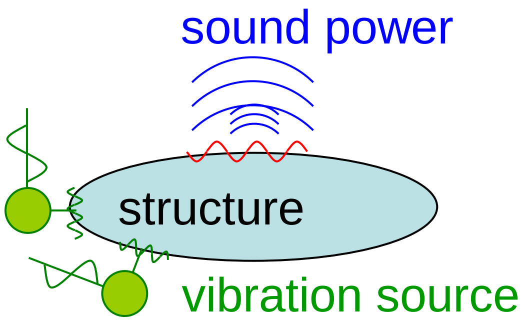
J. S. Bolton (Purdue Univ.)

8/22/2012

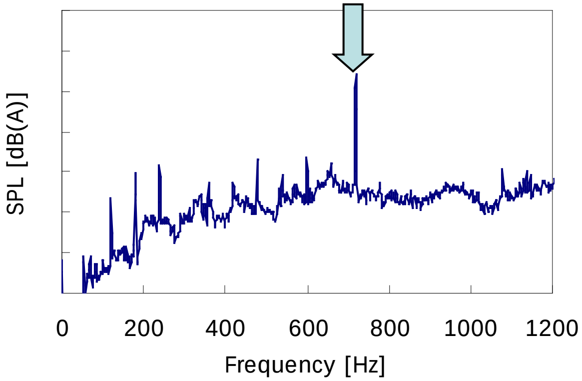
Introduction

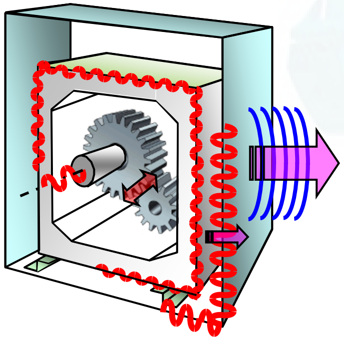
Structure-borne sound from machinery.



- Radiated acoustic power is affected by locations of vibration sources
  (i.e., driving force locations)

especially tonal noise





E.g. pulsation noise, gear or motor noise, etc.

Identify the vibration source locations which minimize the radiated sound

Introduction

To minimize the radiated sound...

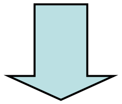
vibration modal analysis is often applied

However...

vibration reduction does not always reduce radiated sound

[1] Tanaka, et al, JSME,C，66(648)，106-112，1991
[2] Pan, J., et al, J. Acoust. Soc. Am., 91(4), 2056-2066, 1992

It is necessary to consider not only vibration but also radiated sound.



Radiation Modes

8/22/2012

Radiation Modes

- Developed in the field of ANC (1990s -)

[3] N. Tanaka, Y. Uchino, Transactions of the JSME, Series C，66(648)，106-112，2000.
[4] S. J. Elliot, et al., J. Acoust. Soc. Am, 94(4), 2194-2204, 1993.

- depend only on the structure’s geometry
- independent of structure’s surface vibration

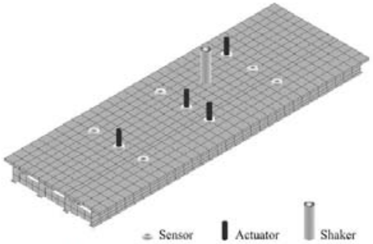


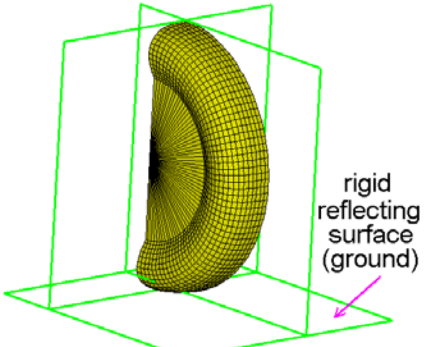
Fig. 8. Placement of sensors and actuators for feedback active control.

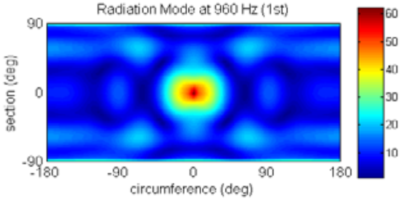
Powerful tool for interpreting sound radiation

- Application to practical subjects
  - low-frequency noise from a highway bridge
  - tire/road interaction noise

[5] T. Chanpheng, et al., Applied Acoustics, 65, 109-123, 2004.
[6] K. Yum, J. S. Bolton, Noise-Con 2004.

etc.

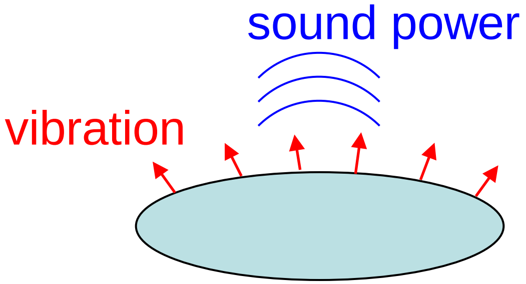




Objective

Radiation modes

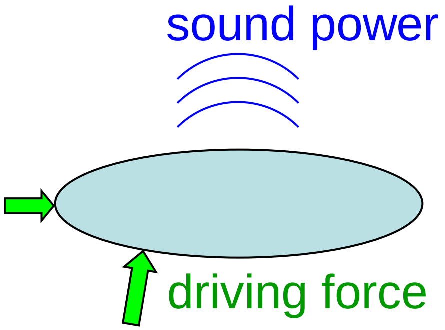
- $\color{red}{\text{vibration distribution}}$ and $\color{red}{\text{sound power}}$.



Previously

Extended radiation modes
(f_{rad}-mode: force radiation mode)

- driving force distribution and sound power



⇨ Verified the usefulness of the new modes

Often we cannot change the location of the vibration source

Objective of this study:

To study the modification of the f_{rad}-modes by purposely changing near-source geometry to reduce sound radiation

Radiation Modes

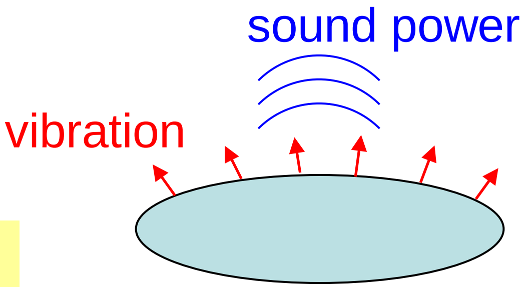
sound power

acoustic transfer vector

$$W = \frac{S}{2N}\mathrm{Re}\left\{ \mathbf{v}_e^{\mathrm{H}}\mathbf{p}_e \right\} = \frac{S}{2N}\mathrm{Re}\left\{ \mathbf{v}_e^{\mathrm{H}}\underline{\mathbf{Z}_e\mathbf{v}_e} \right\}$$

vibration velocities
of the structure

sound pressure on
the surface



$$= \mathbf{v}_e^{\mathrm{H}}\mathbf{R}\mathbf{v}_e$$

Radiation resistance matrix

eigenvalue/eigenvector decomposition

$$\mathbf{R} = \mathbf{Q}^{\mathrm{T}}\underline{\boldsymbol{\Lambda}}\,\underline{\mathbf{Q}}$$

Eigenvalue

Eigenvector

⇩

Radiation Modes

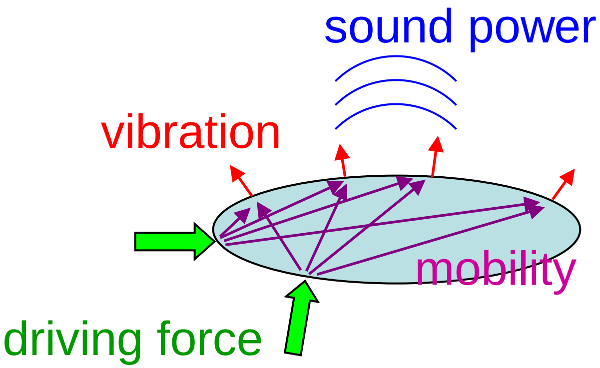
Force Radiation Modes (f_{rad}-mode)

vibration velocities on the boundary

$$\mathbf{v}_e = \underline{\mathbf{T}}\,\underline{\mathbf{f}_e}$$

Mobility of structure

Driving force



$$W = \boxed{\mathbf{v}_e^{\mathrm{H}}}\mathbf{R}\boxed{\mathbf{v}_e} = \boxed{\mathbf{f}_e^{\mathrm{H}}\mathbf{T}^{\mathrm{H}}}\mathbf{R}\boxed{\mathbf{T}\mathbf{f}_e} = \mathbf{f}_e^{\mathrm{H}}\boxed{\mathbf{C}}\mathbf{f}_e$$

eigenvalue/eigenvector decomposition

Eigenvalue

$$\mathbf{C} = \underline{\mathbf{M}}^{\mathrm{T}}\boxed{\mathbf{\Phi}}\underline{\mathbf{M}}$$

Eigenvector

Force Radiation Modes (f_{rad}-mode)

$$\mathbf{C} = \mathbf{M}^{\mathrm{T}} \mathbf{\Phi} \mathbf{M}$$

Eigenvalue

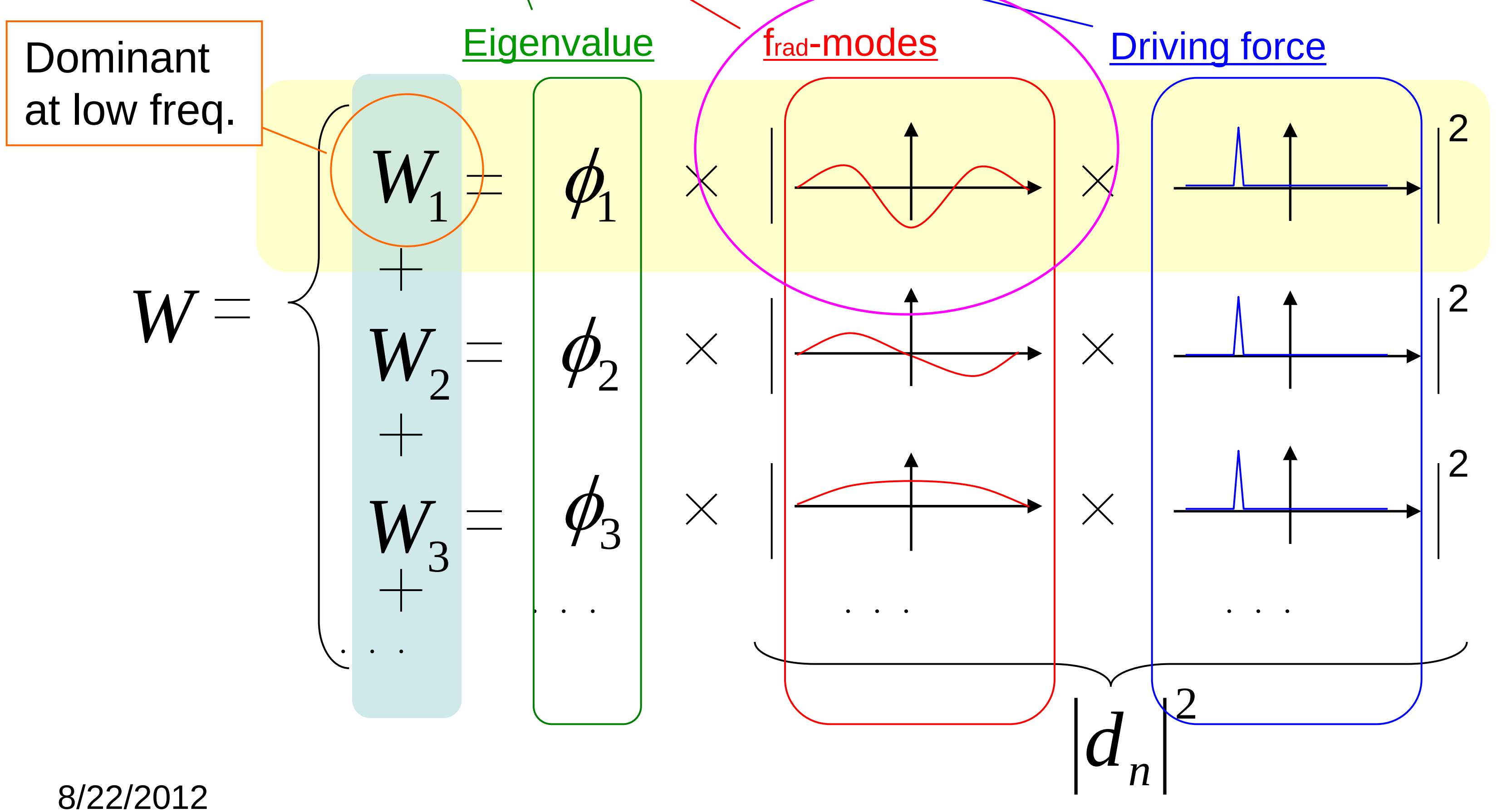
Eigenvector: Force Radiation Mode

$$\mathbf{\Phi} = \begin{bmatrix} \phi_1 \; \text{1st} & & & 0 \\ & \phi_2 \; \text{2nd} & & \\ & & \ddots & \\ 0 & & & \phi_n \end{bmatrix}$$

$$\mathbf{M} = \begin{array}{cl} \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1n} \\ m_{21} & m_{22} & & \vdots \\ \vdots & & \ddots & \\ m_{n1} & \cdots & & m_{nn} \end{bmatrix} & \begin{array}{l} \text{1st} \\ \text{2nd} \\ \\ \\ \end{array} \end{array}$$

Force Radiation Modes (f_{rad}-mode)

$$W = \mathbf{f}_e^{\mathrm{H}} \mathbf{M}^{\mathrm{T}} \boldsymbol{\Phi} \mathbf{M} \mathbf{f}_e = \mathbf{d}^{\mathrm{H}} \boldsymbol{\Phi} \mathbf{d} = \sum_{n=1}^{N} W_n = \sum_{n=1}^{N} \phi_n \left| d_n \right|^2$$



Dominant at low freq.

Eigenvalue

f_{rad}-modes

Driving force

KOBELCO

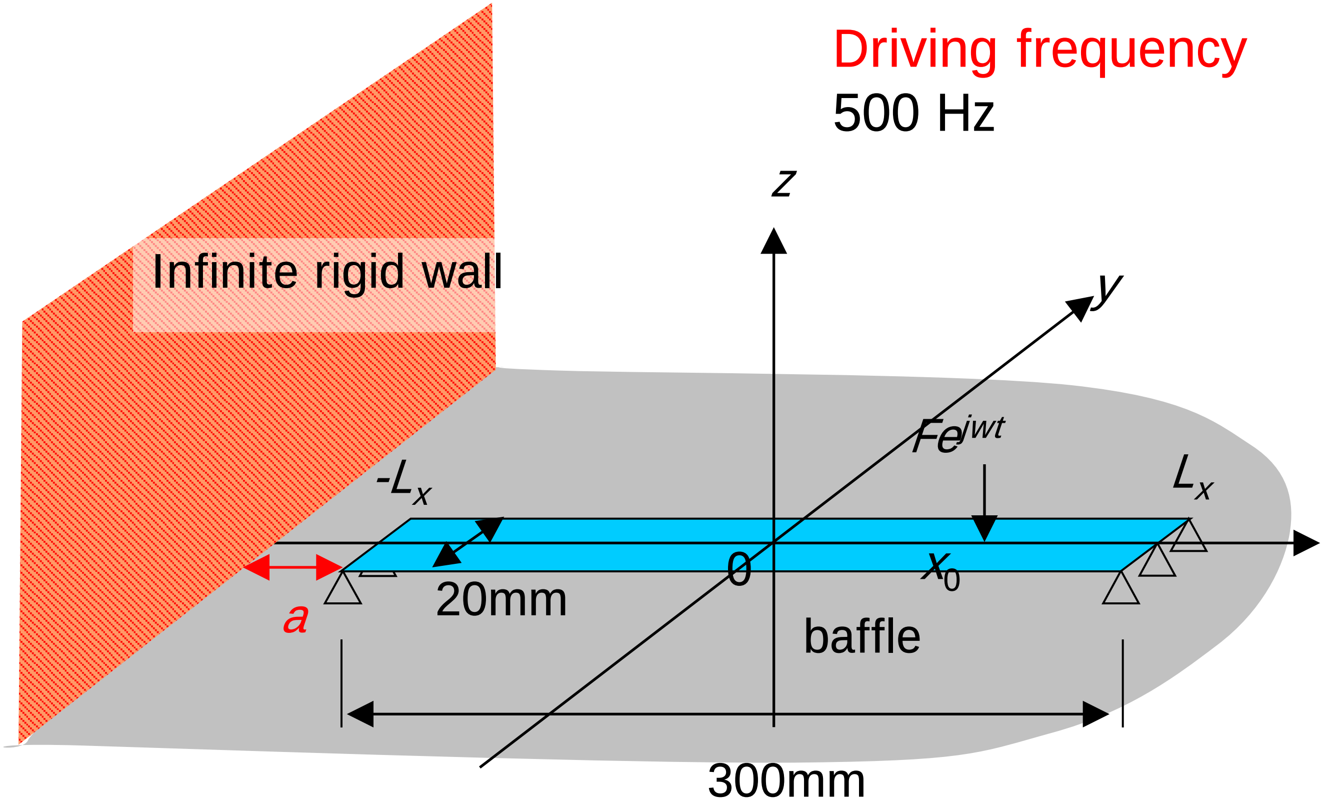
Calculation Model

Beam (steel)

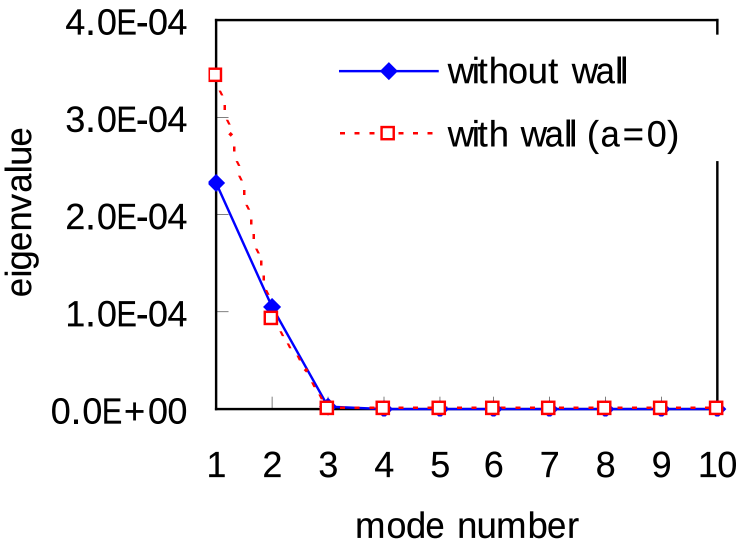
thickness: 1 mm, width: 20 mm,
length: 300 mm (= 2Lx)

Driving frequency

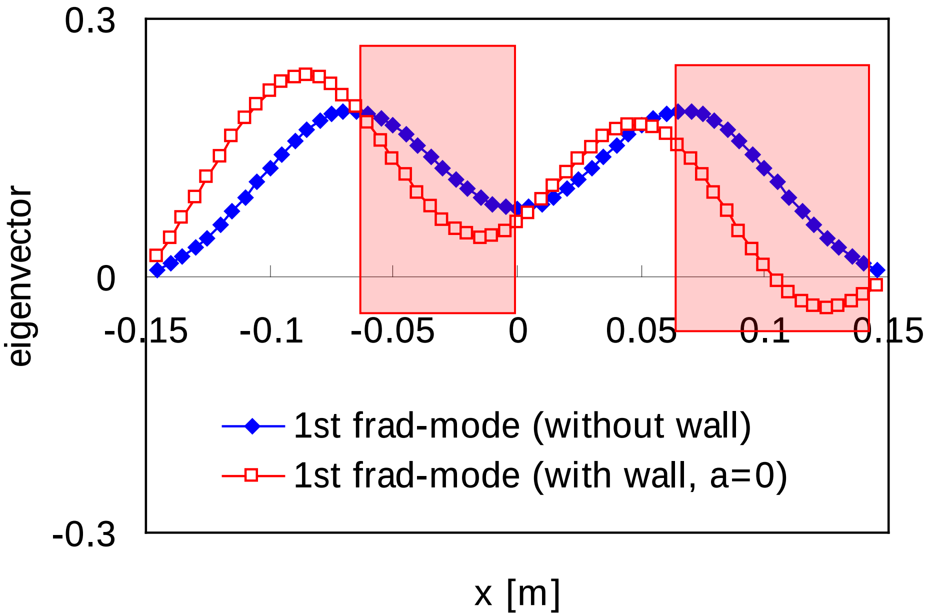
500 Hz



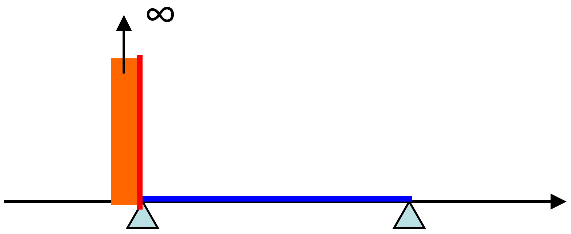
*f*rad-modes (500 Hz)



Eigenvalue



1^{st} frad-mode

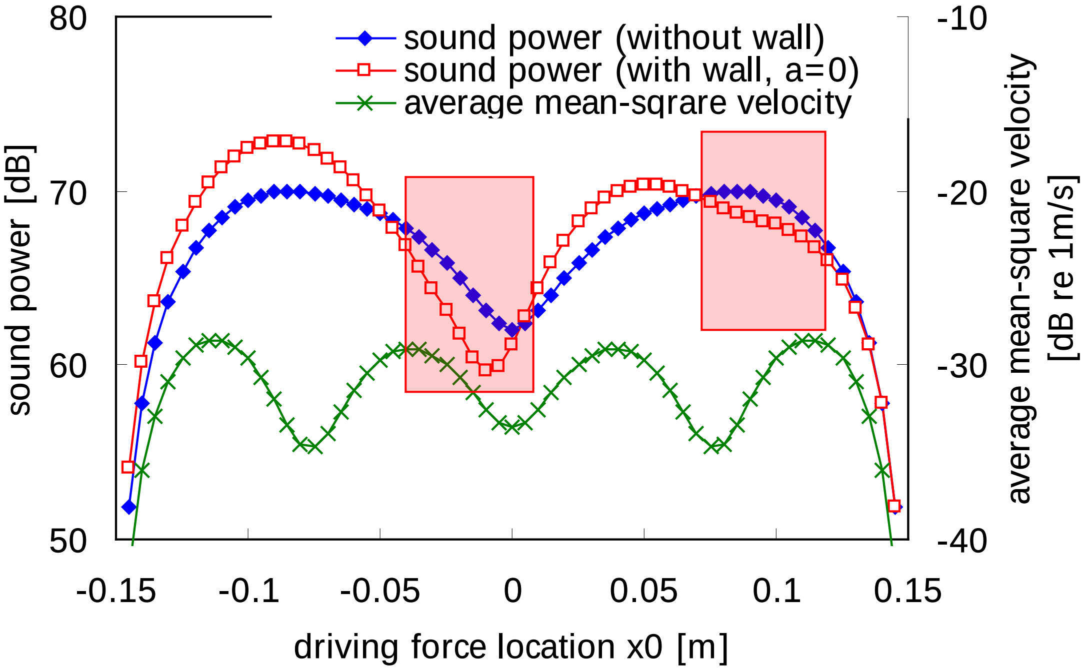


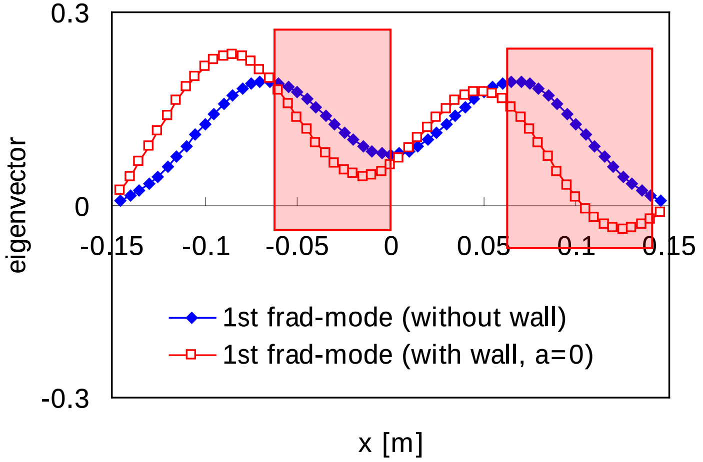
Sound power

$$W = \mathbf{f}_e^{\mathrm{H}} \mathbf{M}^{\mathrm{T}} \underbrace{\mathbf{\Phi}}_{\text{Eigenvalue}} \underbrace{\mathbf{M}}_{f\text{rad-modes}} \underbrace{\mathbf{f}_e}_{\text{Driving force}}$$

Generally, the value of the *f*rad-mode near the rigid wall becomes larger in magnitude than that at the farther end of the strip.

Sound power (500 Hz)

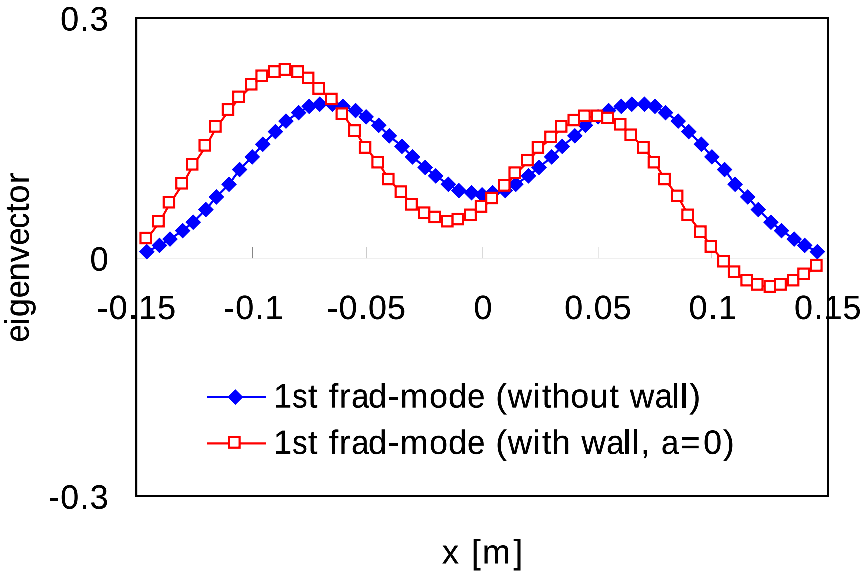




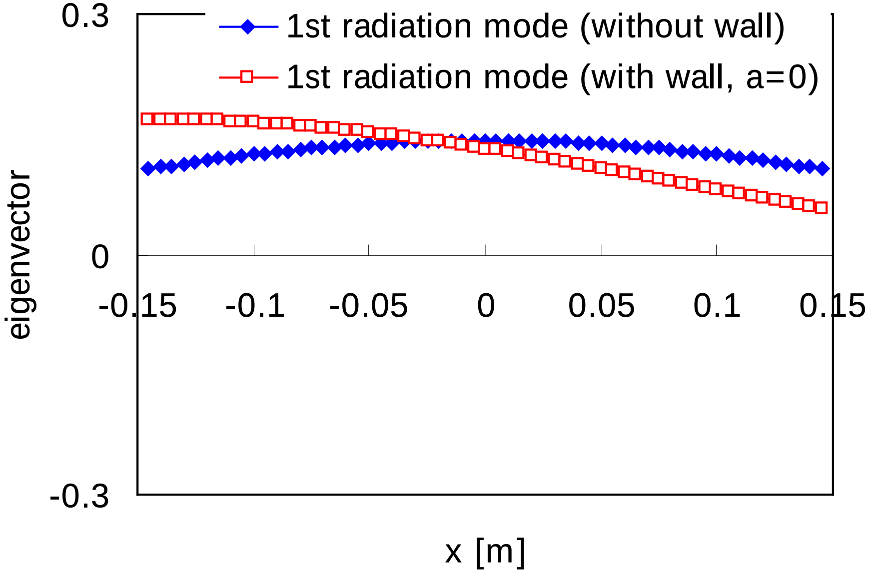
The relationship between the driving force location and the sound power is strongly influenced by the first *f*rad-mode.

In contrast, the vibration modes are not generally affected by the sound field

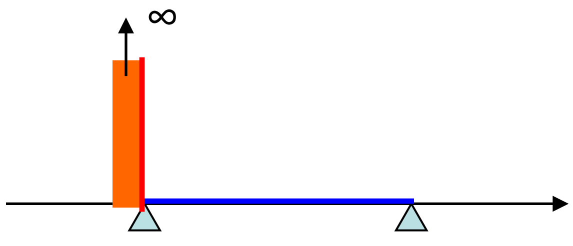
Radiation modes (500 Hz)



1st *f*rad-mode

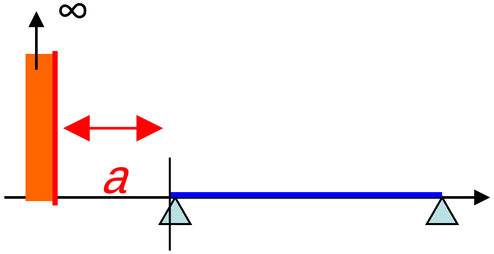


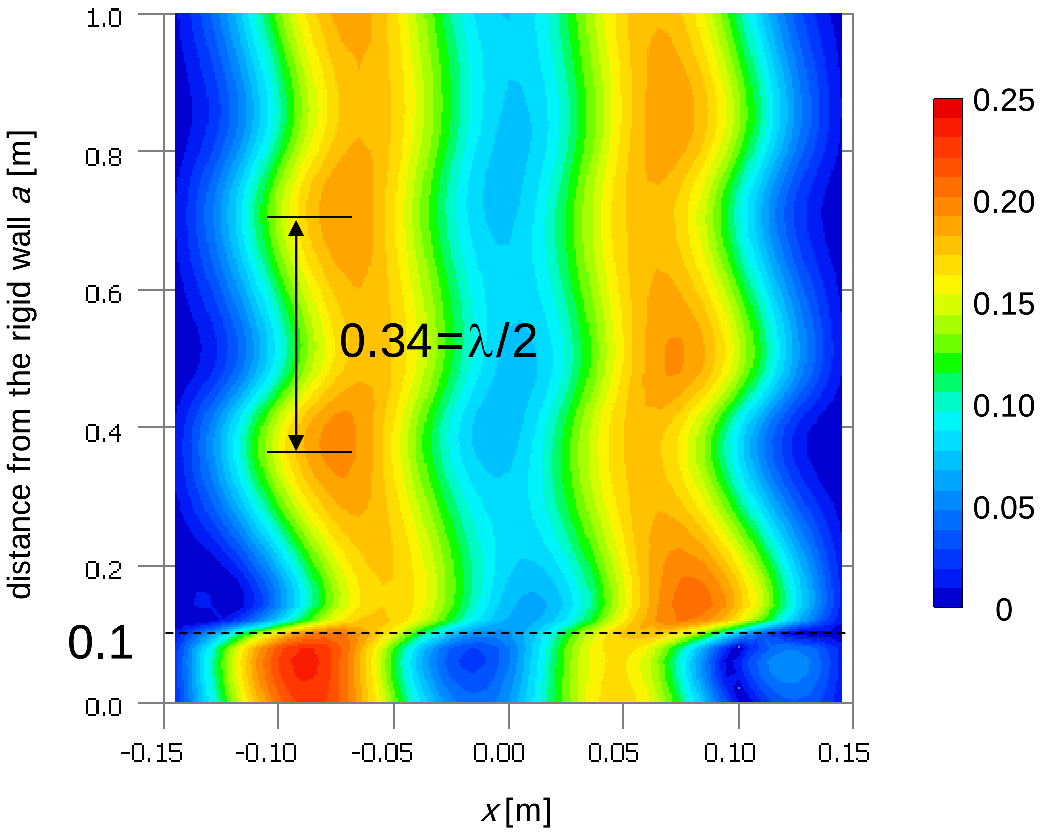
1st Radiation mode



the value of the radiation mode on the side of the strip near the wall becomes larger than that on the farther side of the strip

Effect of the wall position (500 Hz)





a = 0 m ~0.1 m, the mode shape is almost the same as when *a*=0

a > 0.1 m, the effect of the wall is relatively small but some effect was still observed in a half wavelength (0.34 m) cycle.

Conclusion

An infinite rigid wall was placed beside the vibrating object, in order to study the modification of the *f*rad-modes by purposely changing the near-source geometry.

・ The change of geometry alters the *f*rad-modes.

・ When an infinite rigid wall is placed right beside the vibrating object the value of the *f*rad-mode tends to increase near the wall.

・ When the wall is placed not too close to the vibrating object, the effect of the wall is relatively small, but some effect was still observed in a half wavelength cycle.

The vibration modes themselves are typically not affected by the change of the near-source geometry; the *f*rad-mode concept will be useful when applied to a real, complicated sound field.

Thank you.