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# WAVE PROPAGATION IN SWAGED PANELS

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## 1. INTRODUCTION

Stiffened panels are very frequently used for body structures of automobiles, aircrafts, submarines, etc., to suppress the vibration level. Considerable works have been focused to the analysis of the stiffening effect and the transmissibility of vibratory power through attached stiffeners; *e.g.* ribs, stringers [1]. However, few works have been done on swaged panels. The main difference between rib-like stiffeners and swages is that the latter does not change the total weight of structures. In this paper, the power transmissibility of swage is investigated, where the swage is modeled as an incomplete circular ring. The power transmission and reflection coefficients of swaged beam are estimated and compared with experimental results.

## 2. THEORY

### Transfer Matrix

**Swages.** For the analysis of vibrational characteristics of swages, the well-known transfer matrix method is utilized. The transfer matrix relates state variables, which represent the vibratory power at a point in a structure to those at adjacent ones [2]. For the geometric configuration in Fig.1, 6 variables are selected as state variables: $\mathbf{z} = [\, u\ w\ \psi\ M\ V\ N\,]^{\mathrm{T}}$. The first derivatives of those variables along the axis of angular span can be expressed by themselves from the equation of motion and constitutive relations as follows:

$$\frac{\partial \mathbf{z}}{\partial \phi} = \mathbf{A} \cdot \mathbf{z}\ . \qquad (1)$$

Here, $\mathbf{A}$ can be found in various previous articles: for example, see reference [3].

The solution of Eq. 1 gives the transfer matrix of swages as [2]

$$\mathbf{z}(\phi) = \exp(\mathbf{A}\phi)\cdot\mathbf{z}(0) \equiv \mathbf{T}_c\cdot\mathbf{z}(0)\ , \tag{2}$$

where $\mathbf{T}_c$ is the transfer matrix and $\phi_o$ the angular span.

**Point Transfer Matrix.** The junction between the swage and straight beam is assumed to be rigid. Thus, at this point, coordinate transformation by the amount of $\phi_o/2$ occurs only, and this can be expressed by matrix, $\mathbf{G}$. Finally, the whole transfer of state across the swage can be written as

$$\mathbf{z}^f_{tran} = \mathbf{G}\cdot\mathbf{T}_c\cdot\mathbf{G}\cdot\mathbf{z}^f_{inc} \equiv \mathbf{T}\cdot\mathbf{z}^f_{inc}\ . \tag{3}$$

**Transmissibility of Vibratory Power**

There are 6 types of waves and corresponding propagation constants, $\lambda$: 1 in-plane motion, 2 out-of plane motion, and their directional pairs. Consequently, there are 3 *admissible* wave types at each incident and transmitted region, according to the direction of propagation. Also, there are constitutive relations between those wave types, which we will call as *eigen vectors*, $\mathbf{c}_j$ for the $j$ th wave type. Using these, states of waves caused from the incident wave of unit amplitude, $\mathbf{c}_o\exp(\lambda_0 y)$, can be expressed as

$$\mathbf{z}^f_{inc} = \mathbf{c}_o e^{\lambda_o x} + \sum_{j=1}^{3} r_j \mathbf{c}_j e^{\lambda_j x}\ ,\quad \mathbf{z}^f_{tran} = \sum_{j=1}^{3} t_j \mathbf{c}_j e^{\lambda_j x}\ , \tag{4}$$

or, in matrix form,

$$\mathbf{z}^f_{tran} = \mathbf{P}_{tran}\cdot\mathbf{t} = \mathbf{T}\cdot\mathbf{z}^f_{inc} = \mathbf{T}\cdot\left[\mathbf{P}_o + \mathbf{P}_{inc}\cdot\mathbf{r}\right]\ , \tag{5}$$

where $\mathbf{t}$ and $\mathbf{r}$ are transmission and reflection coefficients, respectively. $\mathbf{P}_j$ is the eigen vectors corresponding to the admissible wave types at each region. Therefore, the transmission and reflection coefficients, $\mathbf{W}$ can be given by

$$\mathbf{W} = \mathbf{P}^{-1}\cdot\mathbf{T}\cdot\mathbf{P}_o \tag{6}$$

where $\mathbf{P} = \left[\mathbf{P}_{tran} \,\vdots\, -\mathbf{T}\cdot\mathbf{P}_{inc}\right]$ and $\mathbf{W} = \left\{\mathbf{t} \,\vdots\, \mathbf{r}\right\}$. From Eq. 6, the power transmission and reflection coefficients can be obtained by squaring each element of $\mathbf{W}$.

## 3. NUMERICAL CALCULATIONS

In case of bending wave incidence, resulting values are { $\tau_{BL}$ $\tau_{BB}$ $\tau_{BB}'$ $\rho_{BL}$ $\rho_{BB}$ $\rho_{BB}'$ }, where $\tau$ and $\rho$ mean power transmission and reflection coefficients, respectively, $B$ and $L$ represent 'bending' and 'longitudinal' waves, respectively, and $(\cdots)'$ means evanescent component. Figs. 2 and 3 show the power distribution calculated by Eq. 6, where $\Omega$ ( $= (\rho/E)^{1/2}R\omega$ ) is the frequency normalized by the *ring frequency* of swage. In Fig. 4, $\tau_{BB}$ has peaks at some frequencies which lie between natural frequencies of swage with free and fixed ends. From this fact, it can be said that they form the bounding frequencies of 'stop band' where the vibratory power can not be transmitted across the swage. In case of longitudinal wave incidence, swage can generate transverse displacement that is undesirable in the view point of noise and vibration.

## 4. EXPERIMENTAL RESULTS

An end of swaged beam is made to be immersed in a sand for anechoic termination and the wave decomposition technique [4] using two accelerometers is used in the measurement of $\tau$ and $\rho$ of two swaged beams of different angular span. In Fig. 6, good agreements between measured and predicted transmission coefficient can be observed.

## 5. CONCLUSIONS

There exist 'stop-' and 'pass band' for wave transmission across swages. This fact implies that undesired wave components can be effectively damped out by proper design of swage and this feature would be very useful in the control of noise and vibrations.

**References**
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[3] M. S. Issa, T. M. Wang, and B. T. Hsiao, J. Sound. Vib., 114(2), 297 (1987).
[4] A. F. Seybert and D. F. Ross, J. Acoust. Soc. Am., 61(5), 1362 (1977).

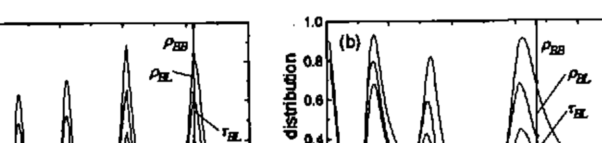


Fig. 1. Configuration of swaged beam of infinite extent.

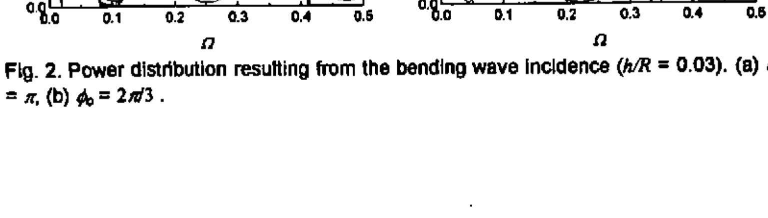


Fig. 2. Power distribution resulting from the bending wave incidence ($h/R$ = 0.03). (a) $\phi_o = \pi$, (b) $\phi_o = 2\pi/3$ .

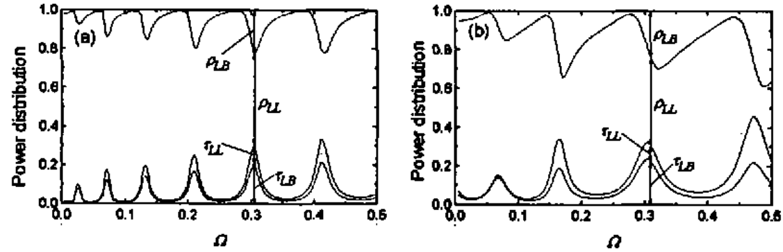


Fig. 3. Power distribution resulting from the longitudinal wave incidence ($h/R$ = 0.03). (a) $\phi_o = \pi$, (b) $\phi_o = 2\pi/3$ .

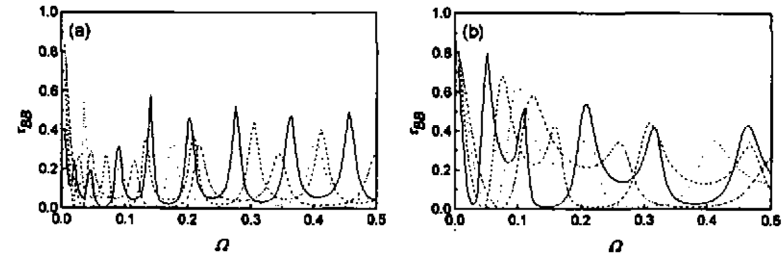


Fig. 4. Power transmission coefficients resulting from the bending wave incidence: ——, $h/R$=0.02; - - - - -, $h/R$=0.03; ······, $h/R$=0.04; —·—·—, $h/R$ =0.05. (a) $\phi_o = \pi$, (b) $\phi_o = 2\pi/3$ .

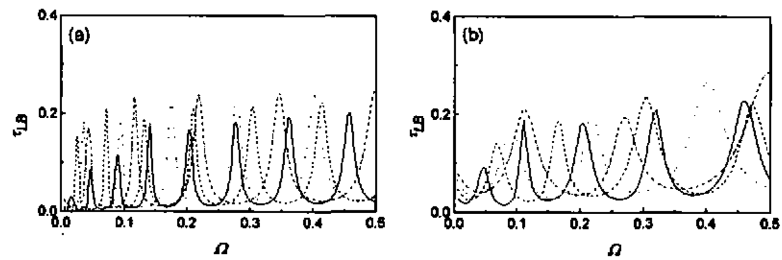


Fig. 5. Power transmission coefficients resulting from the longitudinal wave incidence: —— $h/R$=0.02; - - - - -, $h/R$=0.03; ······, $h/R$=0.04; —·—·—, $h/R$ =0.05. (a) $\phi_o = \pi$, (b) $\phi_o = 2\pi/3$.

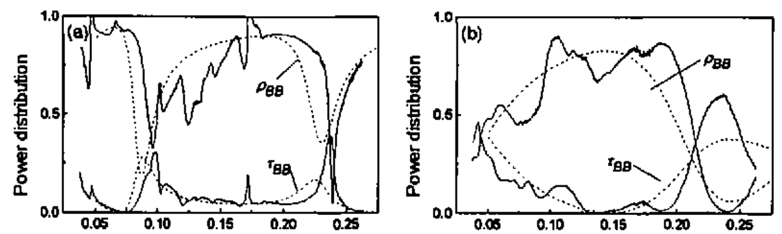


Fig. 6. Power transmission and reflection coefficients resulting from the bending wave incidence ($h$=0.003, $R$=0.0315): ——, experiment; - - - - -, prediction. (a) $\phi_o=\pi$, (b) $\phi_o=2\pi/3$.