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THE EFFECT OF FLANGED JOINTS ON NOISE AND VIBRATIONAL TRANSMISSION

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SUMMARY

Flanged bolted joints occur commonly on many types of machinery and engine structures, typically being used to attach oil sumps, water tanks and couple pipe, ductwork, etc. For the prediction of noise from such structures using Statistical Energy Analysis (SEA), it is necessary to determine the coupling loss factors through these junctions. This paper describes an investigation into the vibrational behaviour of plate structures coupled by flanged joints, including the effects of gasket materials. Formulae for calculating coupling loss factors through flanged joints with or without gaskets have been derived and information for minimising vibration transmission is presented.

1. INTRODUCTION

SEA[1] offers a very powerful method for calculating the distribution of vibrational energy in coupled structures. In recent years SEA has been successfully applied to many types of aerospace and other structures to analyse power flow, vibrational energy distribution and noise radiation. The coupling loss factor is an important SEA parameter for characterising the vibrational transmission between coupled systems. For simple plate-like or beam-like components coupled at points or along common edges, coupling loss factors can generally be obtained from theoretical relationships[1][2].

In a joint any gasket material may provide some vibration isolation. Corner connections with an elastic interlayer have been investigated by L. Cremer[3]. It was shown that for an elastic interlayer the softer the layer or the greater the thickness the greater the attenuation of vibration. However, for a thick elastic layer or for high frequency vibrations when the flexural wavelength is no longer large compared to the layer thickness, resonances occur and the damping of layer has a great effect on vibrational transmission.

In this investigation, the effect of a flanged joint on the coupling of two plates has been investigated, including the effects of gasket materials. Theoretical relationships have been developed using the wave propagation method, and formulae for calculating coupling loss factors through flange joints with or without gaskets derived.

Two sets of experiments have also been carried out using two plates, each 0.5 metre square; coupled by a flange. In one series of experiments the flange dimensions were changed and in the other different gasket materials were used. The input power method[4] was used to measure the coupling loss factor using three excitation positions on each plate. The experimental values were then compared with theoretical values calculated from the developed formulae and good agreement was found.

2. VIBRATION TRANSMISSION

Waves propagating within practical structures soon encounter locations where changes in material, dimensions or structural configuration occur. Each such discontinuity will cause some reflection and attenuate the energy of the propagating wave front. The following gives an analysis of the attenuating effects of a flange joint with a gasket on the vibrational transmission between two plates. The schematic configuration is shown in Figure 1.

Suppose plate 1 is excited by a harmonic force which generates a flexural wave. The wave is incident obliquely at the joint as shown in Figure 1(b), which causes reflected and near-field waves in plate 1. The flexural velocity can be expressed as:

$$v_1 = v_0 e^{i\omega t}[e^{-ik_1[(x+b_1)\cos\Phi_1+y\sin\Phi_1]} + re^{ik_1(x+b_1)\cos\Phi_1-y\sin\Phi_1)} + r_j e^{k_1((x+b_1)\cos\Phi_1-iy\sin\Phi_1)}] \quad (1)$$

where v_0, r and r_i are constant, k_1 is the flexural wave-number of plate 1. Φ_1 is the incident angle. In plate 2, there are both transmitted and near-field waves. The velocity in plate 2 is:

$$v_2 = v_0 e^{i\omega t}[te^{-ik_2((x-b-b_2)\cos\Phi_2+y\sin\Phi_2)} + t_i e^{-k_2((x-b-b_2)\cos\Phi_2+iy\sin\Phi_2)}] \quad (2)$$

where t and t_i are constants. The boundary conditions can be written as:

$$\dot\theta_1|_{x=b1} = \dot\theta_2|_{x=b+b2} = 0$$

$$F_1|_{x=b1} - F' = j\omega m_1 v_1|_{x=-b1}$$

$$F' - F_2|_{x=b+b2} = j\omega m_2 v_2|_{x=b+b2}$$

$$F' = K(v_1|_{x=-b1} - v_2|_{x=b+b2})/j\omega$$

where m_1 and m_2 are the masses of the flanges of plates 1 and 2 respectively, $K = \frac{GS}{b}$ is a spring constant, G is the shear modulus of gasket material, S is the area of gasket. Combining equations (1) - (3), we can obtain the average energy transmission coefficient of per unit length of flange joint[2], $\bar\tau$.

$$\bar\tau = \frac{\rho_2 h_2 c_2}{\rho_1 h_1 c_1}\frac{2}{\pi}\int_0^{\pi/2}\frac{4\alpha_3^2(1+\eta^2)\cos\Phi_2 d\Phi_1}{[\alpha_1(1-\eta)-2-\beta_1-\eta\alpha_2]^2 + [\alpha_1(1+\eta)-\beta_1-\beta_2+\alpha_2]^2} \quad (4)$$

where ρ_i, h_i,c_i are density, thickness and flexural wavespeed of plate i respectively. η is the internal loss factor of gasket material.

$$\alpha_1 = \frac{K_\gamma}{B_1 k_1^3\cos^3\Phi_1} + \frac{K_\gamma}{B_2 k_2^3\cos^3\Phi_2}$$

$$\alpha_2 = \frac{K_\gamma}{B_1 k_1^3\cos^3\Phi_1}\ \frac{\omega^2}{B_2 k_2^3\cos^3\Phi_2}(m_1 + m_2)$$

$$\alpha_3 = \frac{K_\gamma}{B_2 k_2^3 \cos^3\Phi_2} \quad (5)$$

$$\beta_1 = \frac{m_1\omega^2}{B_1 k_1^3 \cos^3\Phi_1} + \frac{m_2\omega^2}{B_2 k_2^3 \cos^3\Phi_2}$$

$$\beta_2 = \frac{m_1\omega^2}{B_1 k_1^3 \cos^3\Phi_1} \quad \frac{m_2\omega^2}{B_2 k_2^3 \cos^3\Phi_2}$$

where K_γ is the real part of K, ω is radian frequency. The coupling loss factor η_{12} from plate 1 to plate 2 can be expressed[1]

$$\eta_{12} = \frac{LC_1}{\omega S_1}\bar{\tau} \quad (6)$$

where S_1 is the area of plate 1.

Equation (4) can be simplified in the following cases:

(a) If the wave is normally incident upon the flange joint, eqn. (4) becomes an algebraical equation,

(b) If there is no gasket between the flanges, eqn. (4) can be simplified as

$$\bar{\tau} = \frac{\rho_2 h_2 c_2}{\rho_1 h_1 c_1}\frac{2}{\pi}\int_0^{\pi/2}\frac{4\cos\Phi_2}{(1+\alpha)^2 + (1+\alpha+\beta)^2}d\Phi_1 \quad (7)$$

where

$$\alpha = \frac{B_2 k_2^3 \cos^3\Phi_2}{B_1 k_1^3 \cos^3\Phi_1},$$

$$\beta = \frac{\omega^2}{\beta_1 k_1^3}\frac{m_1+m_2}{\cos^3\Phi_1}.$$

When the wave is normally incident upon the flange joint, equation (7) becomes an algebraical equation.

3. EXPERIMENTAL STUDY

Two sets of experiments were carried out. The first was used to examine the effects on vibrational transmission of changing the cross-sectional area of the flange and to compare the results with calculated values from equations (6) and (7). The second was to examine the effects on vibrational transmission of different gasket materials and to compare the result with calculated values from equations (6) and (5). The power input method[4] using three excitation points on each plate were used to calculated the coupling loss factors. Eight randomly chosen response positions were used on each plate to obtain the surface averaged vibration levels.

The experimental set-up was composed of two mild steel plates, each 0.5 m square. Plate thicknesses were 5 mm (plate 1) and 1.5 mm (plate 2). Each plate had a flange along one edge formed by bolting on a mild steel strip. This configuration allowed different strips to be fitted to obtain different dimensions. Two plate's flanges were coupled together in the following three different ways:

(a) The two flanges were directly bolted together by seven bolts.

(b) The two flanges were coupled together without bolts by a gasket stuck in position with double-sided tape.

(c) The two flanges were bolted together through a gasket. The bolts were tightened using a torque wrench to maintain a constant tightness.

Figures 2 and 4 show a comparison of coupling loss factor (from plate 1 to 2) of theoretical and measured results. The measured values agreed with the theoretical results calculated by assuming the wave is obliquely incident upon the joint when the flexural wavelength of plate 1 is greater than twice the distance between two bolts; and those calculated by assuming the wave is normally incident upon the joint when the flexural wavelength of plate 1 is less than twice the distance between two bolts.

Figure 3 shows the effect on measured energy ratios, $\frac{E_2}{E_1}$, of changing the dimensions of the flange on plate 1 (plate 1 excited). In general, the ratio is reduced as flange dimensions increase as would be expected from the theory. However, at certain frequencies, this was not always the case.

Figure 5 shows a comparison of measured energy ratios, $\frac{E_2}{E_1}$, for three different gasket materials. This shows that in general the smaller the real part of the shear modulus of the gasket material, the smaller the energy transmission. However, this is not true for the highly damped gasket at high frequencies.

Figures 6 to 9 show the comparisons of energy ratios, $\frac{E_2}{E_1}$, measured for the plates connected in different configurations and with different tightnesses of the bolts. It can be seen that for a bolted flange vibrational energy is transmitted mainly through the bolts and the gasket material has little influence on transmission. This is very apparent in Figure 6. It was also found that the tightness of the bolts only has a small effect on the vibrational transmission. For the hand tight bolts it was found that the gasket material did have a small but noticeable effect on vibration transmission.

4. CONCLUSIONS

From the theoretical investigation and experimental work, the following conclusions have been drawn.

1. Increased coupling damping between coupled structures not only increases energy dissipation but also has the effect of increasing vibrational transmission at high frequencies.

2. When two plates are only coupled through a gasket without bolts, the gasket acts as an isolator. Vibration transmission is low for materials with a low real part of shear modulus. However, vibrational transmission increases with increased coupling damping in high frequencies.

3. When two plates are bolted through a gasket, the vibrational energy is transmitted mainly through bolts and the characteristics of gasket material only has a small effect upon vibrational transmission. This effect is reduced with tightness of the bolts.

4. Vibrational transmission is reduced by increased flange dimensions or mass.

REFERENCES

[1] R.H. Lyon, 1975, Statistical Energy Analysis of dynamical systems: theory and applications, Cambridge, MIT Press.

[2] R.H. Lyon and E. Eichter, 1964. Random vibration of connected structures. Journal of the Acoustical Society of America 36(7), 1344-1354.

[3] L. Cremer, 1950, Propagation of structure-borne sound. DSIR Report No. 1 (Series B).

[4] D.A. Bies and S. Ramid, 1980, In situ determination of loss and coupling loss factors by the power injection method. Journal of Sound and Vibration 70(2), 187-204.

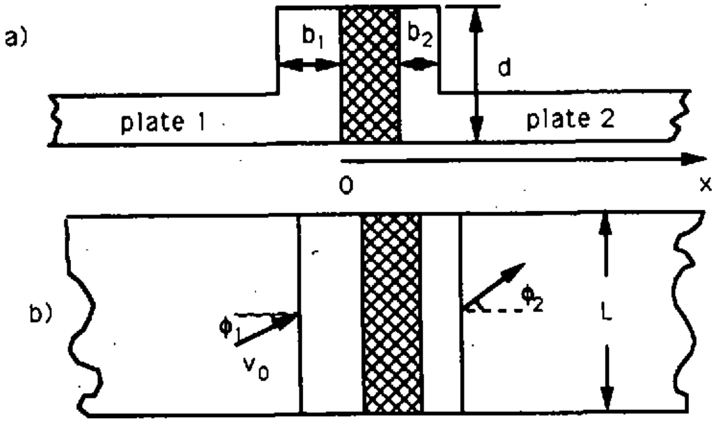


Figure 1 Scheme of plates coupled through flange joint with gasket

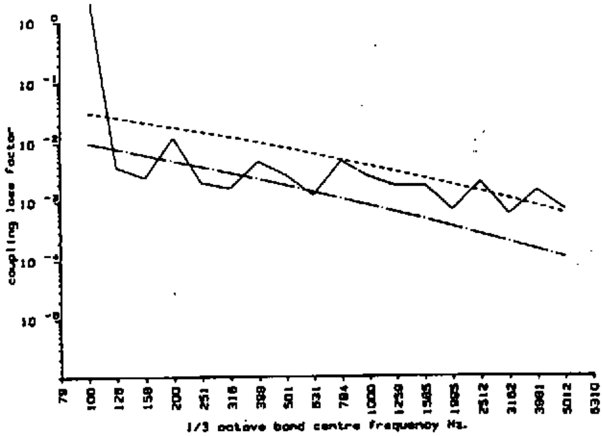


Figure 2. Coupling loss factor η_{12} for bolted flange without gasket.

- ––– assuming incident wave is normal
- –.– assuming incident wave is oblique
- —— measured results

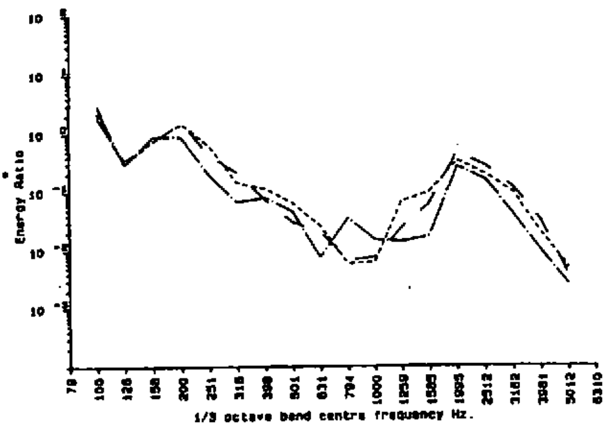


Figure 3. Measured energy ratios, E_2/E_1, for bolted plates without gasket but various flange dimensions on plate 1 (plate 1 excited).

- ––– 20 x 20 mm
- —— — 25 x 12.5 mm
- –.– 38 x 19 mm

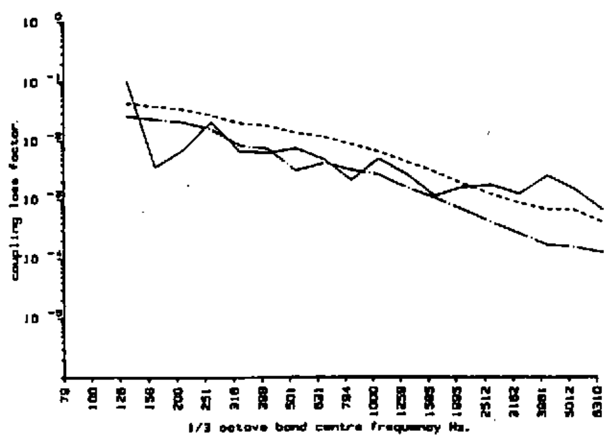


Figure 4. Coupling loss factor η_{12} for plates coupled through highly damped gasket without bolts.

- ––– assuming incident wave is normal
- –.– assuming incident wave is oblique
- —— measured results

Figure 5. Measured energy ratios, E_2/E_1, for plates coupled through different gasket without bolts. Plate 1 was excited only.

--- cork gasket
— — highly damped gasket
-.- soft rubber gasket

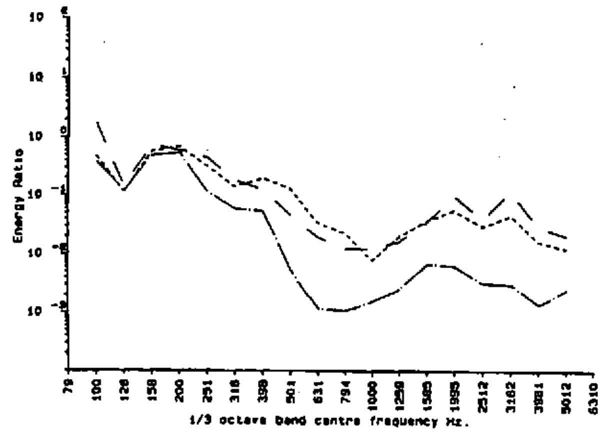


Figure 6. Measured energy ratios, E_2/E_1, plate 1 is excited only.

—— bolts without gasket

—— soft rubber gasket and 7 bolts (hand tight)

— — soft rubber gasket and 7 bolts (very tight)

-.- soft rubber gasket without bolts

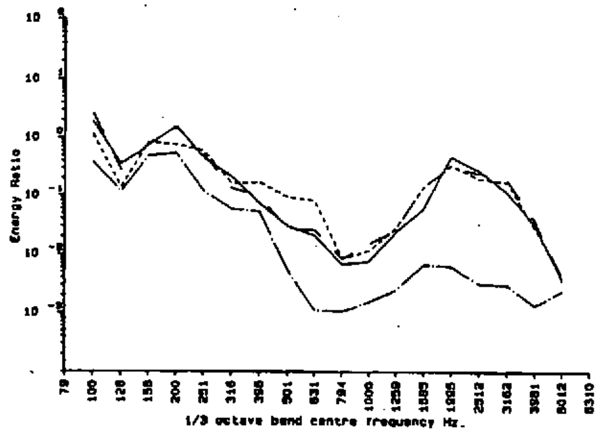


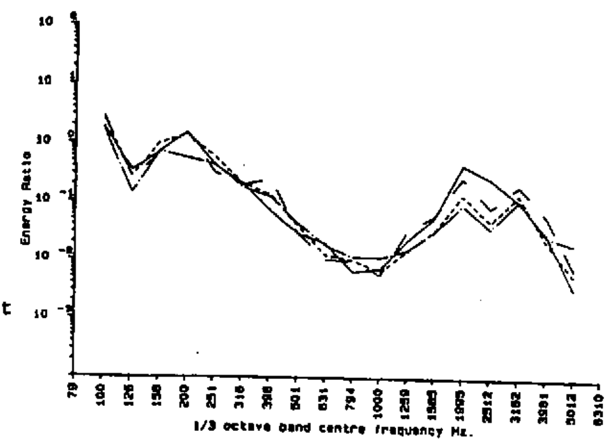
Figure 7. Measured energy ratios, E_2/E_1, plate 1 is excited only.

—— bolt without gasket

—— damped gasket and 7 bolts (hand tight)

— — damped gasket and 7 bolts (very tight)

-.- damped gasket without bolts



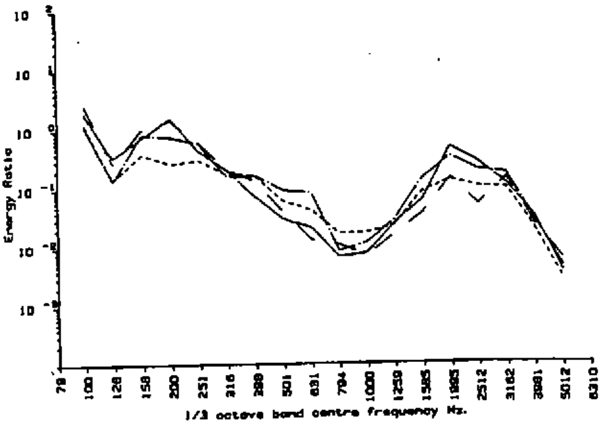


Figure 8. Measured energy ratios, E_2/E_1, plate 1 is excited only.

—— bolts without gasket

—— cork gasket with 7 bolts (hand tight)

— — damped gasket with 7 bolts (hand tight)

-.- soft rubber gasket with 7 bolts (hand tight)

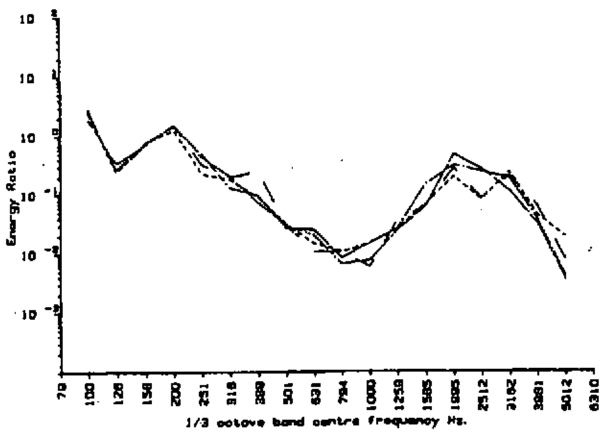


Figure 9. Measured energy ratios, E_2/E_1, plate 1 is excited only.

—— bolts without gasket

---- cork gasket with 7 bolts (very tight)

— — damped gasket with 7 bolts (very tight)

-.- soft rubber gasket with 7 bolts (very tight)