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INVESTIGATION OF VIBRATION POWER TRANSMISSION OVER A RECTANGULAR EXCITATION AREA USING EFFECTIVE POINT MOBILITY

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This paper investigates the vibration response and power transmission for a thin infinite plate which is excited over a rectangular area by a uniform conphase force distribution. The use of the effective point mobility concept allows the distribution of power flow and vibration over the contact region to be determined. The distribution is found to depend on the physical and geometrical properties of the plate and the Helmholtz number (based on the width of the contact region). This demonstrates that the surface mobility of the contact region decreases with increasing frequency of excitation and increasing contact area. The effect of the shape of the contact region on the surface mobility is highlighted by comparing the results for a strip, a circular region and a rectangular region with various aspect ratios for a fixed contact area. Experimental measurements confirm the nature of the relationship between power flow and Helmholtz number for an infinite plate.

1. INTRODUCTION

In the study of vibration isolation, the mobility of a source or receiving structure is often employed in the analysis of the dynamic characteristics of build-up systems. The concept of mobility is convenient and efficient for handling problems concerning vibration transmission because power, force and velocity are easily related to mobility. Classical mobility methods simplify the excitation area between two subsystems as a point-like contact, making calculation easy and clear. The mobility derived from this kind of simplification is called point mobility. However, in a practical situation, almost every contact area between a machine and its supporting structure has a characteristic dimension which is not negligible. For flexural waves in a plate, if the dimensions of the contact area are larger than approximately 10% of the governing wavelength [1], point mobility estimates can lead to significant errors, and hence a means of calculating surface mobility is highly desirable. Two approaches, complex power and effective point mobility, can

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each be used to derive surface mobilities of build-up structures. Their difference lies in the fact that the complex power approach emphasizes a system description, whereas the effective point mobility approach actually describes the spatial influence, i.e., it gives a more detailed description of the power transmission process within the contact area.

The concept of effective point mobility was introduced by Petersson and Plunt [2]. It can be employed to deal with multi-point connection or continuous contact area between substructures. Based on the approaches of complex power and effective point mobility, Hammer and Petersson developed the concept of strip mobility [3, 4]. Contact along a strip was considered and treated one dimensionally. This allowed strip mobility to be derived for infinite homogenous thin plates excited on a strip by either a uniform conphase force distribution or a uniform conphase velocity distribution. Following the concept of Hammer and Petersson, Zhao *et al.* [5] determined theoretical expressions for the surface mobility of large circular contact areas on plates. The results of experimental measurements of surface mobility for different circular contact areas were also presented by Norwood *et al.* [6, 7]. However, due to the axi-symmetry, the surface mobility of a circular contact area is dependent only on the radius, that is, mathematically, it is treated as one dimensional.

To investigate power transmission over a two-dimensional contact area, Dai [8] studied rectangular contact areas which are the most common shape of contact areas in practical situations and obtained the theoretical surface mobility based on the complex power approach. In order to further describe details of power transmission within the contact area, the concept of effective point mobility over rectangular contact areas is developed below. By means of effective point mobility, not only the distribution of power transmission over a contact area can be obtained but also surface mobility can be calculated conveniently. Using this concept, power transmission over a rectangular contact area with two aspect ratios, 1/1 and 2/1, is calculated and analyzed for a uniform conphase force distribution over an infinite thin plate excited in bending.

2. EFFECTIVE POINT MOBILITY FOR UNIFORM CONPHASE FORCE DISTRIBUTION

2.1. PREPARATORY CONSIDERATIONS

As mentioned in the introduction, effective point mobility can be employed to investigate power transmission. In order to calculate effective point mobility over a rectangular excitation area, a plate-like structure was chosen as a supporting part in a built-up system. Plate-like structures are one of the most common supporting parts used in practice. For the sake of simplifying calculations, the following assumptions are made: the plate is infinite and homogeneous, losses in the plate and local damping are neglected, the thickness of the plate is only a fraction of the governing bending wavelength; and only bending waves are considered in the plate, ignoring the minor effects of other wave types.

2.2. EFFECTIVE POINT MOBILITY OVER A DISCRETIZED CONTACT AREA

According to the principle of effective point mobility introduced in reference [3], the effective point mobility can be used to describe the power transmission at arbitrary points over the excitation area. If the response at the ith point is considered, the effective point mobility at the same point is written as

$$M^{iie} = \frac{v^i}{F^i} = \left(\sum_{k=1}^{N} M^{ki} F^k \right) \Big/ F^i, \tag{1}$$

where v^i is the complex velocity at the ith point caused by the forces acting at all contact points, F^i is the complex force acting at the ith point, F^k is the complex force acting at the kth point, M^{ki} is the transfer mobility from the kth point (x_k, y_k) to the ith point (x_i, y_i), N is the number of exciting points, and the ith point is included in the N points.

To investigate the power transmission through a rectangular excitation region, a typical continuous contact area, length l and width w, between a machine and its plate-like supporting structure is shown in Figure 1 based on the Cartesian co-ordinate system. In Figure 1, the distance r between point (x_k, y_k) and point (x_i, y_i) is given by

$$r = \sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}\,. \tag{2}$$

The power injected into the plate can be calculated from the real part of the transfer mobility. Under the assumptions of a plate-like supporting structure, the bending wave equation for infinite homogeneous thin plates can be used and then the transfer mobility between two arbitrary points (x_k, y_k) and (x_i, y_i) for an infinite homogeneous thin plate can also be derived as [1]

$$M^{ki} = M(x_k, y_k \,|\, x_i, y_i) = M_0 \Pi(kr) = M_0[H_0^{(2)}(kr) - H_0^{(2)}(-jkr)], \tag{3}$$

where M_0 is the ordinary point mobility of an infinite homogeneous thin plate, $H_0^{(2)}(kr)$ and $H_0^{(2)}(-jkr)$ are the zero-order Hankel functions of the second kind,

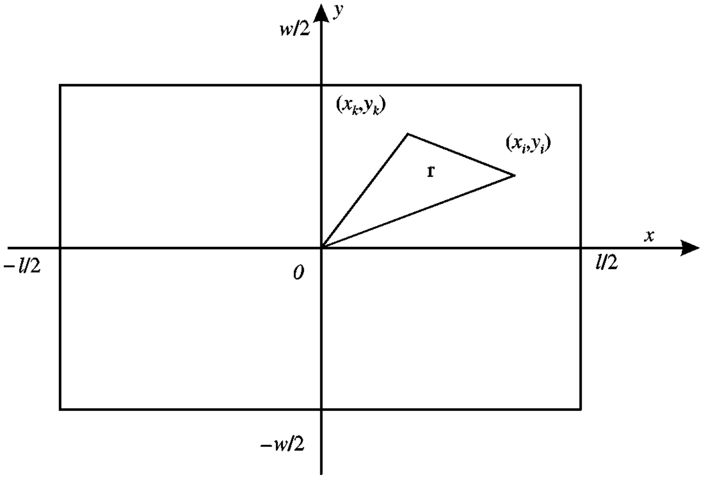

Figure 1. Rectangular contact area.

$\Pi(kr) = H_0^{(2)}(kr) - H_0^{(2)}(-jkr)$ is the propagation function which is defined as the difference between the two Hankel functions, k is the bending wavenumber, and r is the distance from the excitation point (x_k, y_k) to the response point (x_i, y_i).

Thus, from equation (3), the real part of the transfer mobility can be derived approximately as

$$\mathrm{Re}[M(x_k, y_k \mid x_i, y_i)] = M_0 \mathrm{J}_0(kr), \tag{4}$$

where $\mathrm{J}_0(kr)$ denotes Bessel function of the first kind of zero order.

In order to simplify the calculations, the continuous region which is excited by a force distribution is usually discretized. For a contact area discretized into N subregions subject to a uniform conphase force distribution, the effective point mobility can be obtained from equation (1) as

$$M^{iie} = \sum_{k=1}^{N} M^{ki}. \tag{5}$$

From equations (4) and (5), the real part of the effective point mobility can be calculated by

$$\mathrm{Re}(M^{iie}) = \sum_{k=1}^{N} M_0 \mathrm{J}_0(kr), \tag{6}$$

where r is the distance between the centre of the kth subregion and that of the ith subregion. Equation (6) can be used to reflect the details of power transmission under different circumstances.

2.3. EFFECTIVE POINT MOBILITY OVER A CONTINUOUS CONTACT AREA

When the dimensions of contact points are comparable to the governing wavelength, the contact points are replaced by continuous contact areas. The effective point mobility at a point (x_i,y_i) as given in Equation (1) has to be modified to give

$$M^e(x_i, y_i) = \frac{\sum_{k=1}^{N} \int_{S_k} M(x_k, y_k \mid x_i, y_i)\sigma(x_k, y_k)\, \mathrm{d}S_k}{\sigma(x_i, y_i)}. \tag{7}$$

In equation (7), S_k represents the kth continuous region over which there is a stress distribution of $\sigma(x_k, y_k)$, $\sigma(x_i, y_i)$ represents the force distribution over the ith infinitesimal region, $M(x_k, y_k \mid x_i, y_i)$ is the transfer mobility from point (x_k, y_k) to point (x_i, y_i), $\mathrm{d}S_k$ represents the infinitesimal region. The summation expresses the contributions from all N separated excitation regions.

Under the circumstance of a uniform conphase force distribution, $\sigma(x, y)$ is equal to a constant. For the sake of simplifying the calculation of the effective point mobility, let the number of separated contact regions be one, i.e., $N = 1$. Then equation (7) can be written as

$$M^e(x_i, y_i) = \int_S M(x_k, y_k \mid x_i, y_i)\, \mathrm{d}S, \tag{8}$$

where S represents the contact area which includes both points (x_i, y_i) and (x_k, y_k).

By substituting equation (3) into equation (8), we have

$$M^e(x_i, y_i) = \int_S M_0[H_0^{(2)}(kr) - H_0^{(2)}(-jkr)]\,\mathrm{d}S. \tag{9}$$

Thus, for a uniform conphase force distribution, the real part of the effective mobility at an arbitrary point (x_i, y_i) within the rectangular continuous contact area can be obtained from equations (6) and (9) as

$$\mathrm{Re}[M^e(x_i, y_i)] = \int_{-w/2}^{w/2}\int_{-l/2}^{l/2} M_0\,\mathrm{J}_0(kr)\,\mathrm{d}x_k\,\mathrm{d}y_k \tag{10}$$

By means of equation (10), the power transmission at any arbitrary point (x_i, y_i) over the whole contact area can be calculated.

3. SURFACE MOBILITY

In practice, the power injected into the supporting structure is equal to the real part of the total complex power, Q. For a continuous force distribution, it can be obtained as

$$\mathrm{Re}(Q) = \mathrm{Re}\left[\frac{1}{2}\int_S v(x_i, y_i)\sigma(x_i, y_i)^*\,\mathrm{d}S\right]$$
$$= \frac{1}{2}\int_S \mathrm{Re}[M^e(x_i, y_i)|\sigma(x_i, y_i)|^2]\,\mathrm{d}S, \tag{11}$$

whereas for a discretized force distribution, the real part of the total complex power is given by

$$\mathrm{Re}(Q) = \frac{1}{2}\sum_{i=1}^{N}\mathrm{Re}(M^{iie})|F_i|^2. \tag{12}$$

Therefore, the real part of surface mobility, based on the concept of complex power which is calculated by means of effective point mobility, can be written as

$$\mathrm{Re}(M^S) = \frac{2\mathrm{Re}(Q)}{|F|^2}, \tag{13}$$

where F is the total force acting on the contact area.

For a continuous contact area, substituting equation (11) into equation (13), the real part of surface mobility is obtained as

$$\mathrm{Re}(M^S) = \frac{\int_S \mathrm{Re}[M^e(x_i, y_i)|\sigma(x_i, y_i)|^2]\,\mathrm{d}S}{|\int_S \sigma(x_i, y_i)\,\mathrm{d}S|^2}. \tag{14}$$

According to the assumption of uniform conphase force distribution, equation (14) can be simplified as

$$\mathrm{Re}(M^S) = \frac{1}{S^2}\int_S \mathrm{Re}[M^e(x_i, y_i)]\,\mathrm{d}S. \tag{15}$$

On the other hand, if the contact area is discretized into N subregions, the real part of surface mobility for uniform conphase force distribution can be obtained by substituting equation (12) into equation (13), giving

$$\mathrm{Re}(M^S) = \frac{\sum_{i=1}^{N} \mathrm{Re}(M^{iie})|F_i|^2}{|F|^2} = \frac{1}{N^2} \sum_{i=1}^{N} \mathrm{Re}(M^{iie}). \tag{16}$$

Thus, the characteristics of total power transmission under different conditions can be obtained from either equation (15) for a continuous contact area or equation (16) for a discretized contact area.

4. INVESTIGATION OF POWER TRANSMISSION THROUGH A RECTANGULAR EXCITATION AREA OF AN INFINITE PLATE

4.1. ANALYSIS OF POWER TRANSMISSION

In the calculations of the surface mobility of an infinite plate from effective point mobilities, the parameters of governing wavenumber k, width dimension w and aspect ratio $\eta = l/w$ of the contact area are specified. In order to compare the power transmission over rectangular contact areas, two typical aspect ratios of $l/w = 1$ and 2 were used to calculate the effective point mobility using equation (6). Theoretically, when a continuous contact area is discretized, there are an infinite number of points (regions) which could be selected to calculate values of effective point mobility, but in practice a finite array of points is chosen to represent the power transmission over the rectangular contact area of an infinite plate. The number of points chosen would influence the accuracy of the calculations. The influence of the number of discretized regions on the accuracy of the calculations is documented by Dai [8]. For calculations presented here, the array of points chosen was 21×21 for both aspect ratios.

Figures 2–5 display the calculated spatial distributions of the normalized effective point mobility (NEPM) for different conditions. Here, effective point mobilities are normalized by the ordinary point mobility of an infinite plate. As seen from equation (12), the spatial distribution of effective point mobilities is directly related to the spatial distribution of power transmission for uniform conphase force distribution. Figures 2(a–d) display the spatial distribution of the normalized effective point mobility over a square contact area ($\eta = 1$) for various Helmholtz numbers $kw/2 = 1$, 5, 10, and 20 respectively. Similarly, Figures 3(a–d) display the results for a rectangular contact area with $\eta = 2$. It can be seen from Figures 2 and 3 that the pattern of power transmission over a contact area depends on the values of the width-based Helmholtz number $kw/2$. Furthermore, the number of peaks increases as $kw/2$ increases, thus indicating that for a fixed contact area, the number of peaks is inversely proportional to the governing wavelength λ. When $kw/2$ is quite large such as in Figures 2(d) and 3(d), the spatial distribution of the effective point mobility over the whole contact area becomes more uniform, thus indicating more even distribution of the power injected into the supporting plate and more even distribution of the power transmitted back to the exciting machine.

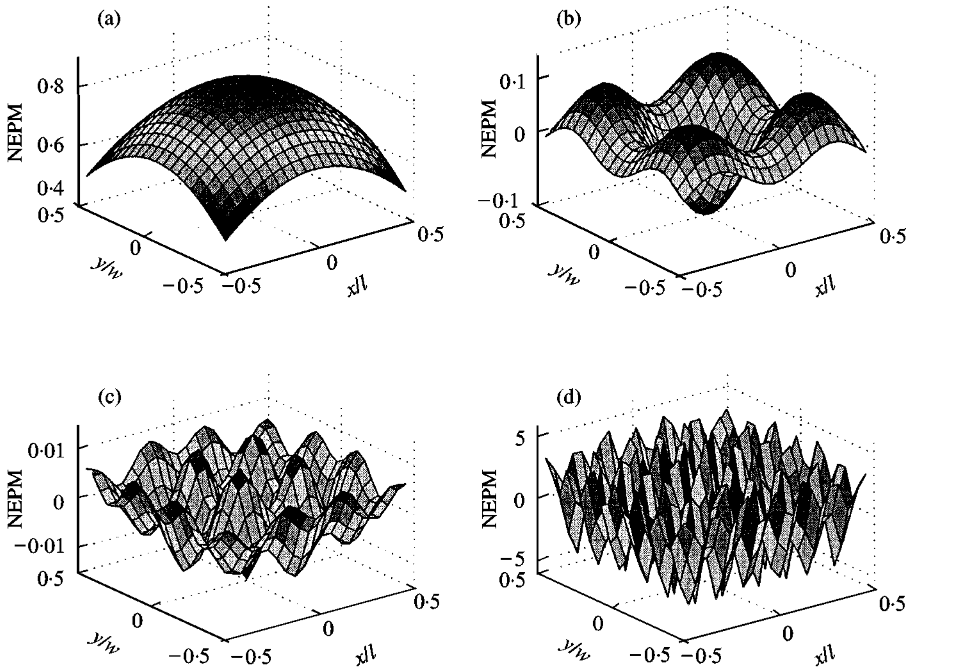

Figure 2. Normalized effective point mobility (NEPM) over a square contact area, $\eta = l/w = 1$, for a uniform conphase force distribution. (a) $kw/2 = 1$; (b) $kw/2 = 5$; (c) $kw/2 = 10$; (d) $kw/2 = 20$.

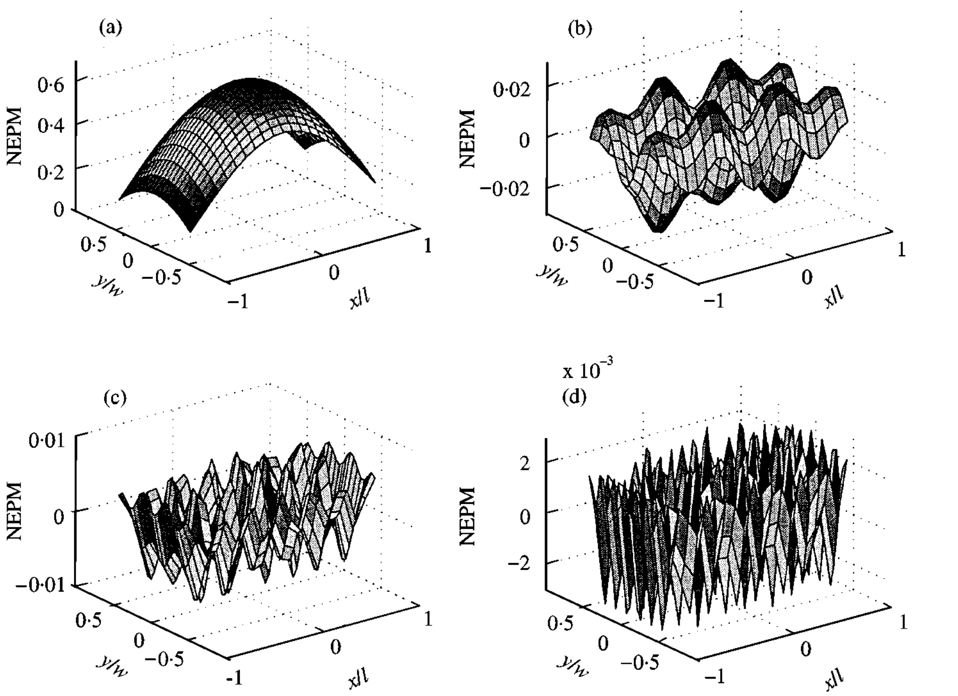

Figure 3. Normalized effective point mobility (NEPM) over a rectangular contact area of the aspect ratio of $\eta = l/w = 2$ for a uniform conphase force distribution. (a) $kw/2 = 1$; (b) $kw/2 = 5$; (c) $kw/2 = 10$; (d) $kw/2 = 20$.

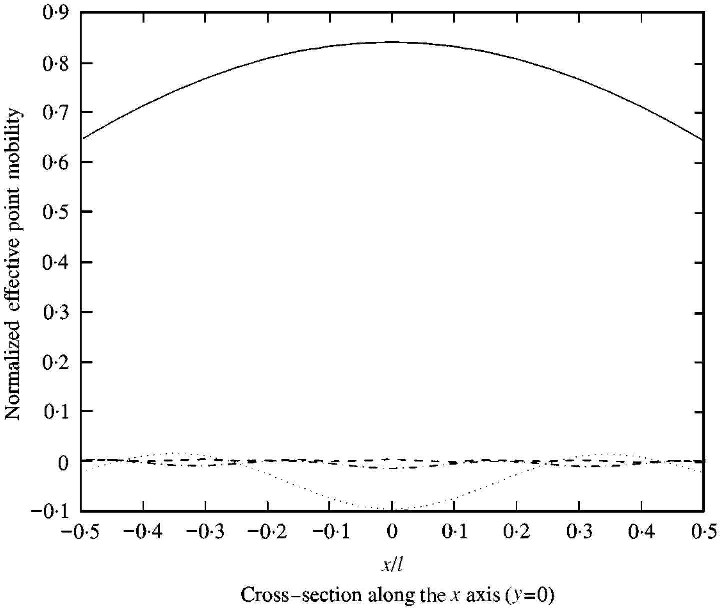

Figure 4. Normalized effective point mobility (NEPM) over a square contact area in the central cross-section of $y = 0$: (a) — $kw/2 = 1$; (b) ······ $kw/2 = 5$; (c) - - - $kw/2 = 10$; (d) - - - - $kw/2 = 20$.

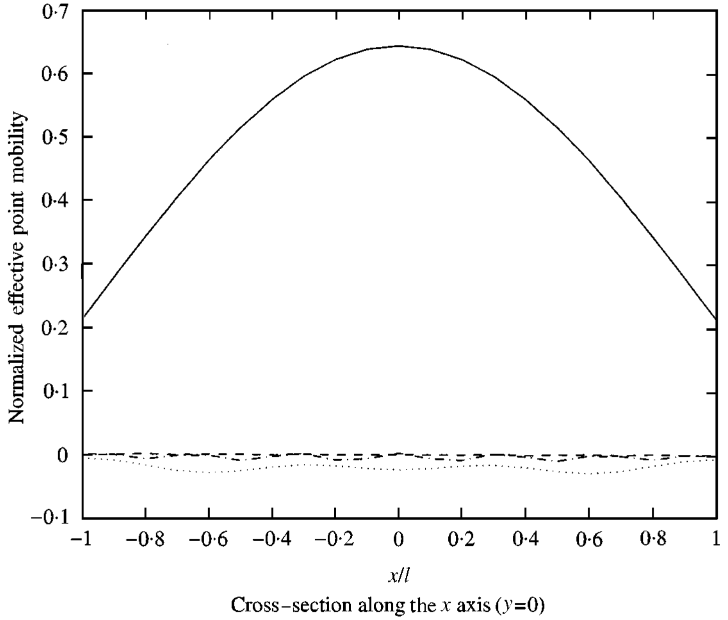

Figure 5. Normalized effective point mobility (NEPM) over a rectangular contact area of the aspect ratio of $\eta = l/w = 2$ in the central cross-section of $y = 0$: (a) — $kw/2 = 1$; (b) ······ $kw/2 = 5$; (c) - - - $kw/2 = 10$; (d) - - - - $kw/2 = 20$.

Power transmission is bi-directional. Figures 2 and 3 show that when $kw/2$ is large enough (such as 5), the values of the real part of the effective point mobility can be both positive and negative. Positive value means that the vibration power is injected from the exciting machine into the supporting plate, whereas negative value implies that the vibration power is transmitted from the supporting plate back to the exciting machine. Note that the net power is only positive if the receiver is passive and no other sources or excitation areas are present. Although the surface mobility over the contact area is positive, indicating overall power transmission from the exciting machine to the supporting plate, the power transmission at each point within the contact area can be quite different.

Figures 4 and 5 display the variation of the normalized effective point mobility with x/l along $y = 0$ for a square contact area and a rectangular contact area with $\eta = 2$ respectively. These results indicate that the vibration power injected into the supporting plate is influenced by the Helmholtz number $kw/2$. As $kw/2$ increases, the magnitude of the real part of effective point mobility becomes smaller and smaller. This implies that for a practical structure, the input vibration power decreases as the exciting frequency increases. This is basically the consequence of a spatial mismatch between the applied stress and the free bending wave. This trend is also the same as that of the surface mobility with respect to $kw/2$, as discussed below (Figure 6).

It can be seen from Figures 2 and 3 that the peaks of the effective point mobility for a homogeneous infinite thin plate produced within the contact area show a periodic distribution. In the direction of the width, the number of peaks for the

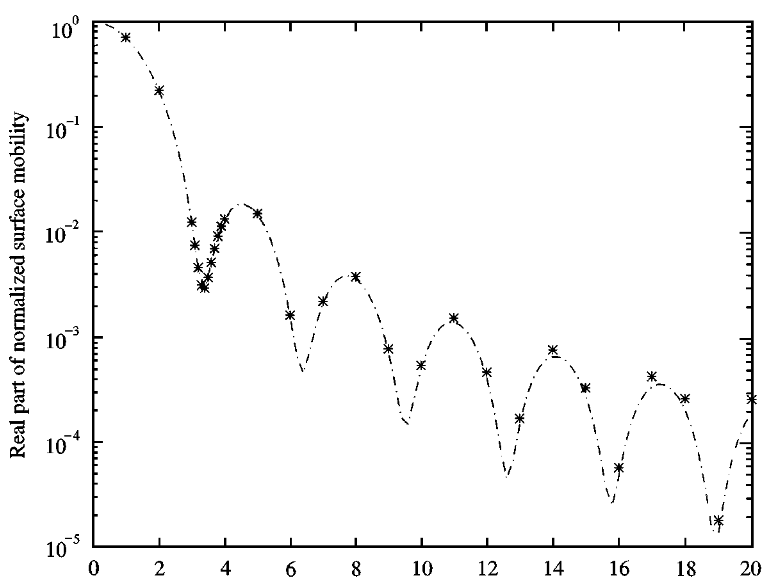

Figure 6. Comparison of the real part of the surface mobility of a homogeneous infinite thin plate for a uniform conphase force distribution over a square contact area calculated by the complex power method and the effective point mobility method. ------ complex power; * Effective point mobility.

same Helmholtz number (eg. $kw/2 = 5$ in Figures 2(b) and 3(b)) is independent of the aspect ratio. However, the ratio of the number of peaks in the direction of the length to that in the direction of the width is equal to the aspect ratio of the contact area. Thus, the pattern of the peak distribution of the effective point mobility over a rectangular contact area is not dependent on the aspect ratio. This implies that the pattern of peak distribution of the effective point mobility over a contact area is dependent on the physical and geometrical properties of the supporting plate and the Helmholtz number. Furthermore, for the same value of $kw/2$, the magnitude of the maximum effective point mobility over a rectangular contact area with a smaller aspect ratio is greater than that with a larger aspect ratio. This is because for a given $kw/2$, a smaller aspect ratio is equivalent to a smaller contact area, thus resulting in a larger magnitude of the effective point mobility.

4.2. SURFACE MOBILITY

Effective point mobility can be used to calculate surface mobility from either equation (15) or equation (16). While effective point mobility reflects the power transmission at a point within the contact area, surface mobility represents the total power transmission over the whole contact area. Generally, the calculation of the surface mobility over a continuous contact area, based on effective point mobility, is a four-dimensional integration and solution is not easy to obtain analytically. Thus, it may be more convenient to calculate the surface mobility from a discretized model using effective point mobilities, as given in equation (16). Figure 6 shows the comparison between the results of the surface mobility obtained by the complex power approach [8] and the approximate calculation of surface mobility over a square contact area using effective mobility method with 21×21 discretized regions. It can be seen that there is good agreement between the results obtained from effective point mobilities and those from the complex power approach.

In order to compare the effect of the shape of the contact region, the real part of the surface mobility is calculated for a square contact region, two rectangular contact regions with $\eta = 2$, 100 and a circular contact region is shown in Figure 7. For a circular contact area, r is the radius. For a rectangular contact area with an aspect ratio η, r is an equivalent radius of a circle that has the same area as the rectangle. That is, $r = w\sqrt{\eta/\pi}$. Hence, for a rectangular contact area, the width-based Helmholtz number of $kw/2$ is given as $(2\sqrt{\eta/\pi}) \times kw/2$ on the kr axis of Figure 7, which shows a general reduction in surface mobility as either the dimension of the contact area, (r or w), or the frequency of excitation increases. For a fixed contact area, a square ($\eta = 1$) and a circular contact region have similar surface mobility characteristics at low Helmholtz numbers except that the circular contact region exhibits deeper dips which occur when the circle diameter is equal to approximately integer multiples of the exciting wavelength.

It can be determined from Figure 7 that the point mobility approximation is within 5% of the surface mobility if the diameter of circular contact area is less than 10% of the governing wavelength, thus confirming the rule of thumb proposed by Cremer *et al.* [1]. Furthermore, it can be determined from Figure 7 that this rule

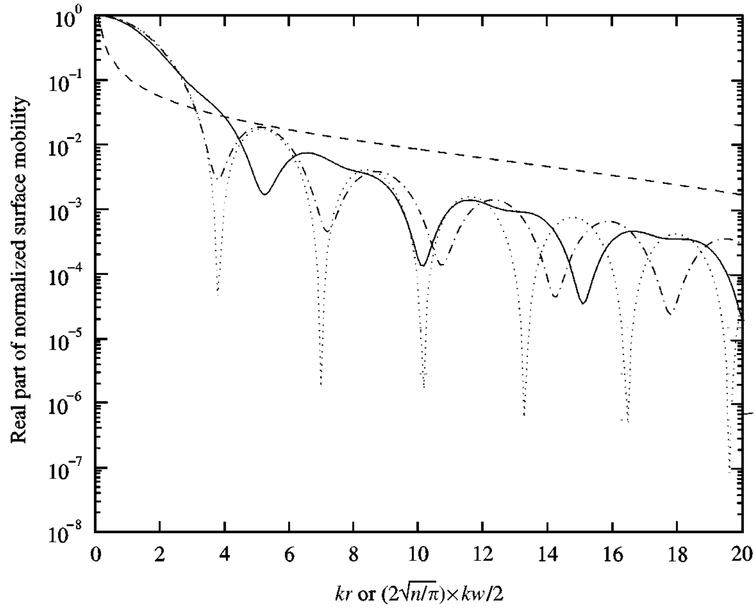

Figure 7. Real part of the normalized surface mobility for a constant contact area. ······ circular; -·-·-· $\eta = 1$; —— $\eta = 2$; - - - - - - $\eta = 100$.

can be extended to a rectangular contact region with an aspect ratio not greater than 2.

Since a strip is a particular case of a rectangle, the results of the real part of the surface mobility calculated for rectangular contact regions with aspect ratio $\eta = 1$, 2, 5, 10 and 20 and that calculated by Hammer and Petersson [3] for a strip are compared in Figure 8. It can be seen from Figure 8 that as the aspect ratio of a rectangular contact area increases (i.e., as the area approaches a strip), the real part of the surface mobility converges to the result of the strip mobility, thus indicating that the method of calculating the rectangular surface mobility can also be used to calculate the strip mobility. More importantly, at high Helmholtz numbers (kl) based on the contact length, the effect of the width of the contact area with small aspect ratio becomes very significant. For small aspect ratios (such as 1 and 2), the surface mobility shows oscillating dips while for large aspect ratios (greater than 5), there are no dips in the surface mobility. Figure 8 shows that if the aspect ratio of a rectangular contact area is greater than 20, the differences between the strip mobility obtained by Hammer and Petersson [3] and the surface mobility are less than 15% for Helmholtz numbers (kl) up to 20.

5. EXPERIMENTAL RESULTS OF SURFACE MOBILITY

In order to provide comparisons with theoretical surface mobility calculations for a rectangular contact region with a uniform conphase force distribution and to develop an experimental procedure for determining surface mobility based on

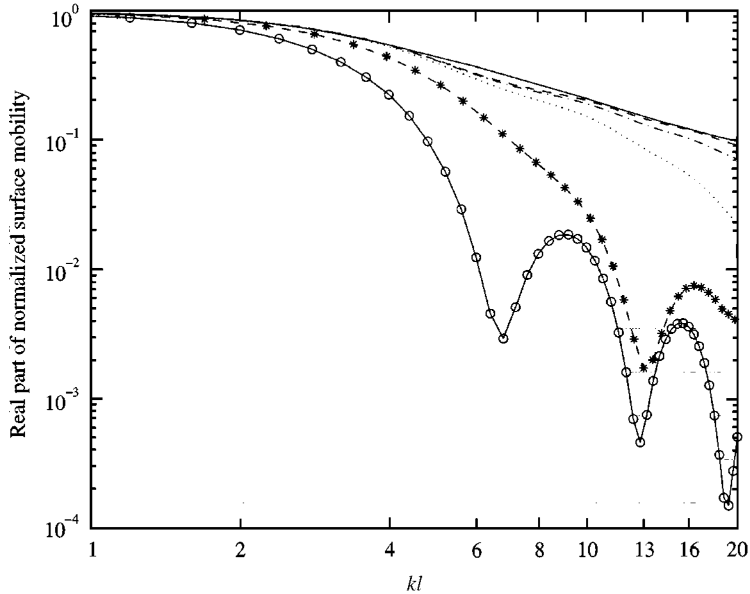

Figure 8. Comparison of the real part of the normalized rectangular surface mobility and the normalized strip mobility: -⊖- $\eta = 1$; -*- $\eta = 2$; ······ $\eta = 5$; -·-·· $\eta = 10$; ---- $\eta = 20$; — strip (calculated by Hammer and Petersson [3])

equation (16), an experiment was designed to measure ordinary point and transfer mobilities over an array of points. The experimental technique also involved curve fitting and interpolation of experimentally measured mobilities [9]. In the experiment, a square contact area with 9×9 square sub-regions was chosen. The length of each sub-region was chosen arbitrarily to be 17 mm. Since the system under consideration is passive and linear, the reciprocity principle is valid, i.e. $M(x_k, y_k \,|\, x_i, y_i) = M(x_i, y_i \,|\, x_k, y_k)$. Therefore for the array of points in a contact region, the mobility matrix is symmetrical. In addition, for a uniform conphase force distribution over the contact area on an infinite plate, the exciting force $F^i$and the point mobility are the same everywhere within the contact area. Hence, in this case the transfer mobility between two points is only dependent on the distance between the excitation and response points. These assumptions were used to reduce the number of measurements of mobility required.

The normal procedures for point and transfer mobility measurement were used. A Bruel and Kjael (B&K) shaker-type 2608 was used to excite the "infinite plate" which was a thin aluminium plate, 2·4 m × 1·2 m × 0·001 m, with edges embedded in sand. The force and acceleration at the driving point were measured using a B&K impedance head-type 8000. The response accelerations at a second point on the plate were measured with a mini B&K-type 4374 accelerometer to determine the transfer mobility. All transducer signals were conditioned using B&K-type 2635 charge amplifiers and data from all channels were acquired simultaneously using an HP 3566A analyzer. The analyzer was controlled by an NEC Versa 4050 notebook computer via a PCMCIA-GPIB card.

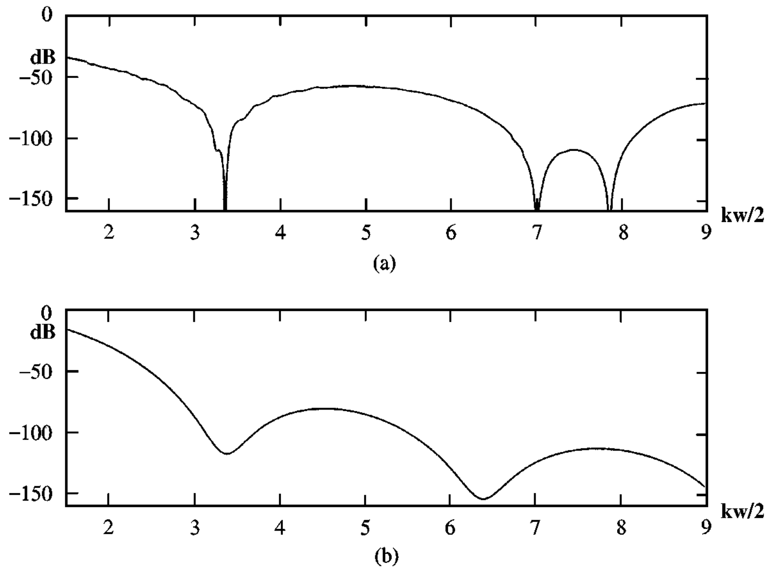

Figure 9. Real part of surface mobility for a square contact area with 9×9 sub-regions ($17\ \text{mm} \times 17\ \text{mm}$) (a) experimental (b) theoretical.

Figure 9(a) shows the surface mobility calculated for a square contact region from experimental measurements using curve fitting and interpolation and equation (16). It can be seen that the experimentally determined surface mobility also exhibits the oscillating behaviour with Helmholtz number as predicted analytically (Figure 9(b)). The position of the first dip agrees well with the theoretical results. The slight discrepancy in the position of the second dip between measurements and theoretical calculations and the appearance of a third dip in the measurements at Helmholtz number close to 8 are being attributed to the "imperfect" simulation of the infinite plate in the experiment and the limited dynamic range of the measuring instrumentation.

6. CONCLUSIONS

Based on the concept of effective point mobility, the power transmission of an infinite homogeneous thin plate excited by a uniform conphase force distribution over a rectangular contact area has been investigated theoretically and experimentally.

It has been shown that the power transmission at every point within a rectangular contact region is different. There are some points over the rectangular contact area through which power is injected into the supporting plate, whereas there exist other points from which power can be transmitted back to the exciting machine. The pattern of power transmission over the excitation area is a series of peaks which depends on the width-based Helmholtz number $kw/2$. The aspect ratio of the contact area has only a minor influence on the pattern. As $kw/2$ increases, the number of peaks increases but the magnitude of effective point mobility decreases.

A simplified method of calculating surface mobility by effective point mobilities has been derived and the results compare well with those obtained by the complex power approach and experimental measurements. The surface mobility of an infinite plate has been shown to decrease with increasing contact area and increasing excitation frequency. For a rectangular contact area with small aspect ratios (such as 1 and 2), the surface mobility exhibits dips in the Helmholtz number domain. These dips occur when the half-width of the contact region is approximately equal to integer multiples of the excitation wavelength. The use of point mobility to approximate the surface mobility can be significantly in error especially for rectangular contact areas with small aspect ratio.

The effect of the aspect ratio of a rectangular contact area on the surface mobility of an infinite plate is significant for aspect ratios less than 5 and for Helmholtz number (based on length) greater than 2. The strip mobility is a good approximation to the surface mobility of a rectangular contact area with an aspect ratio greater than 20.

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