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MEASUREMENT OF VIBRATION POWER FLOW IN THIN PLATE STRUCTURE WITH CROSS POWER SPECTRAL DENSITY-BASED TECHNIQUE

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ABSTRACT--*The out of plane vibration is measured to investigate the dynamic characteristics and the power flow behavior of the plate structure. The power flow is expressed in terms of the cross power spectral density and contour map of power distribution over the plate at different natural frequencies. During measurement, the effectiveness and accuracy of the results are monitored against coherence function. The frequency response functions are also measured to generate the dynamic characteristics of the plate. The results show that the magnitudes of power flow are decreasing with respect to distance from the exciting point, and the higher natural frequency, the more spreading of vibration power over the plate. The higher vibration power flow occurs mostly near the edges of the plate. The reason of this behavior could be the boundary of the plate. These vibration power flow distribution maps provide information for the effective control of the vibration of the structure such as where the structure should be strengthened, and where the high vibration power occurs at certain frequency.*

KEYWORDS--*vibration power flow, cross power, thin plate, and dynamic characteristic*

I. INTRODUCTION

The plates of various thickness are being utilized in many engineering fields under diff

erent conditions which causes damage and degradation. Vibration is one of the reasons to happen that problems. Dynamic characteristics and vibration power flow play important role for structural integrity, reducing vibration level, design and product development process. Basically, to determine the vibration power flow, experimental method and numerical method can be conducted. Most researchers prefer the numerical analysis of vibration power flow due to easily available computers with high technology and economic benefits while the experimental method consumes longer time and more funds for equipment. However, experimental measurement is essential for vibration power flow analysis to confirm the reliability of the results.

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Previously, Khaled M. Ahmida and Jose Roberto F. Arruda predicted active power flow inTimoshenko beams using spectral element method [1]. Xiong Zhang et al. conducted the vibration power flow characteristics analysis in a simply supported laminated composite plate [2]. Young-Ho Park performed numerical study of progressing out-of-plane waves in coplanar coupled Mindlin plates considering the effects of shear distortion and rotatory inertia [3]. YH Chen et al. studied analytically on the vibration power flow of coupled cylindrical shell-plate structure under general boundary conditions and coupling conditions in which the interactions of all moments and internal forces for both the plate and shell were taken into account [4]. Wenwei Wu et al. investigated power flow characteristics of built-up plate structure utilizing the dynamic stiffness method which is taken into account both in-plane and out-plane of vibrations [5]. M. Nefovska-Danilovic and M. Petronijevic also used the dynamic stiffness method for response analysis of isotropic rectangular plates under arbitrary boundary conditions considering in-plane free vibration [6]. Verheij, J.W. formulated cross power spectral density methods for bending, longitudinal and torsional waves [7]. F. Han et al. also expressed input power of vibrating beams and plates in term of the cross-power spectral density [8]. To analysis the mechanical vibration problems, Kenji Kanazawa and Kazuta Hirata proposed procedure of the cross-power spectral density which generate better estimation to remove the additional noise peaks than the FFT method [9]. However, experimental measurement of vibration power flow is very limited.

The knowledge of the dynamic behaviour of the structure is important because structural vibration problems present a major hazard and limitation in design and manufacturing process. To minimize this issue, understanding of the dynamic characteristics and creative ways to identify vibration power flow is necessary. In this study, the vibration power flow of a thin plate is investigated experimentally utilizing cross power spectral density-based technique.

In many practical circumstances, the dynamic characteristics of every structure plays importance role for stability, integrity, durability, and system design of the structure. Since plates of various thickness with the advancement of technology are being used in civil work, mechanical, aerospace, naval architecture and marine engineering etc., this study will be helpful for these industries. Then, the vibration power flow indicates the vibration transmission path or the position of high and low vibration level. It can be utilized for structural diagnostic such as damage detection or mounted stiffness identification.

II. METHODOLOGY AND EXPERIMENTAL SETUP

In this study, shaker excitation is selected for the experiment because it is easier to get good signal and coherence than the impact test due to the same exciting point during experiment while impact testing is difficult to excite at the same point with hammer. The natural air-cooling and portable smart shaker, in which an ultra-compact power amplifier is integrated in its base, is selected because of its advantages such as wide frequency range, excellent indicator, high reliability, small floor space, easy to move, easy to operate, and it does not need extra cumbersome power amplifier. The SIEMENS LMS SCADAS mobile which is composed of the SYSCON system controller and two 8-channel input modules, is used for data acquisition. For measurement of force and acceleration,

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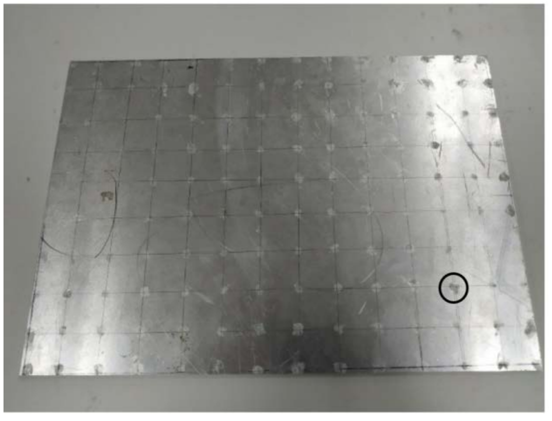
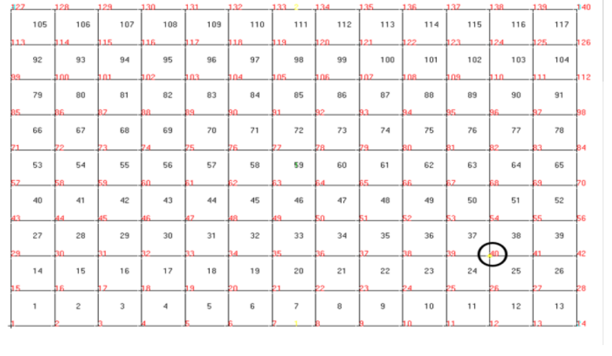
one mechanical impedance sensor and five ultra-miniature accelerometers are utilized. Consideration of the support of the structure under the experiment is an important part of the experimental setup. For laboratory testing of structure (aluminium plate), the free boundary condition is the most frequently employed. Since, the interesting boundary condition of the plate is a free-free condition, small diameter of rubber string form bungee cord was used to simulate free-free model of plate. This cord has very small stiffness and a much lower frequency than the lowest frequency of the plate. So, the effect of these suspension cords can be negligible. A small diameter and seven centimetres length of stinger rod that should be rigid in the axial direction and flexible in the lateral direction was used in this experiment to decouple the shaker from the testing object and transmit force to the testing object. The testing object (aluminium plate) and measuring point wireframe are shown in Figure 1.



a) Testing object



b) Measuring point wireframe

Figure 1: testing object and measuring point wireframe

In this figure, the circle mark indicates the excitation point. The dimensions of the plate are 0.328m width, 0.232m height, and 0.003m thickness. A spectral testing program that is suitable for shaker testing in LMS Test.Lab software is utilized to obtain more precise vibration properties. Sine sweep signal which changes one frequency to another in a uniform way is selected as an excitation signal over a range of frequency (0 Hz to 520Hz). In addition, 10 times linear amplitude average method was used to reduce error. The photo of experimental setup is shown in Figure 2. Before starting measurement, calibration of all accelerometers was conducted in the calibration tab of the spectral testing software using a portable vibration calibrator to make sure that the input data of the sensitivity of the accelerometer is correct.

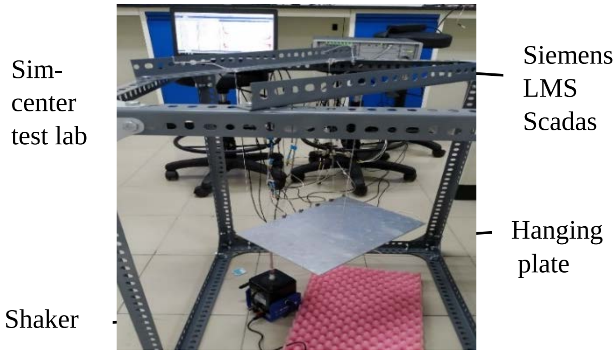


Figure 2: Photo of experiment setup

III. RESULTS AND DISCUSSION

When actual measurement is started, there is an option to confirm the measurement, and then accept and save this measurement implicitly. During measurement, coherence function which is an indication of the quality of the experimental work should be noticed to be unity except resonance frequency. If the coherence function is less than unity, one or more of the following main conditions existing: extraneous noise is present in the measurement; resolution bias errors are present in the spectral estimates; the system is not linear; and the measured response is due to other external inputs. The coherence of the measurement is shown in Figure 3. In this figure, the coherence function is nearly one which mean the quality of measurement is good and reliable.

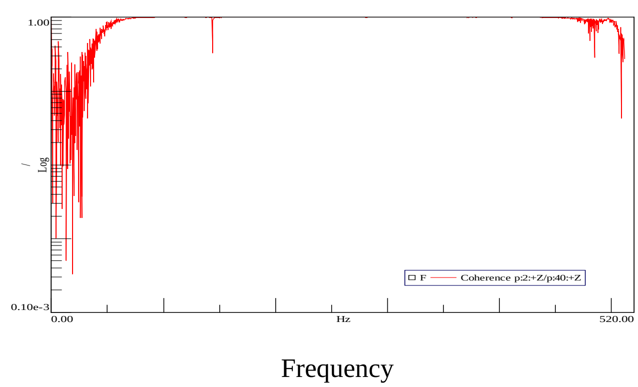


Figure 3: Coherence of the measurement

The measured frequency response function with phase form is depicted in Figure 4. This result is from measuring pint 2 of the measuring point wireframe of the plate. There are six peaks of FRF in the figure that can be

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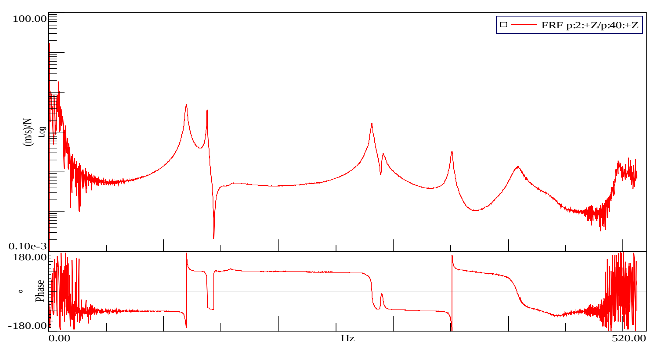
clarified with phase angle. The coherence, cross power spectral density, frequency response function and phase form can be simultaneously monitored while taking measurements. From the results, the dynamic characteristics of the plate such as natural frequency are generated. As there are six peaks of frequency response function, six natural frequencies of the plate are generated. They are shown in Table 1.

Table 1: Natural frequency of the plate

	Natural Frequency
First mode	119.46 Hz
Second mode	137.93 Hz
Third mode	280.70 Hz
Fourth mode	292.12 Hz
Fifth mode	351.38 Hz
Sixth mode	410.36 Hz



Frequency

Figure 4: The measured frequency response function with phase form

Since vibration power flow is the energy per unit time flowing across a surface defined within the structure by its normal, it is shown in units of watt. In power transmission, the transfer force and bending moment play important role. In this study, the transverse vibration of the plate is measured to reveal the vibration power flow distribution pattern over the range of frequency by cross power spectral density technique.

In figure 5, three vibration power flow distribution patterns are presented. Among them, generally, power flow at measuring point 40 which is also force exciting point to the structure is the highest magnitude. The measuring point 53 is 0.035m away from the exciting point and the measuring point 66 is 0.07m away from the exciting point respectively. These two points are in line. It can be seen that the magnitude of these two power flow patterns are decreasing with respect to distance from the exciting point. This is because of the effect of structural damping.

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However, the level of the vibration power could be increasing at areas near the edges of the plate, if there is far field effect. Therefore, the measurement should be conducted with suitable grid of measuring point over the whole area of the plate to study the power flow behavior of the structure. In total, there are 140 measuring points. The frequency response function, coherence function and cross spectral density function of each and every measuring point were saved and analyzed.

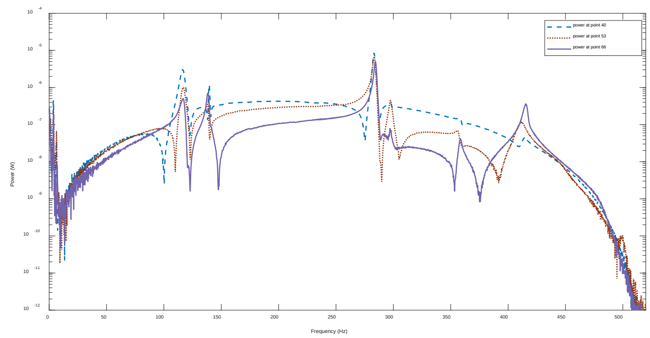
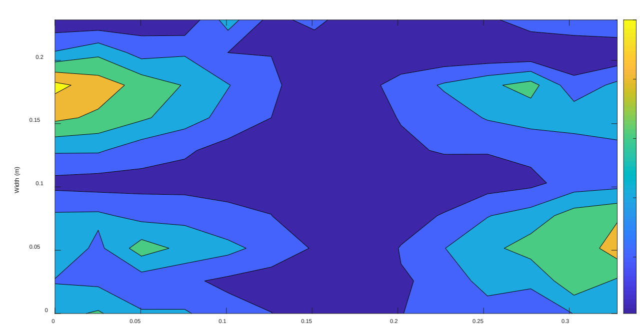


Figure 5: Power flow at different points

In order to have better understanding of the power flow behavior of the plate, the vibration power distributions over the plate were investigated. Since the vibration of a structure at equivalence of its natural frequencies amplifies its vibration amplitude significantly which could be detriment to the structure. The power flow of the plate at its natural frequencies should be emphasized. In figure 6, the power flow contours of the plate at its natural frequencies are depicted. From this figure, the level of vibration power at every location over the plate can be determined. At first natural frequency, the high level of vibration occurs at the area nearby the exciting point and its opposite location at opposite edge. It can be noticed that the higher natural frequency, the more spreading of vibration power over the plate. The higher vibration power flow occurs mostly near the edges of the plate. The reason of this behavior could be the boundary of the plate.



a) Power at first natural frequency

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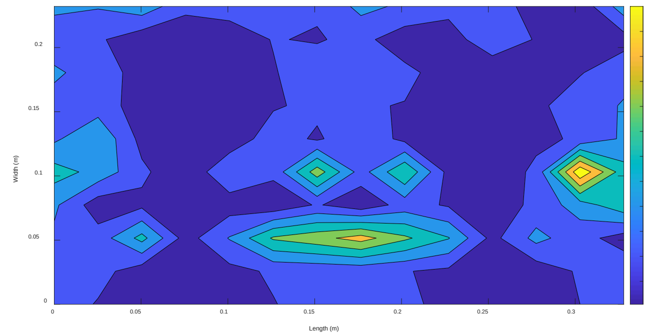
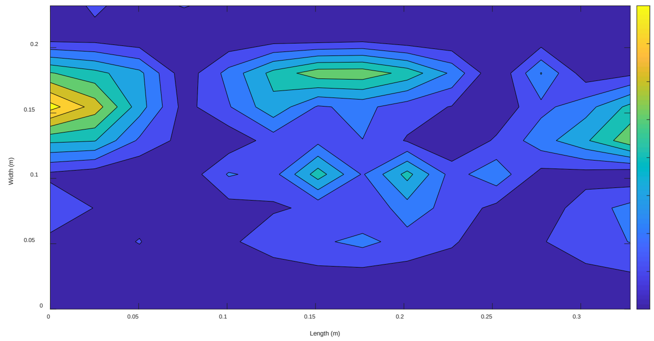
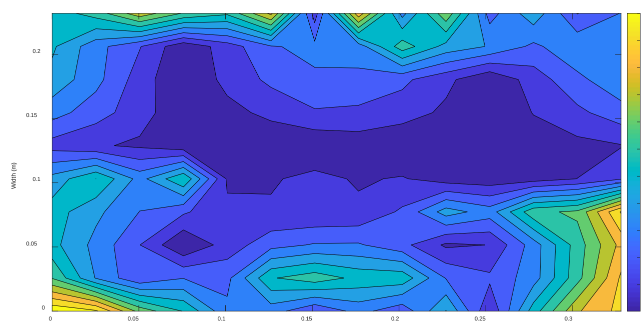


b) Power at second natural frequency



c) Power at third natural frequency



d) Power at fourth natural frequency

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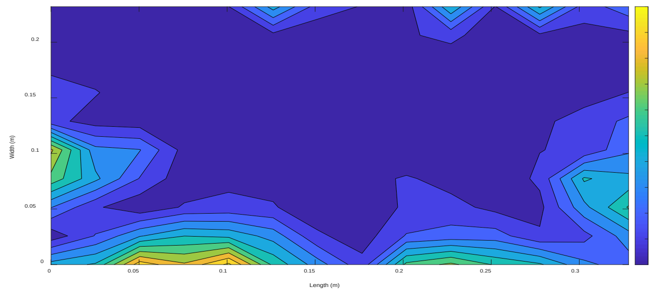
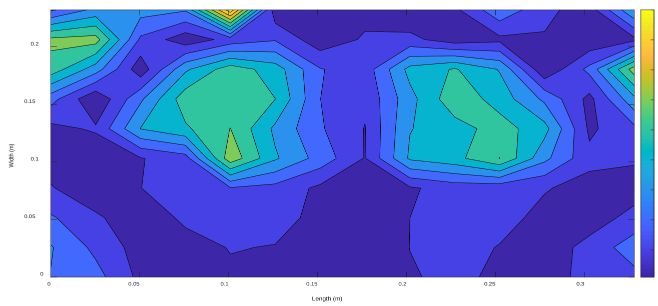


e) Power at fifth natural frequency



f) Power at sixth natural frequency

Figure 6: Power flow over the plate at different natural frequencies

IV. CONCLUSION

The measurement of the transverse vibration of the plate was conducted in this study. The experimental setup was carefully installed, and coherence function was continuously monitored during measurement to get the reliable measurement results. The dynamic characteristics of the plate such as natural frequency, frequency response function was generated. Then, the vibration power flow over a range of frequency (0 to 520 Hz) was measured. According to the results, the magnitudes of the power flow are decreasing with respect to distance from the exciting point. This is because of the effect of structural damping. However, the level of the vibration power may be increasing at areas near the edges of the plate, if there is far field effect. The power flow distributions over the plate at different natural frequencies were presented with contour map. The results show that the higher vibration power flow occurs mostly near the edges of the plate. These vibration power flow distribution maps provide information for the effective control of the vibration of the structure such as where the structure should be strengthened, and where the high vibration power occurs at certain frequency.

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