A STUDY OF VIBRATION MODE SHAPE AND NOISE EMISSION OF A RECTANGULAR PANEL

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ABSTRACT

Contemporary procedures for the determination of structural vibration, relies on vast computer storage with excessive time for manipulation. This thesis resorts to an investigation of the vibration and noise radiation of flat panels*. It avoids prolong calculation and presents novel approximate formulae devised in this work. An outline of some of the formulae is given. In vibration of Plates, an approximate method using a technique of 'length equivalencing' reduces and simplifies the classical solution procedure. A method of determining the local modes of a rectangular plate with a number of symmetrical parallel stiffeners is also given. This is achieved by observing linearity in the modal configuration. Hitherto, this phenomenon has not been reported in research literature. The purpose of investigating the noise radiation of the plates was to determine the noise level in the proximity of the plate within a room or enclosure. The room of industrial/manufacturing areas is reverberant hence its acoustic properties must be measured before prediction of the noise level is possible. The classical property is the measurement of Reverberation Time (RT). In this investigation, a novel technique of predicting a family of decay curves of varying absorption coefficient, α and fitting them with the actual decay measured has been calculated. Thus a protracted advance into the detailed conventional acoustic properties was alleviated.

ABSTRAK

Kaedah moden untuk menentukan getaran pada struktur perlukan pada storan komputer yang sangat besar dan masa berlebihan untuk proses pengolahan. Tesis ini memberi alternatif kepada penyelidikan ke atas getaran dan kebisingan kepingan. Ianya untuk mengelakkan proses pengiraaan yang panjang dan ditunjukkan di sini kaedah rumus baru yang hampir dalam kerja kajian ini. Satu garis kasar ke atas rumus-rumus tersebut diberi. Pada getaran kepingan, satu kaedah yang hampir dengan menggunakan teknik 'length equivalencing' memudahkan lagi tatacara penyelesaian secara klasik. Satu kaedah untuk menentukan mod tempatan (local mode) pada satu kepingan empat segi sama dengan pengukuh-pengukuh simetri juga telah diberi. Ini dicapai dengan mengawasi satu kelelurusan berlaku pada tatarajah modal. Sehingga kini, fenomenon ini belm dilaporkan hasilnya dalam kajian literatur yang telah dibuat. Tujuan mengkaji sinaran bunyi pada kepingan adalah untuk menentukan tahap kebisingan pada kawasan yang berhampiran dengannya di dalam satu bilik atau kawasan tertutup. Oleh sebab bilik-bilik di kawasan industri/pembuatan bergema, sifat-sifat akustiknya diukur dahulu sebelum membuat jangkaan terhadap tahap kebisingan. Cara yang klasik ialah mengukur Masa Penggemaan (MP). Dalam kajian ini, satu teknik baru yang meramalkan satu keluarga lengkung-lengkung susut dari pelbagai Pekali Serapan α dan sesuaikannya dengan lengkung susut sebenar yang diukur dan telah dikira. Dengan itu, satu lanjutan kaedah menyeluruh diguna dalam kajian ini menggantikan kaedah ciri-ciri akustik yang lama dan terperinci.

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LIST OF SYMBOLS

a	-	Longer side of panel, m
A	-	Amplitude of deflection, dB
A	-	Area, m^2
b	-	Shorter side of panel, m
c	-	Speed of sound, m/s
C	-	Celsius
E	-	Energy, J
E	-	Modulus of elasticity or energy of panel, N/m^2
f	-	Frequency, Hz
G_x, G_y	-	Functions of m and n in frequency expression
H_x, H_y	-	Functions of m and n in frequency expression
g	-	Gravitational acceleration, m/s^2
h	-	Panel thickness, m
J_x, J_y	-	Functions of m and n in frequency expression
k	-	Constant
K	-	Stiffness Matrix of ALGOR software

L_W	-	Sound power level of panel, dB_{re} 1pW
L_P	-	Sound pressure level of panel, dB_{re} 20μPa
L_{PR}	-	Sound pressure level of reference source, dB_{re} μPa
L_{WR}	-	Sound power level of reference source, dB_{re} 1pW
M	-	Mass of Accelerometer, gram
m,n	-	Vibration modes
n	-	Number of bays
p,q	-	Iteration vector of ALGOR software package
Q	-	Directivity
r	-	Distance from noise source, m
v	-	Measured velocity/ surface velocity, m/s
v	-	Required velocity, m/s
V	-	Volt
W	-	Sound Power, Watts
ω	-	Angular velocity, radian/s
w	-	Mode shape integral
α	-	Absorption Coefficient, dimensionless
σ_{rad}	-	Radiation ratio/ Radiation efficiency
λ	-	Mode shape function or frequency factor
η_s	-	Structural loss factor
$\eta_{acoustic}$	-	Acoustic loss factor
π	-	Pi
ρ_m	-	Density of material, kg/m^3
ρ	-	Density of air, kg/m^3
θ	-	Angle of directivity, degree

υ - Poisson's ratio

$\overline{}$ - Space average over the panel surface

< > - Time average over a given time period

$\sum$ - Summation

LIST OF ABBREVIATIONS

DOF	-	Degree of Freedom
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
BEM	-	Boundary Element Method
R_c	-	Room Constant
RMS	-	Root Mean Square
RT	-	Reverberation Time
SLM	-	Sound Level Meter
SPL	-	Sound Pressure Level
SWL	-	Sound Power Level
OCMA	-	Oil Company Materials Association
OSHA	-	Occupational Safety and Health Administration

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CHAPTER I

INTRODUCTION

Plates are used in a multitude of industrial applications; machine tool structures, motor car bodies, aeroplane fuselages, ventilating system bodies, windowpanes and similar applications. All of the above are subjected to vibration and resulted in noise radiation into the environment. It is therefore, justified to investigate the effect of vibration and noise into the area of working condition in locations near the recalcitrant vibrating plate.

The amount of noise disturbance received due to plate vibration is governed by the following:

(1) The frequencies of the plate.
(2) The amplitude of the plate in vibration which is a function of the plate damping.
(3) In general, the noise radiation of a plate given by Richard (1979) and later developed by McNulty (1979) for a manufacturing situation in term of sound power, W is given by:

$$W = \rho\, c < \overline{v^2} > \sigma_{rad} A \tag{1}$$

where,

ρc is the impedance of the medium in this case, air

σ_{rad} depends on the geometry and frequency of the plate vibration

A is the area of the plate

$\langle v^2 \rangle$ is the space and temporal (time) average vibration of the panel

(4) The acoustic properties of the enclosure of the plate.

1.1 Background

The study on vibration of plates and structures has been progressively developed over the last fifty years. Warburton (1954) wrote a definitive type paper on the vibration of rectangular plates in which he used beam functions. Many doctorate and masters theses on plate vibrations emerged after Warburton (1954) and McNulty (1979) thesis on noise and vibration of flat plates is typical.

The advent of large storage computers in the early 1970's initiated other techniques and the Finite Element Method (FEM) was born. FEM has made the earlier work redundant to a great extent. The published work on FEM to solve plate and structural vibrations is prolific. This has been further accelerated by the use of large packages such as PAFEC (David, 1987), COSMOS and ALGOR etc. However, vibration of structures is not an end in itself. It leads to the study of fatigue or noise radiation from the structure. This is a complex mechanism and has been simplified by Richards (1979) who related the vibration of the plate to its acoustic intensity through the plate geometry.

If the plate is situated in an enclosure, the acoustics of the enclosure should be known and the relationship between the acoustic intensity and the enclosure's acoustics for a number of sources and a number of receivers had been developed by McNulty and Rosehume (1976).

The activity described above has become sophisticated and in some ways has made simple solutions remote. The next section will outline the place of this work to address this balance and enable designers to come to a quick solution for a specific situation.

1.2 Statement of The Problem

To study the vibration characteristics of flat plate and its associated noise radiation due to vibration. The prediction of the sound pressure level in the immediate reverberant environment of a vibrating plate is to be determined.

1.3 Purpose of The Study

This research project is designed with the following objectives in order to achieve the scientific findings through the following steps:

1. To conduct study on the vibration of panel at its natural frequencies with respect to its mode shapes for a given boundary condition.

2. Attempts are made using the finite element based software to study the effect of stiffeners on the vibration mode shape. To what extent the contribution from these simulated stiffeners in reducing vibration and thus noise radiation from a vibrating panel will be considered.

3. Examine the relationship between Sound Power Level (SWL) and surface vibration velocity of the panel.

4. Determination of absorption coefficient, α for the evaluation of room constant, R_c so as to evaluate the resulting Sound Pressure Level (SPL) within an enclosure from a single noise source.

1.4 Importance of The Study

This research project undertakes the necessary framework contributed to the area of noise and vibration control. It is necessary to understand the vibration mechanism and the phenomena of noise radiation before any controlling measure can be taken.

The study of simulated stiffener caters for the weights constrain needed in design process in cases where noise criteria are needed. Further study of panel with stiffeners results in the simplified method of obtaining the required in between natural frequencies within a frequency band.

A proposed novel method of obtaining the absorption coefficient, α will also simplify the conventional approach of obtaining this quantity through Reverberation Time (RT) measurement.

To this end, this research provides another dimension in getting a better understanding of noise and vibration of a simple structure from the perspective of its noise source and transmission path.

1.5 Scope of The Study

In the study of natural frequencies of the rectangular panel, a comparative study of results was performed from various approaches. Theoretical derived results from the classical Warburton's (1954) approach based on his coefficient table were compared with those from ALGOR's finite element software package. Experiment natural frequencies were estimated from Klandi's figures where the results obtained depend on the visualization of the nodal lines for a particular mode shape.

Frequency response curve measured from the respective natural frequency provides a mean for material loss factor estimation through the 'Half Power Point' method.

Extension of panel vibration work is the study of change in mode shape due to the presence of stiffeners where its arrangement is confined to 4 bays and 8 bays array. This is to establish a reliable result for the relationship between their natural frequencies and vibration mode number.

Measurement of surface velocity and the rest of the experiments mentioned above can be done in the laboratory environment. The same excitation setting as with surface velocity measurement ensure the same experiment condition is restored for determination of Sound Power Level (SWL) from the vibrating source. This part of experiment work attempts to estimate the radiation ratio of the panel based on octave band measurement.

Final part of this research is the determination of the acoustic property for the institute's main hall where room constant, R_c will be evaluated from the determination of its variable parameter, absorption coefficient, α. Thus, a prediction of SPL into its proximity is possible.

CHAPTER II

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Review from Previous Work

Literature review for this research work on noise and vibration of plate (panel) initiated this research project. Basic plate vibration theory comes from Warburton (1954), Warburton, *et. al* (1983) and later an introduction of simulated stiffeners to panel was referred to McNulty (1979) and Berry, *et. al* (1994). ALGOR software package available from this institute serves as a valuable tool to study the effect of panel vibration with and without the addition of stiffeners. Thus, published paper from Atalla, *et. al* (1994) was referred to for review of numerical approach of finite element on plate vibration. Much research work had been done on the area of noise radiation from a plate. However, comprehensive one comes particularly from Ver, *et. al* (1992) and Richard (1979).

Warburton (1954) considered the free transverse vibrations of rectangular plates with all possible boundary conditions obtained by combining free, freely supported, and fixed-edges. 'Rayleigh' method assuming waveforms similar to those of beams was used to derive a simple approximate frequency expression for all modes of vibration. Thus, for a plate with all its edges fixed, the waveform assumed is the product of the characteristic functions for two beams with fixed ends. For rectangular plates, the nodal pattern consists of lines approximately parallel to the sides of the plate. This approach into which a frequency factor, λ which is

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