THEORETICAL STUDIES REGARDING THE VIBRATION OF THIN PLATES

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ABSTRACT: During the manufacturing process of materials and assemblies, structural defects can occur. Thin plates used in industrial engineering typically have thicknesses of a few millimeters or less, making it impossible to use conventional non-destructive testing methods such as ultrasound or eddy currents. As a result, knowledge of their internal integrity is not possible.This study highlights the natural vibration modes of the plates by identifying specific frequencies in modal analysis to avoid overlapping in operation, which can lead to resonance and rapid destruction of the structure when it exits the assembly's service. In addition, a source study of variable frequency vibrations was conducted to observe the design (arrangement) of nodes and antinodes on the thin plates studied. This is necessary to prepare the technical framework that validates the use of vibrations for non-destructive testing of thin plates.

KEYWORDS: plates, vibrations, Matlab.

1. Introduction

This research falls under a major field of interest regarding the vibration behavior of mechanical structures. The information contained in vibration signals for assessing the severity and location of defects can be used in the early detection of structural defects, allowing for scheduled maintenance. In this study, a dynamic modal analysis method for defect identification was proposed, with the major advantage being that it does not require access to the affected area. Essentially, a defect in a structure represents a deviation from the material or geometric properties of the structure, which alters its modal behavior through vibrations that produce displacements and stresses that modify certain mechanical and dynamic characteristics. Thus, the monitored parameters are: natural frequencies, modal shape, stiffness or flexibility.

Defect detection can also be performed through an algorithm. In this case, the algorithm's ability to detect defects, practical applicability, repeatability of the experiment for verifying results, extrapolation of the characteristic, and graphical representation can be optimally utilized through the dynamic analysis of plates.

2. Methods and Materials used in simulations:

• Modal Analysis

The theoretical framework of the modal analysis method involves the following elements:

a. Equation of Motion:

The equation of motion is a partial differential equation that describes the dynamic behavior of a structure or mechanical system. For linear systems, the equation of motion can be written in the form:

$$F(t) = M \times x''(t) + C \times x'(t) + K \times x(t) \qquad (1)$$

where:

M = mass matrix

$x(t)$= displacement vector

$x'(t)$= velocity vector

$x''(t)$ = acceleration vector

C = damping matrix

K = stiffness matrix

$F(t)$= vector of applied external forces

For linear and isotropic systems, the equation of motion, using the equilibrium equations for a continuous material, can be written as follows:

$$\rho \times \frac{\partial^2 u}{\partial t^2} = \nabla \bullet \sigma + f \tag{2}$$

where:

ρ = material density

u = displacement vector

σ = stress tensor

f = vector of applied external forces on volume

∇ = gradient operator

• = divergence operator

$\frac{\partial^2 u}{\partial t^2}$= second derivative with respect to time

The gradient operator is an operator that acts on a scalar field and produces a vector field. The gradient of a scalar field (a scalar function with spatial variables) indicates the direction and maximum rate of change of the scalar function in space. In three dimensions, the gradient of a scalar function f(x, y, z) is defined as:

$$\nabla f = \left(\frac{\partial f}{\partial x}\right) i + \left(\frac{\partial f}{\partial y}\right) j + \left(\frac{\partial f}{\partial z}\right) k \tag{3}$$

where:

- ∇f gradient of function f

-$\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial f}{\partial z}$ partial derivatives of the function f

- i, j și k unit vectors in the directions of x,y and z

The divergence operator acts on a vector field and produces a scalar field. The divergence of a vector field measures the rate of change of the vector flux in an infinitesimal volume around a point. In three dimensions, the divergence of a vector field A(x, y, z) is defined as:

$$divA = \nabla \bullet A = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} \tag{4}$$

where:

- $divA$ divergence of a vector field A

-A_x, A_y, A_z the components of the vector field in the directions of x, y and z

- $\frac{\partial A_x}{\partial x}, \frac{\partial A_y}{\partial y}$ și $\frac{\partial A_z}{\partial z}$ partial derivatives of the vector field components A with respect to x, y and z.

b. Eigenvalue problem: To determine the natural frequencies and mode shapes, the equation of motion is transformed into an eigenvalue problem. This is generally done by applying a Fourier or Laplace transform, followed by the elimination of terms containing time derivatives. The resulting eigenvalue problem takes the form:

$$(K - \omega^2 \times M) \times x = 0 \tag{5}$$

where:

ω = angular velocity (rad/s)

x = modal shape

c. Solving the eigenvalue problem: Solving the eigenvalue problem involved in modal analysis can be done through numerical methods such as the Jacobi method or the Lanczos method. These methods produce pairs of eigenvalues and eigenvectors that correspond to natural frequencies and mode shapes.

d. Interpretation of results: The natural frequencies and mode shapes obtained from solving the eigenvalue problem can be used to characterize the dynamic behavior of the structure or mechanical system.

For example, modal analysis can be used to evaluate the effects of design changes, to identify resonance issues, or to develop active or passive vibration control strategies. The theoretical framework of the modal analysis method involves formulating the equation of motion for the structure or mechanical system of interest, transforming this equation into an eigenvalue problem, solving the eigenvalue problem to obtain natural frequencies and mode shapes, and interpreting the results to understand and control the dynamic behavior of the system. This method can be applied in a variety of contexts, such as civil structure analysis, aircraft and ground vehicle vibration analysis, as well as the study of the dynamic behavior of mechanical or electronic components.

Modal analysis can be performed both experimentally, by measuring the response of the structure to external excitations and identifying modal parameters, and numerically, using finite element techniques or finite difference methods to efficiently solve eigenvalue problems.

The methodology used by ANSYS for modal analysis includes the following steps:

- Creating the geometric model:

The geometry of the first thin plate with sub-millimeter thickness (0.6 mm) is modeled in ANSYS, with dimensions of 240 x 240, in rectangular form.

- Defining the material:

The material for the plate is chosen, S235 steel for the plate with dimensions of 240x240x0.6 mm.Steel S235 is a construction material from the carbon steel family, with medium tensile strength and high elasticity. It is used in various industrial applications, such as the construction of metal structures, machinery and equipment, as well as in the automotive industry.The mechanical and physical characteristics of the material from which the rectangular plates are constructed are:

1) Longitudinal elastic modulus or Young's modulus, E = 210,000 MPa
2) Transverse elastic modulus, G = 81,000 MPa
3) Poisson's ratio, ν=0.3
4) Density, ρ=7850 kg/m^3 .

3. General description of the vibration study setup

The proposed vibration study setup consists of the following main components:

- Frequency generator: capable of generating a wide range of frequencies between 50 Hz and 20 kHz, with coarse adjustment at the hertz level and fine adjustment at the 0.1 Hz level.

- Threaded rod with a diameter of 5 mm and a length of 50 mm, fixed at one end to the frequency generator, and the other end threaded for 5 mm to allow for fixing of the sample in the setup.

- Fixing washers: Two fixing washers are required, one at the bottom and one at the top, with an outer diameter of 10 mm and a thickness of 0.3 mm. They serve to place the thin plate on the rod. They ensure a safe and stable fixing of the plate on the rod without affecting the plate's modes of vibration.

- Front control panel: includes an electronic display indicating the working frequency of the generator, a button for coarse frequency adjustment, a button for fine adjustment, and a switch button.
- Steel sample: with dimensions of 240 x 240 x 0.6 mm, fixed on the rod using fixing washers and a nut. Salt will be sprinkled on its surface to highlight the plate's natural modes of vibration.

4. Analysis of experimental results and discussions

The first natural mode of vibration that provided a clear arrangement of talcum powder on the steel plate was at a frequency of 1054 Hz (see Fig.1). A regular pattern is observed on both sides of the plate's axes of symmetry. This arrangement may contribute to the symmetry of nodal and ventral arrangements in the plate's natural vibration modes at its own frequencies of vibration for S235 steel.

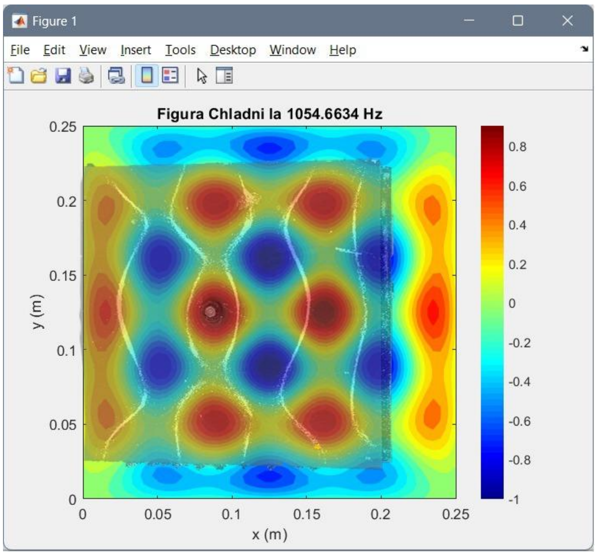

Fig. 1. Figura Chladni la 1054,6634 Hz

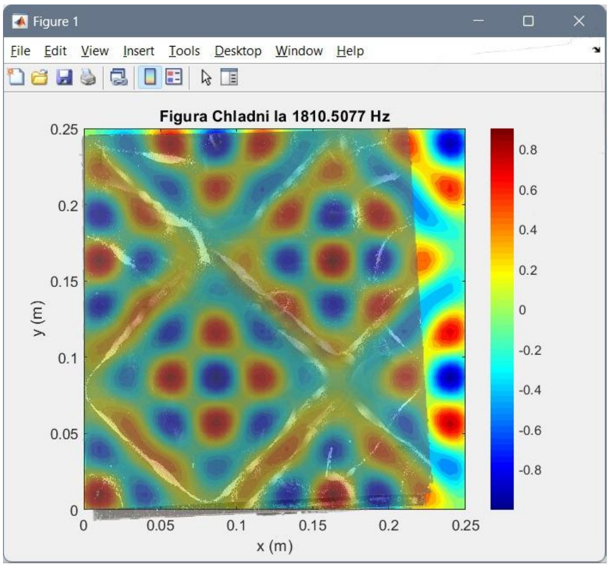

Fig. 2. Figura Chladni la 1810,5077 Hz

The way energy is applied can influence the vibration modes and the arrangement of nodal and ventral lines in modal analysis. For example, when applying a sustained vibration at a constant or variable frequency, the general vibration modes may be similar, but small differences may exist in terms of the frequencies and amplitudes of these vibration modes. These differences can influence the design of nodal and ventral lines in modal analysis.

In general, the symmetry and arrangement of nodal and ventral lines in a steel plate are influenced by several factors, such as the type of crystal lattice, crystal orientation, plate size and shape, how it is fixed, and how energy generating vibration is applied.

The next vibration mode that provided a clear arrangement of talcum powder was obtained at 1810 Hz (see Fig.2). At higher frequencies, the number of nodal and ventral lines present on the plate increases due to the reduction in the wavelength of the mechanical oscillation produced by the generator.

The next vibration mode that provided a clear arrangement of talcum powder was obtained at 1297 Hz (see Fig.3).

The experimental setup was validated by comparing the same vibration modes, for the same eigenvalues of frequency, in both the real and numerically simulated versions using the MATLAB program.

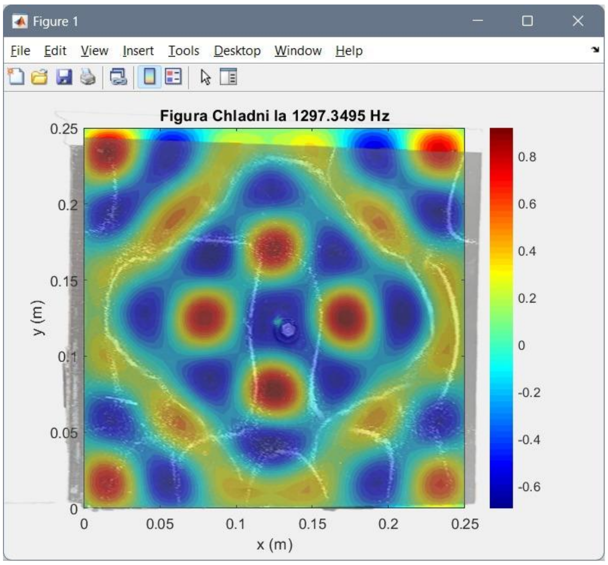

Fig.3. Figura Chladni la 1297,3495 Hz

5. Conclusions

There are several factors that can influence the arrangement of nodal and ventral lines in thin steel plates, including crystal orientation, plate size and shape, how energy generating vibration is applied, and the type of crystal lattice. Symmetry can be explained by using the cubic crystal system with a centered volume of the material, which produces a symmetric arrangement of nodal and ventral lines in the S235 steel plate, regardless of size or shape. Modal analysis and numerical simulation are important methods for understanding the vibration modes of thin plates and for detecting defects in various industries. This study can be extended to include other types of thin plates and to analyze the vibration modes of three-dimensional structures. Furthermore, ongoing research in the field of composite materials can offer new solutions for improving the performance of thin steel plates by combining them with other materials with complementary properties. Additionally, the development of new technologies for analyzing and monitoring the vibrations of thin plates can contribute to improving the safety and efficiency of structures in various industries, such as construction, transportation, or the aerospace industry. In conclusion, the study of the vibrations of thin steel plates is essential for the development and improvement of technologies in various fields and can lead to significant innovations in the future. In addition, by using advanced technologies such as X-ray tomography or electron microscopy, it is possible to obtain detailed images of the internal structure of thin plates, which can lead to a better understanding of how they vibrate and how their performance can be improved. In conclusion, the study of vibrations in thin steel plates is an important and complex subject, with many possibilities for further research and development.

6. Bibliography

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