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USING VIBRATIONS IN SMART FURNITURE DESIGN

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Abstract: *This paper presents the new design of a furniture piece (table) that integrates a Chladni device. After a brief introduction regarding the Chladni device, in the first part there are presented the mathematical model and its implementation in order to realize the proposed product. The second part shows the CAD model designed and the eigenmodes calculation of integrated squared plate using finite element analysis. Following the finite element analysis, the real simulation was performed on the table prototype. The results of this simulation give some particular pattern wave of salt grains at chosen frequencies. Some of the salt shapes resulted are compared with the result of the eigenmodes calculations, and these are almost similar. The device could represent the core functionality of an innovative furniture product, aimed at commercial beneficiaries, cafes, restaurants, clubs, etc.*

Key words: Chladni plate, eigenmodes, pattern wave, furniture design.

1. INTRODUCTION

The Chladni device was developed in the late 18th century by the physicist and musician Ernest Chladni, also known as the "father of acoustic" [3]. He discovered the complex patterns of the standing waves, vibrations that can occur in a two dimensional object.

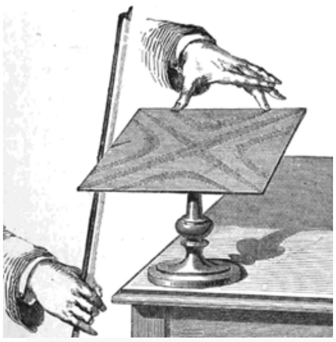


Fig. 1. Chladni plate for creating various figures [2]

The study of vibrations was performed of circular and square plates fixed in the center and driven with a violin bow, as seen in fig. 1, [2]. His experiment shows the visual determination of the normal mode of vibration, performed by fine sand, sprinkled uniformly over the plates. The fine sand is moved towards the nodal region when a violin bow crosses over the edge of the plate. The shape of the Chladni patterns depends only on frequencies, and amplitude depends on the intensity of turbulence and velocity of the sand grains moving on the plate [2]. Chladni was not the first to see the vibration pattern; others are Leonardo Da Vinci and Galileo Galilei [1].

The aim of this article is to establish a concise connection between the vibrations and new furniture product design. In this study there are determined the vibration modes of a square thin plate. For generating vibration, in the experiment it used a mechanical driver controlled by an electrical oscillator. The corners of the plate are rigidly connected and the edges are free. The source of vibration is placed in center of plate. Before performing the practical experiment, the vibration modes are determined using the finite element method to view the specific shape of the Chladni patterns and their frequency values. All component of this device are built to realize the prototype of a table used in exploratory furniture design. For determining the shape of the Chladni patterns, salt grains are spread on the plate surface.

2. MATHEMATICAL FORMULATION

The following paragraphs present the mathematical formulation needed to understand the modal patterns of the rectangular plates, model presented by Elmore Williamand Mark Heald, in their book "*Physics of Waves*", reference [6] presented in [7].

To begin it is necessary to investigate the solution of the wave equations in two dimensions:

$$\partial_{x,x} u + \partial_{y,y} u = \frac{1}{c^2} \partial_{t,t} u \quad [7] \qquad (1)$$

Assuming a product solution:

$$u(\mathrm{x,y,t}) = \mathrm{X(x)\,Y(y)\,T(t)}\ [7] \qquad (2)$$

By separating the variables will obtain three distinct equations:

$$\partial_{x,x} X + K_x^{\,2} X(\mathrm{x}) = 0\ [7] \qquad (3)$$

$$\partial_{\mathrm{y,y}} Y + K_y^{\,2}\,\mathrm{Y(y)} = 0\ [7] \qquad (4)$$

$$\partial_{z,z} Z + K_z^{\,2}\,\mathrm{Z(z)} = 0\ [7] \qquad (5)$$

where:

$$K_y^{\,2} + K_x^{\,2} = \frac{w^2}{c^2}\ [7] \qquad (6)$$

$$|K| = \sqrt{K_y^{\,2} + K_x^{\,2}}\ [7] \qquad (7)$$

$$w^2 = c^2 \cdot |K|\ [7] \qquad (8)$$

$$w^2 = c^2 \cdot |K|\ [7] \qquad (9)$$

The total solutions of the Cartesian coordinates are:

$$u(\mathrm{x,y,t}) = A \cdot Exp\left[K_x X + K_y Y - wt\right]\ [7]\ (10)$$

$$\phi = K_x X + K_y Y - wt \quad [7]\ (11)$$

The real part of the equation is given by the next relation:

$$u(\mathrm{x,y,t}) = A \cdot \sin\left(K_x X\right) \sin\left(K_y Y\right) \cos\left(wt\right) [7](12)$$

The equations presented before describe two waveforms, one moving in the *x* direction and one moving in the *y* direction. For a rectangular plate with length *a,* and width *b* and fixed edges, the amplitude must go to zero at the boundary.

$$K_x a = \pi \cdot n \qquad n = 1,2,3.... \ [7]\ (13)$$

$$K_y b = \pi \cdot m \qquad \mathrm{m} = 1,2,3.... \ [7]\ (14)$$

thus,

$$u(\mathrm{x,y,t}) = A \cdot \sin\left(\frac{n\pi x}{a}\right) \sin\left(\frac{m\pi y}{b}\right) \cos\left(wt\right) (15)$$

From the relation 7, the modal frequencies will be given by the next relation:

$$w = \pi c \sqrt{\left(\frac{n}{a}\right)^2 + \left(\frac{m}{b}\right)^2} \quad [7] \qquad (16)$$

3. PROTOTYPE HARDWARE

The software of the frequency generator driver is built in the Arduino programming environment. The value of the frequencies generated can be switched by a potentiometer included in the generator interface. The microcontroller built generates a PWM signal, which is converted to an analog signal. This generator presented in fig. 2gives frequencies between 0 and 50 kHz. In order to archive the prototype model has been studies more research, in which is presented the ways to build the prototype model of a table [1, 5].

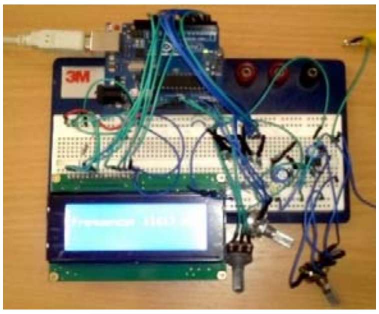


Fig.2. The frequency generator

The square plate has a constant thickness of one millimeter. The experiment is performed according to standard ambient condition of 20°C, 65% relative humidity. The aluminum plate, presented in fig. 3, is placed perfectly horizontally and the edges create a perfectly square shape, and are rigidly connected in the corners.

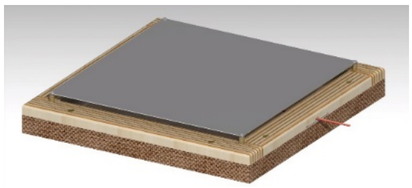


Fig. 3. Square plate assembled on the frame

The material of the plate is directly responsible for its behavior and of the salt grains wave's patterns.

The loudspeaker was built from cooper wire and neodymium magnet, shows in fig. 4, a, b. The neodymium magnet was bonded to the frame of the table and the copper wire was wrapped into a coil bonded to the aluminum plate.

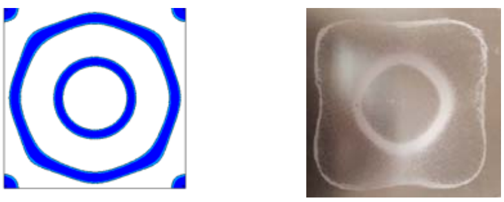
a) The neodymium magnet b) The built coil model

Fig.4.Loudspeaker

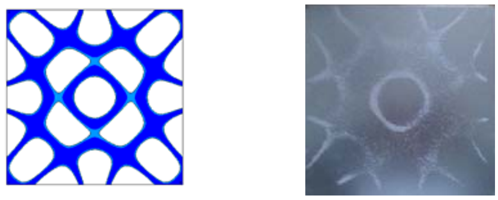
2. EIGENMODES USING FEA

The eigenmodes of a rectangular plate can be given in closed form by solving the wave equation analytically, or can be solved easily using finite element analysis software. In order to determine the frequency values when occurring the particular shapes and to compare to the real results given by the designed prototype. In the following the normal modes of vibration of this rectangular plate are determined using finite element method. The plate is meshed in shell elements with a target size of 1.2mm. It is constrained with a rigid link in each corner. The properties and the thickness of the aluminum material plate are assigned.

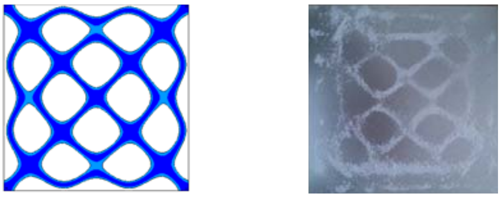
In the following pictures will present the results of eigenmodes simulation. Some Chladni figures resulted after simulation and their correspondence shape resulted after the practical experiment, are shown where is appropriate. It can be seen that the wave patterns are made visible by the salt grains accumulating along the nodal lines.



F=372 Hz



F=745Hz



F=779Hz

F=835 Hz

Fig. 5. Various Chladni figures resulted after simulation and experiment.

The following figure shows the Chladni device integrated into a coffee table.

Fig. 6. Coffee table design.

7. CONCLUSION

The paper presents a new modality to integrate the Chladni device into a furniture design.

Advantages of the electronic plate over its bowed counterpart:

- the wave shape can be more clearly;
- using an oscillator it is easy to show the wave patterns very quick;
- the target frequencies can be specified on the oscillator.

The weakness of this experiment it's constituted by the choice of the plate material. If we would chose a bronze alloy or brass, forms more similar forms as with the FEM simulation and more clearly should appear. Should we choose a material with higher tenacity, the position of the plate surface must be perfectly parallel to the floor, because a tiny tilt makes it impossible to achieve of the wave.

The final design of the table has a transparent cover to protect the grains distributions. This table can be used for creating a various shapes in furniture design, and achieving some form of interactivity with user.

8. ACKNOWLEDGEMENTS

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*** Arduino software: http://www.arduino.cc/, November, 2014

*** Dassault Systèmes Catia V5 software: http://www.catia.com/, November, 2014

UTILIZAREA VIBRAȚIILOR ÎN PROIECTAREA DE MOBILIER INTELIGENT

Lucrarea prezintă integrarea unui dispozitiv Chladni într-un nou design de mobilier inteligent(masă). După o scurtă introducere cu privire la acest dispozitiv, în prima parte se prezintă modelul matematic al fenomenului de generare al diferitelor forme şi integrarea acestui dispozitiv în scopul realizării produsului propus. În a doua parte este prezentat modelul CAD şi determinarea modurilor proprii de vibrație utilizând metoda elementelor finite pentru o placă pătrată, asamblată rigid la colțuri. În urma analizei FEM, simularea practică a fost realizată pe tipul de masă, rezultând forme asemănătoare generate de distribuția granulelor de sare pe suprafața plăcii.Acest dispozitiv reprezintă un produs de mobilier inovativ având ca destinație comercială cafenelele, restaurantele, cluburile, etc.

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