EQUIVALENT STIFFNESS OF THE ELASTIC ELEMENT, TYPE LAMELLA, FOUND IN THE STRUCTURE OF THE MP42 MILL

Bogdan IVANCU[1], Gheorghe VOICU[1*], George IPATE[1], Filip ILIE[1]

The paper covers the stiffness calculation for the elastic elements type lamella, which they are found in the construction of the MP42 corn mill. For sifting the products in the mill, it has a sieve at the bottom that describes a vibrational movement that receives it by means of an oscillating mechanism. The vibration movement of the sifting sieve is achieved by means of elastic elements type lamellas whose elastic deformations during the vibration motion are rigidly conditioned. Knowing the stiffness, the elastic system can be optimized so that it can withstand the action of the efforts introduced in the mill.

Keywords: elastic elements, mechanical behavior, stiffness, frequency, inertance

1. Introduction

The analysis of the elastic systems, type lamella, is necessary to determine the vibration parameters (amplitude and frequency) and correlate them with the others parameters (in this case, the stiffness) in order to simultaneously achieve the required values of the relative movement of the grain that jumps on the sieve. As it has been studied in [1, 2], the failure or breakage phenomena of elastic systems are very complex and differ fundamentally from static cases to variable cases. The protection against vibration increases the lifetime of vibrating equipment thus ensuring reduced costs for maintenance and repairs. A vibrating system consists of the actual structure to which distributed masses (according to a certain law) and / or concentrated masses, are attached.

Any structure is capable, under the action of causes with dynamic character (time variation), to perform relative movement around an equilibrium position. A well-functioning sifting system can be achieved only by optimization of the parameters which determines the sifting process. For that, it requires that the functioning regime of the sifting system, regarding oscillation frequency, size and direction of velocities and accelerations of sieve points needs to be analyzed in the requirements of the sifting process.

Starting from the kinetostatic and kinetic analysis performed for the MP42 mill and presented in the scientific papers [3, 4], it is imperative to continue analyzing the structure of the mill focusing on the elastic elements system.

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[1] Faculty of Biotechnical Systems Engineering, University POLITEHNICA of Bucharest, Romania
[*] Correspondent author, e-mail: ghvoicu_2005@yahoo.com

By means of the elastic elements (lamella type) it is ensured the relative movement of the material on the surface of the sieve originating from the oscillating mechanism. Due to the shape and elastic properties of the material the elastic elements are made of, they allow elastic deformations that are acceptable or appropriate to the requirements under the external solicitations.

The elastic elements, type lamella (with rectangular section) are mainly subjected to bending, being mounted pre-tensioned as they are a part of the equipment that works in a vibrational environment. The sieving process of the particles after they have been milled is influenced by the amplitude of movement [5, 6]. The amplitude depends on the stiffness of the elastic system, the stiffness which represents the ratio between the force acting on the elastic element and their displacement due to the action of the force. Thus, their good functioning is due to their stiffness. The analysis of the elastic system behavior involves calculating the stiffness of the elastic elements and the stiffness of the mill structure.

The dynamic stiffness is the frequency dependent ratio between a dynamic force and the resulting dynamic displacement, and, as it is written in [7] “the increase of the dynamic stiffness will reduce the vibration response of the system”. The stiffness calculations provides information on the: efforts that occurs in the structure of the mill; the vibrations produced by the oscillating mechanism; the deformations of the elastic elements in different points in the structure. In other words, in order for the elastic element to function correctly, the local stiffness of the support supporting the elastic element must be considerably higher than the stiffness of the lamella. This local stiffness characterizes the continuous level of the inertance curve at the point where we make a measurement.

The inertance can be defined by the dynamic acceleration response induced at some point by a single excitation at the same point. The inertance is an important parameter because it allows the evaluation of the power injected into the structure at a certain point, which is then transmitted to the entire structure. Its knowledge is therefore important to be determined at points of excitation or fixation or with high deformation of an operating structure.

The inertance also makes it possible to identify the natural frequencies of a structure and to know the excitation frequencies to ensure they do not resonate. But this structure will vibrate despite this caution, the inertance allows knowledge of the "level" of vibrations in the structure.

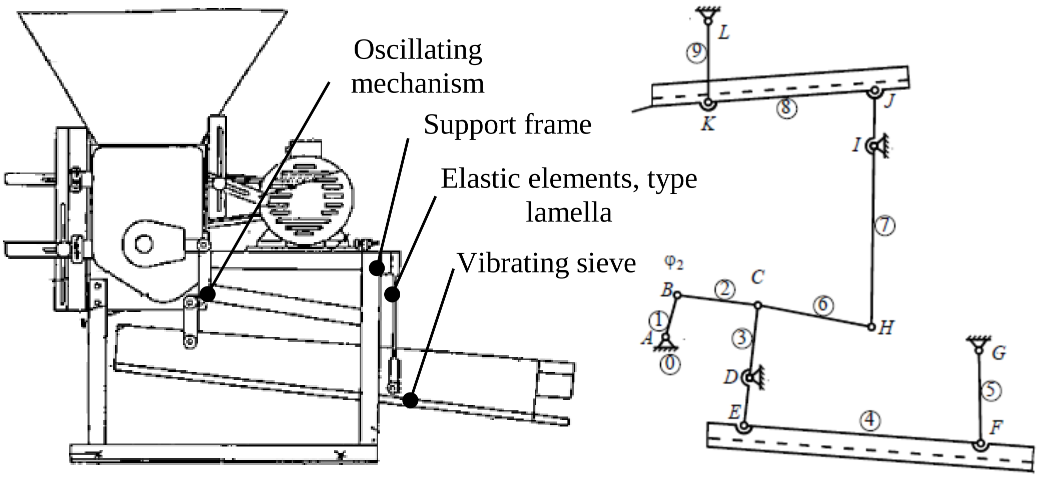
2. Materials and methods

The experiments were performed on the MP42 mill, located at the Faculty of Biotechnical Systems Engineering. The mill is intended for the grinding of maize grains in order to transform them into different sorts of grain for food consumption. The mill can also be used to harvest corn, wheat, barley, soy or other cereal for animal feed.

Due to the milling capacity that exceeds the needs of an individual mill, the mill can be used in private initiatives to serve a wider area comprising a village, a commune or a group of communes, as the case may be. For grinding the ground product, the mill has at the bottom, inside the support frame, a sieve describing a vibrational movement that receives it by means of an oscillating mechanism.

Beside the vibrating plate, the mill also features a cascade type crusher with 4 rolls, grain dispenser, and a strainer for cleaning the corn grain before grinding and aspiration of dust. The electric motor provides the movement of the four rollers with three serial milling, proceeding as follows:

- the first grist with a recommended distance between the rollers of 1 ÷ 1,6 mm;
- the second opening grist with a recommended distance between the rollers of 0, 5 ÷ 0,7 mm;
- the third grinder with a recommended distance between the rollers 0,05 ÷ 0,2 mm, for the final milling.



a) The positioning of the elastic elements b) The kinematic scheme, [1]

Fig. 1. The oscillating mechanism of the MP42 mill

A number of studies dealing with the measurement of the equivalent stiffness for a specified system or piece, have been undertaken in the automotive domain, [8, 9]. Therefore, this paper makes a first attempt to present the steps in calculating the equivalent stiffness of an elastic element using the CHANAL method.

Generally, the stiffness analysis evaluates the effect of the applied external forces on the compliant displacements of the end-effector. Numerically, this property is defined through the "stiffness matrix" K, which gives the relation between the translational displacement and the static forces causing this transition.

To determine the local stiffness, a force is applied at a certain point and the acceleration is measured in the desired direction. The curve obtained is then logarithmic in relation with the frequency. An equivalent stiffness curve (iso-stiffness curve) associated with an inertance curve is defined so that the curvature area on both sides of the iso-stiffness is minimal. The calculation of the iso-stiffness of the inertance curve is achieved using the CHANAL method, [7], defined as follows:

I. Defining the inertance curve, $I\ (x_{inertance}, y_{inertance})$ and $K=10^6$ N/mm,

where, $x_{inertance}$ = the frequency range [f_{min}, f_{max}], where the inertance is calculated.

$y_{inertance} = 20\cdot\log(\gamma/F)$.

K is the reference stiffness, in N/m (*is an iso-stiffness value frequently used by automobile manufacturers: this corresponds to an equivalent displacement of 0.0001 mm under a force of 1 N*).

γ is the measured acceleration, in m/s^2.

F is the reference force ($F = 1$N) used for K.

II. The iso-stiffness curve is calculated as:

$$y_{iso-rigiditatea} = 20\cdot\log\left(\frac{\omega^2}{K}\right) \tag{1}$$

where, $\omega = 2\pi f$ is the pulsation.

III. The average between the $y_{iso\text{-}stiffness}$ and $y_{stiffness}$ curves in the range of frequency [f_{min}, f_{max}], is calculated as:

$$med = \frac{\sum_{i=1}^{n}(y_{ineranta})_i - (y_{iso-rigiditate})_i}{n} \tag{2}$$

where, i represents the value of frequency in the range [f_{min}, f_{max}]

n represents the number of frequency taken into account.

IV. At the end, the equivalent stiffness, K_{ech} is calculated:

$$K_{ech} = 10^{\left(\log\frac{med}{20}\right)} \tag{3}$$

and the iso-stiffness curve is defined by:

$$y_{iso-rigiditate(K_{ech})} = 20\cdot\log\left(\frac{\omega^2}{K_{ech}}\right) \tag{4}$$

Acceleration transducers are used to determine the acceleration. The acceleration transducers, type IMU 10DOF are motion tracking modules. Their design is based on the sensor MPU6050, HMC5883L and BMP180. The sensor MPU6050 is the world's first integrated 6-axis Motion Tracking device that combines a 3 – axis gyroscope, 3 – axis accelerometer, and a Digital Motion Processor™ (DMP), [10]. The transducers are mounted according to the scheme in figure 2, so that accelerations are measured in 4 positions:

- Position *M1* → the accelerations are measured of at the lower part of the elastic element where the largest displacements are occurring;
- Position *M2* → the accelerations are measured on the support frame of the mill;
- Position *M3* and *M4* → the accelerations are measured at the top of the elastic element where they are fixed to the support frame.

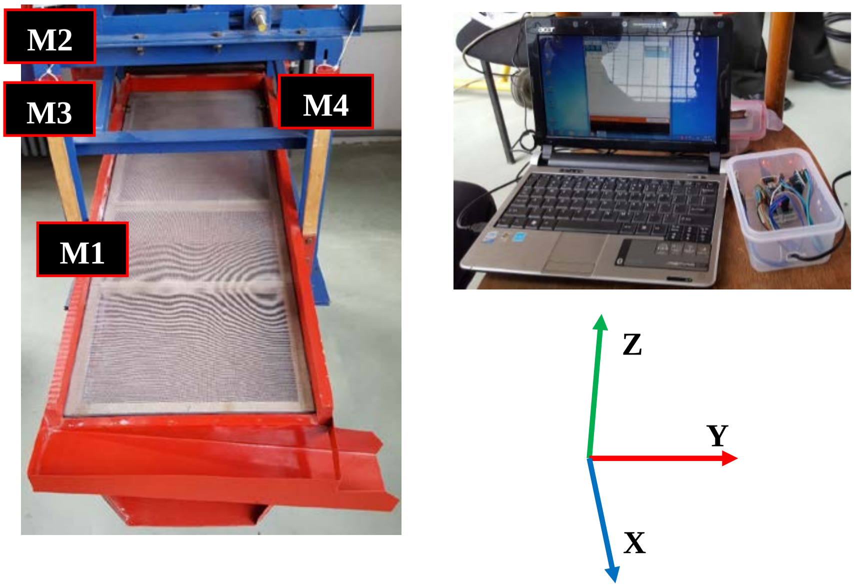


Fig. 2. The mounting scheme of the acceleration transducers and the coordinate system

By mounting the acceleration transducers in the *M1* - *M4* positions it is desired to know the dynamic stiffness of the mill upstream and downstream of the elastic lamella element. Data acquisition was made by means of an Arduino 1.6.2 program, while their processing was made in Excel. By comparison of equivalent stiffness provides information on how the elastic element works. To estimate the degree of importance of the measured inertance for the elastic lamella element, its equivalent dynamic stiffness (obtained by the CHANAL method) is compared with the equivalent dynamic stiffness obtained for the support of the elastic element.

3. Results

The figures below show the inertance curves obtained for the 4 measuring positions. The charts were displayed in the frequency range of [5, 50] and provide information on the structure's eigenmodes for the three directions of motion.

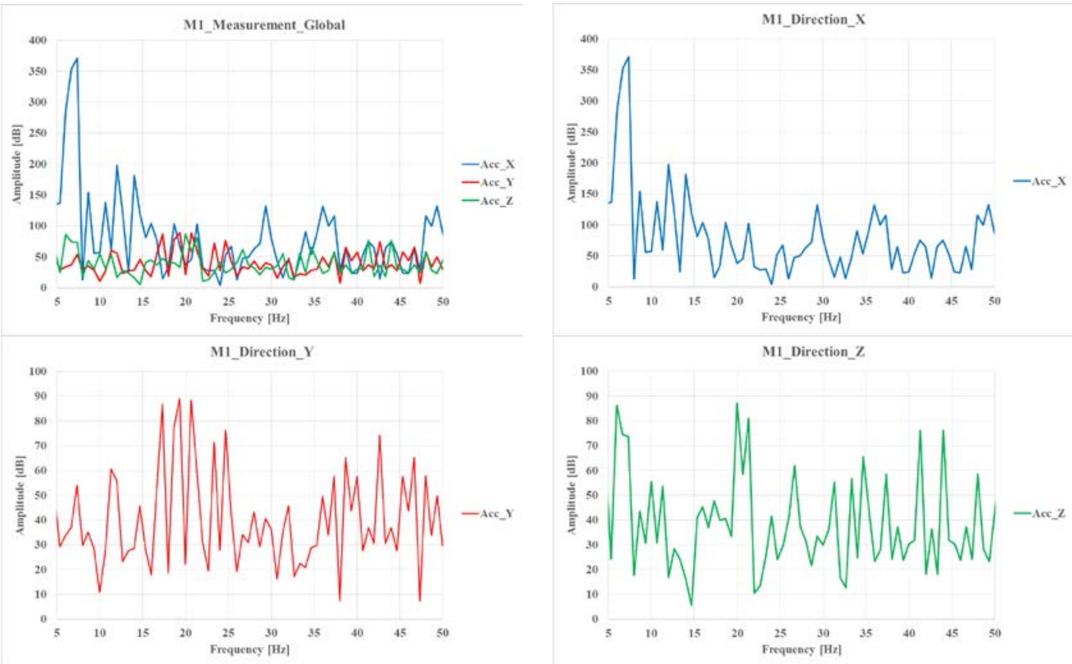
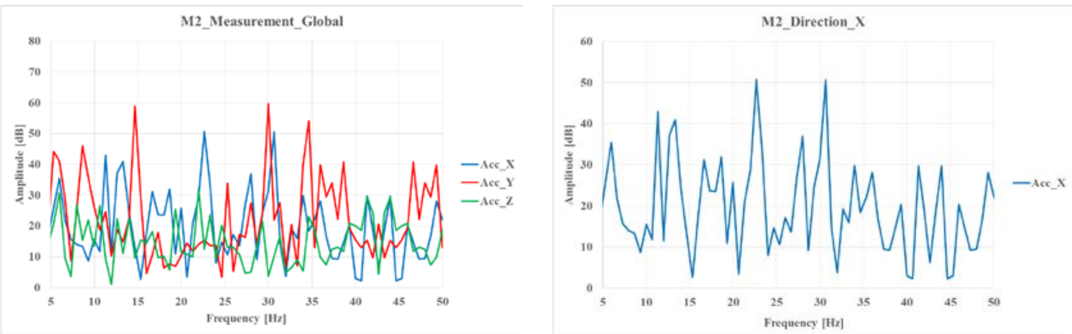


Fig. 3. The inertance curves for the accelerations measured in *M1* position



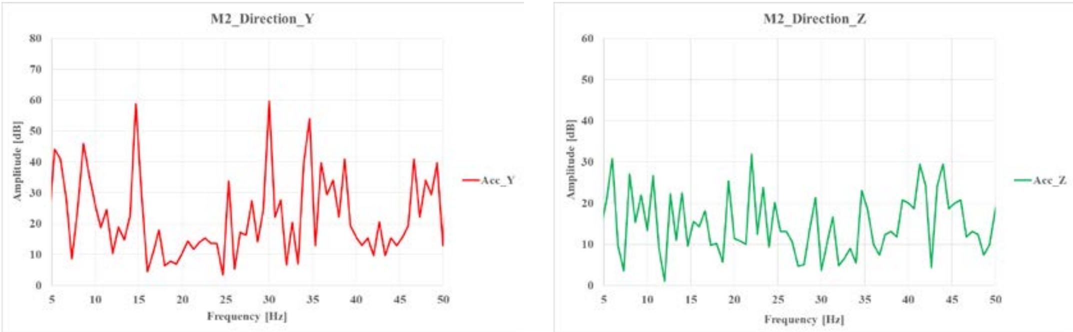


Fig. 4. The inertance curves for the accelerations measured in *M2* position

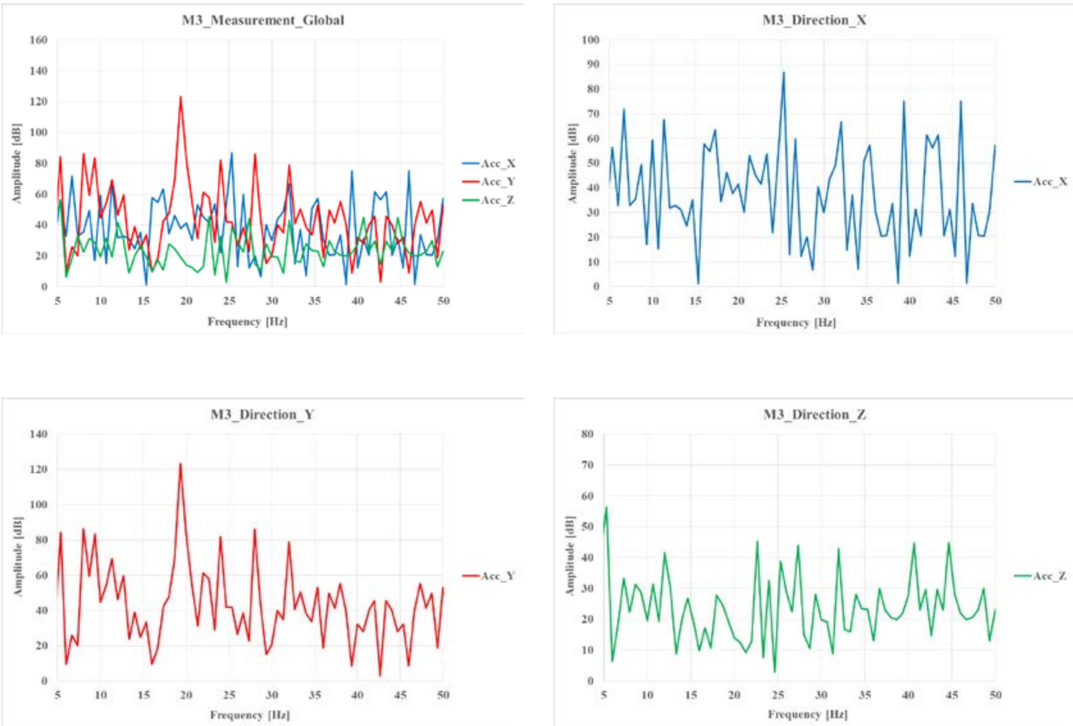


Fig. 5. The inertance curves for the accelerations measured in *M3* position

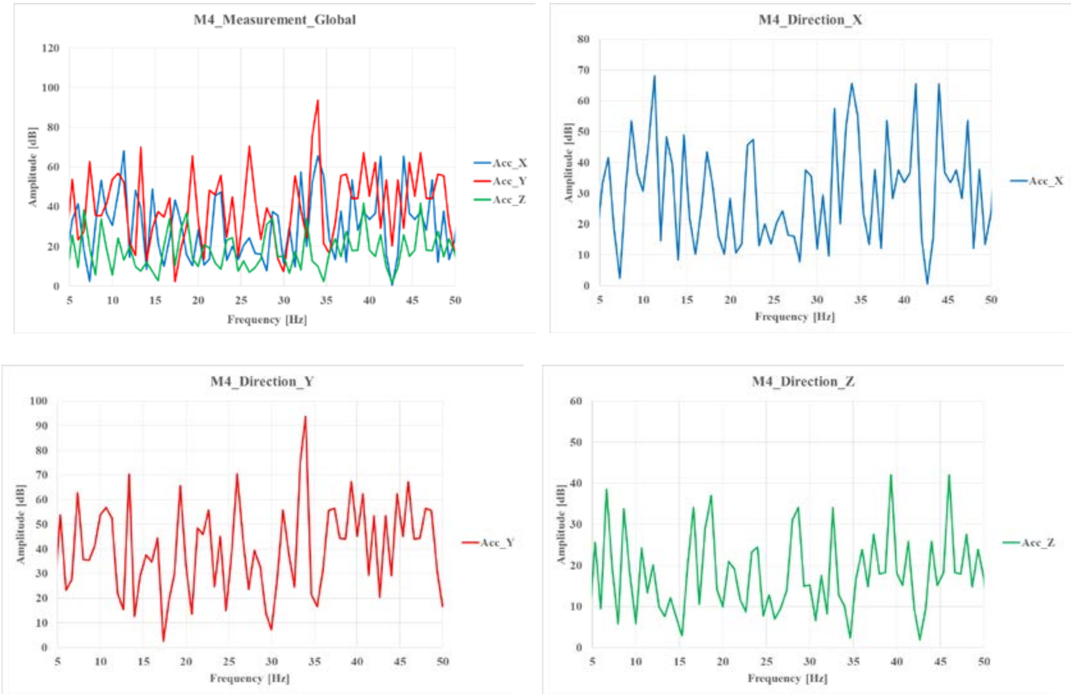


Fig. 6. The inertance curves for the accelerations measured in *M4* position

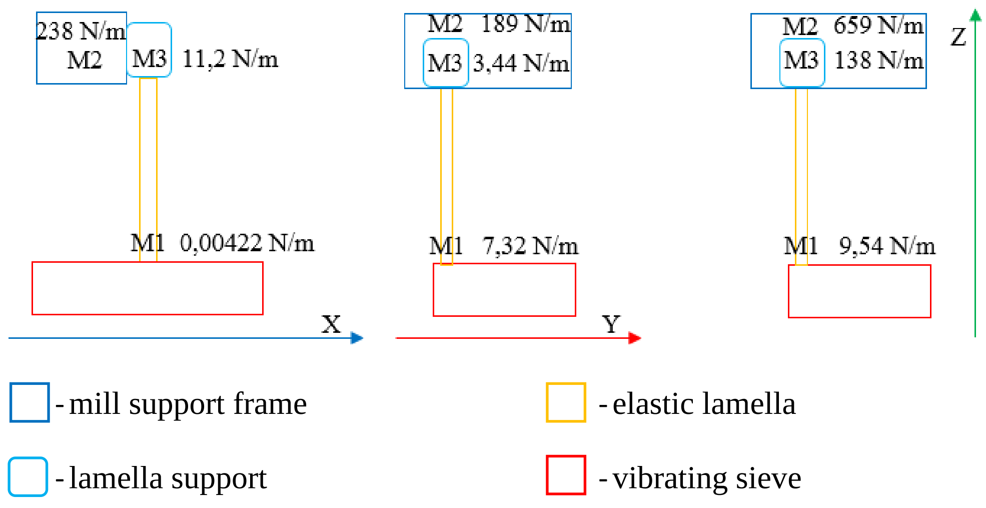
Although the inertance allows us to know the "level" of the vibrations in the structure, the inertance curves cannot provide concrete information about the behavior of the elastic lamella elements. To determine if the elastic lamella element can work properly due to the solicitations that appears in the structure of the mill, is imperative to determine the equivalent stiffness using the CHANAL method with the above-mentioned formulas. Table 1 shows the values of the equivalent stiffness for the 4 measuring points.

Table 1

The equivalent stiffness for the measured positions, *M1 – M4*

Frequency [5-50] Hz	**Direction**	**Equivalent stiffness K_{ech}** [N/m]			
		M1	***M2***	***M3***	***M4***
	X	$4{,}22 \cdot 10^{-3}$	$2{,}38 \cdot 10^{2}$	$1{,}12 \cdot 10^{1}$	$4{,}59 \cdot 10^{1}$
	Y	7,32	$1{,}89 \cdot 10^{2}$	3,44	8,31
	Z	9,54	$6{,}59 \cdot 10^{2}$	$1{,}38 \cdot 10^{2}$	$4{,}05 \cdot 10^{2}$

For a better visualization of the results the figure below shows the distribution of the values of equivalent stiffness measured on the left side of the mill, in the three directions.



4. Conclusions

The measurements and calculations made led to the following:

- in the X direction, the elastic element stiffness value (0,00422 N/m) is lower compared to the stiffness of the support (11,2 N/m);
- in the Y direction, the elastic element stiffness value (7,32 N/m) is higher compared to the stiffness of the support (3,44 N/m);
- in the Z direction, the value of the elastic element stiffness (9,54 N/m) is lower compared to the stiffness of the support (405 N/m);
- in terms of frame stiffness (measurement *M2*), it is higher in all directions compared to the elastic element support (measurement *M3*).

This paper makes a first attempt to present the steps in calculating the equivalent stiffness of an elastic element with a method that is mostly used in automotive industry.

The calculation of the equivalent stiffness using the CHANAL method is a good way to estimate the resistance level of any piece or subassembly.

In the studied case, it provides important information about the stiffness of the elastic lamella element and the frame supports. Correlated with the endurance analysis can tell us exactly when it can break the support (in terms of number of cycles).

R E F E R E N C E S

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