International Journal of Engineering & Scientific Research
Vol.6 Issue 9, September 2018,
ISSN: 2347-6532 Impact Factor: 6.660
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Determination and Comparaison of modal caracteristics of vibratory feeder. Cas of PAN FEEDER CHEMAF/LUBUMBASHI

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Article Received: 10th August, 2018 Article Revised: 18th August, 2018 Article Accepted: 28th August, 2018

Abstract

The study of the mechanical vibratory performances realized in the design and the manufacture of the rotating machines gave rise to more and more modern machines. This makes it more competitive.

It is in the same context that this work aims at checking the vibratory performances of the vibrating feeder of the company CHEMAF when it works with a single motor producing amplitudes of vertical vibrations and when it works with two engines producing horizontal and vertical vibrations to justify the need to use one or two drive motors.

To get there, we start:

- Model the PAN FEEDER structure for the two operating modes (the case of an engine and the case of two motors). The mathematical models obtained allow us to plot using the MATLAB software the different frequency responses for different modes of operation of the structure;
- Then we calculated the five vibratory parameters of the PAN FEEDER structure operating with a single motor and two motors.

The results obtained are:

- For the case of an engine, the vibrations generated have a maximum displacement of 106 dB equivalent to 10-5.3 m at a pulsation of 102.2 rpm with a phase of 2π;
- In the case of two motors, the vibrations generated have a maximum displacement of -71 dB and -70 dB respectively equivalent to 10-3,5 m (for the horizontal motor) and 10-3,55 m (for the vertical motor) at the heart rate of 102.2 rad / sec.

These results show that the vibrations generated by a single motor are lower than those generated by two motors. Which means in practice that the PAN FEEDER operating with a single engine would be less efficient than that operating with two engines.

Some recommendations conclude this work or we ask CHEMAF to use two motors to operate the PAN FEEDER in order to:

- To improve the value of the vibration amplitudes;
- To overcome the efforts of adherence of the ore to the structure;
- To accelerate the movement of minerals;
- And finally, increase the performance of PAN FEEDER, in addition to its performance.

Keywords: *modal, vibratory, feeder*

II. Introduction

For more than two decades, the knowledge and control of the modal characteristics of rotating machines, solicited during their operation by mechanical vibrations, have improved their performance. Thus, from their design, we can impose the desired vibratory characteristics (response, amplitudes, phase shifts, pulsations, ...). It is thus possible to make the vibrating mechanical systems more competitive.

The study of the performances of the vibrating feeder of the company CHEMAF made it possible to highlight this assertion.

Indeed, the vibrating feeder is a machine whose purpose is to ensure the supply of materials in a continuous and regular manner in well defined proportions. Its operation is based on the vibratory effect that ensures the movement of the ore from one point to another. This vibration is generated by two motors, one producing horizontal vibrations and the other producing vertical vibrations. Operators claim that the PAN FEEDER offers almost the same performance as when it operates with two engines.

Thus, the problem under study is therefore to verify this statement by an in-depth analysis of certain indicators. Its purpose is:

- to make a study by simulation on MATLAB of the vibratory performance according to the two modes of operation, that is to say with a single motor and then with two motors. This study of vibratory performances goes through the analysis of the five vibratory parameters. These include: stiffness, proper pulsation, damping, damping coefficient, amplitude of the dynamic response;
- to compare the vibration parameters for the two operating modes in order to judge the possibility of using a motor or both at the same time.

The field of vibration being very vast, we propose to restrict our study by supposing that:

- The vibrations are forced;
- The machines are rotating fixed;
- The excitation is along the vertical and horizontal axis;
- The material used for the Pan FEEDER structure is steel.

I. Overview of the Pan Feeder Structure

The Pan Feeder structure shown in Figure [1]. is a kind of linear following ore feed equipment. This structure ensures the movement of minerals throughout the production line.

Figure 1: CHEMAF Vibrating Feeder

Its characteristics are shown in Table I.1.

- Table 1:The different characteristics of the structure

MODEL	PF-13-07
Mass of equipment without engine	1074
Total weight of equipment	1500
Unbalanced mass	54
Motor mass	426
motor rotation speed	1450
Length of structure	3.4
Width	0.72
Surface	2.448
Materials	mild steel
Modulus of elasticity	210000 N/mm^2
Density	8000 N/mm^3
Date of manufacture	20/10/2014
Reference number	J6207
Diameter of the motor shaft	60 mm
Length of the motor shaft	600 mm
Engine power	9.5 KW

III. Modeling and Performance Study of the pan Feeder Structure

III.1. Case of a Single Engine

III.1.1. Modelization

Modeling is the design of a model. Depending on its purpose and the means used, modeling is called mathematical, geometric, 3D or mechanical. In applied mathematics, this modeling makes it possible to analyze real phenomena and predict results from one or more theories at a given level of approximation.

Considering the PAN FEEDER structure to model driven by a single motor producing vertical vibrations as shown in Figure [2]. It constitutes a fixed rotating machine subjected to forced vibrations of traction-compression and whose excitation is done according to the set of masses in movement making a vertical linear movement of back and forth. This movement is therefore comparable to the vibration of traction compression to a degree of freedom.

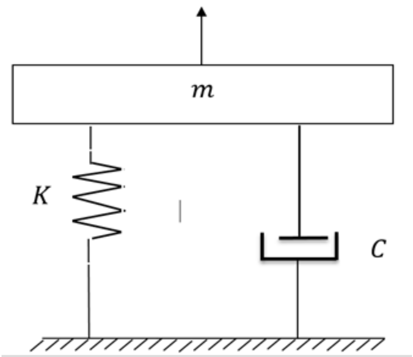

Figure 2: Model (m, k, c) of the FEEDER PAN fed by an engine

With k: the stiffness that characterizes the tensile-compressive rigidity of the moving assembly;

C: the dashpot that characterizes damping (a rubber device that connects all moving masses to the frame);

m: the total mass (structure and motor) in vertical movement

Newton's second law applied to a system expresses the equilibrium between the sum of the forces external to this system and the sum of the forces internal to this system (inertial forces, viscous friction forces and elastic forces).

Applying Newton's second law to the vibrating feed, we obtain the second-order differential equation, with constant coefficients, describing the motion of a linear system with a degree of freedom:

$$m.\ddot{x} + c\dot{x}\,kx = f(t)$$

For an excitation force of the form $f(t) = M.e.w^2 \exp^{jwt}$, the equation of motion becomes:

$$[m\ddot{x} + c\dot{x} + kx] = Me\omega^2 \exp^{jwt}$$

With M: the mass of unbalance;

e: eccentricity;

ω: pulsation

Eccentricity

Starting from the coordinates of the unbalance center of gravity given respectively (x,y) ≅ (0,0925), the eccentricity can be calculated as follows:

$$e = \sqrt{(x - x_0{}^2 + (y - y_0)^2}$$

This implies that $e = \sqrt{(0-0)^2 + (0.0925 - 0)^2}$

Which gives e = 0.0925 m

Angular velocity

Knowing the rotation speed of the motor, we can calculate the angular velocity ω:

$$\omega = \frac{\pi.N}{30}$$

N represents the rotational speed of the engine which is 1450 rpm

This implies that $\omega = \frac{3.14 \text{ x } 1450}{30} = 151.76 \text{ rd/sec}$

III.1.2. Calculation of vibratory parameters

➲ **Calculation of stiffness k**

The stiffness k is given by the following expression:

$$k = \frac{E.A}{L}$$

With E: the modulus of elasticity in N / m2;

L: the length of the PAN FEEDER tree in m;

A: the section of the motor shaft of PAN FEEDER in m2

$$k = \frac{2{,}1\,.\,10^{11} \text{ x } 2{,}448.10^{-3}}{3{,}4} = 151200000 \text{ N/m}$$

➲ **Calculation of the proper gravity ω_0 of the structure**

The proper pulsation of the structure being given by the expression:

$$\omega_0 = \sqrt{\frac{k}{m}}$$

With m = 1500 kg, the total mass of the equipment

$$\omega_0 = \sqrt{\frac{151200000}{1500}} = 317{,}49 \text{ rd/sec}$$

➲ **Calculation of the damping factor ξ**

The rubber damping factor has the value:

ξ = 0.04

➲ **Calculation of depreciation c**

Depreciation is given by the following expression:

$$C = 2\xi\omega_0 m$$

By replacing in the preceding formula each parameter which appears in the second member of the equality by its respective value:

$$\omega_0 = 317.49 \text{ rad/sec}$$
$$m = 1500 \text{ kg}$$

We get the depreciation:

$$C = 38098.8 \text{ Kg/s}$$

- Calculation of the amplitude of the dynamic response of the PAN FEEDER structure

The amplitude of the dynamic response of the PAN FEEDER structure is given by the following expression:

$$F = m\, e\, \omega^2$$

By replacing in the preceding formula each parameter which appears in the second member of the equality by its respective value:

$$e = 0.0925 \text{ m}$$

We obtain the amplitude of the dynamic force:

$$F = 34302{,}12$$

III.2. Case of two Engines

II.2.1. Modelization

Considering the PAN FEEDER structure to be modeled driven by two motors arranged in such a way that one produces the vertical vibrations and the other the horizontal vibrations, this constitutes a fixed rotary machine subjected to forced vibrations of traction-compression and whose excitations are respectively along the horizontal axis and the vertical axis.

By discretizing this structure, we obtain a system with two degrees of freedom where we consider that the total mass (structure and motors) is divided into a sum of two equal masses m1 and m2. This discretized system of the PAN FEEDER structure is shown in Figure [3]. below :

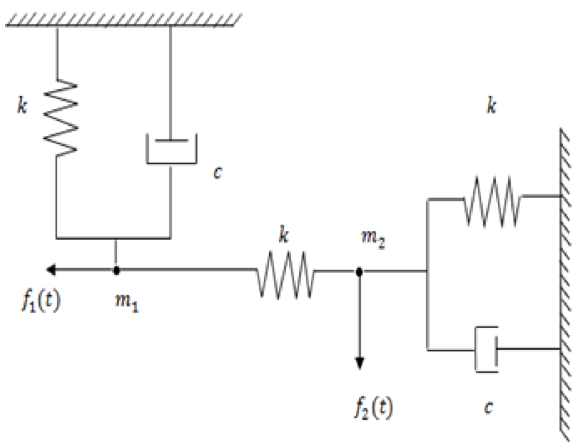

Figure 3: Model (m, k, c) of the FEEDER PAN powered by two engines

To get there, we started:

- Model the PAN FEEDER structure for the two operating modes (the case of a single motor and the case of two motors).
  - For the case of a (vertical) engine, we applied Newton's second law to the PAN FEEDER structure and obtained:
    $$[m\,\ddot{x} + c\dot{x} + k\,x] = M\,e\,\omega^2 exp^{jwt}$$
  - For the case of two motors, we applied the principle of virtual works to the PAN FEEDER structure discretized and we obtained:
    $$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} + \begin{bmatrix} c & 0 \\ 0 & c \end{bmatrix}\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} 2k & -k \\ -k & 2k \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} f_1(t) \\ f_2(t) \end{bmatrix}$$

Applying the Laplace transform to these motion equations, we obtained the following transfer functions:

- in the case of one motor (vertical) :

$$X(p) = \frac{(1 + exp^{\varphi}).2.m.\ e.\ \omega^2}{(p + i.\omega)(m.p^2 + k.p + c)}$$

- in the case of two motors :

$$X_1(p) = \frac{(m_2.p^2 + c.p + 2.k)\left(\frac{2.M.r.\omega^2}{\omega i + p}\right) + k.\frac{2.M.r.\omega^2.exp\frac{\pi}{2}}{\omega i + p}}{(m_1.p^2 + c.p + 2.k)(m_2.p^2 + c.p + 2.k) - k^2}$$

$$X_2(p) = \frac{(m_1.p^2 + c.p + 2.k)\left(\frac{2.M.r.\omega^2.exp\frac{\pi}{2}}{\omega i + p}\right) + k.\frac{2.M.r.\omega^2}{\omega i + p}}{(m_1.p^2 + c.p + 2.k)(m_2.p^2 + c.p + 2.k) - k^2}$$

IV. Presentation, Analysis and interpretation of results

IV.1. Case of the motor generating vertical vibrations

To be able to simulate the vibratory response X (ω) corresponding to the maximum amplitude of the vertical vibrations, we use the MATLAB software and we obtain:

a) **Frequency response curves for different motor positions**

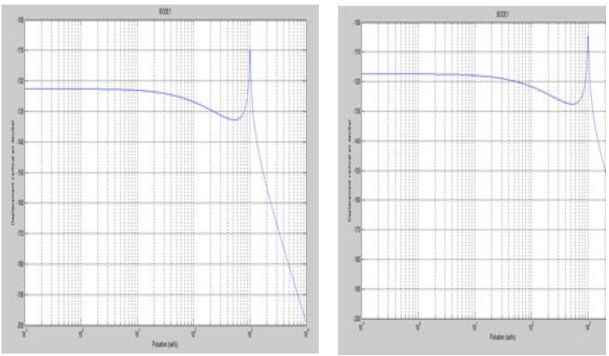

Figure 4: Frequency response of the PAN FEEDER structure for φ = 45° et φ = 90°

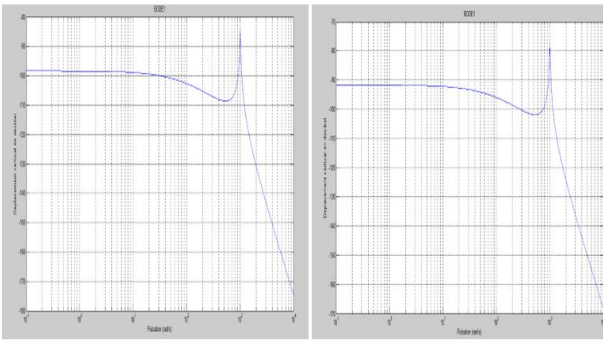

Figure 5: Frequency response of the PAN FEEDER structure for $\varphi = 135°$ et $\varphi = 180°$

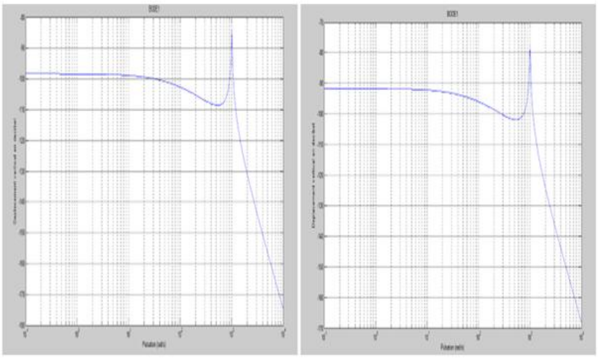

Figure 6: Frequency response of the PAN FEEDER structure for $\varphi = 225°$ et $\varphi = 270°$

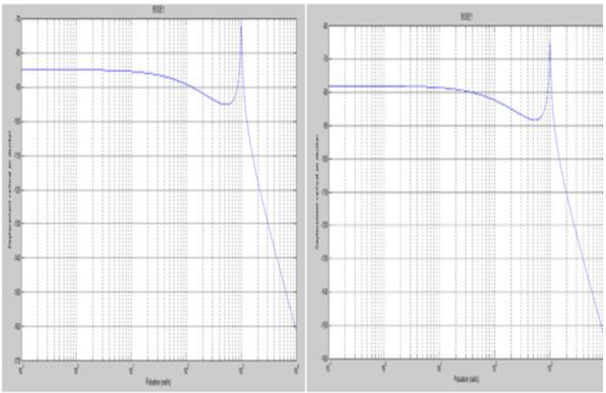

Figure7: Frequency response of the PAN FEEDER structure for $\varphi = 315°$ et $\varphi = 380°$

a) Values of five vibratory parameters

Table III.1 below shows the values of vibration parameters previously calculated for the case of a single motor.

Table 2: Vibratory parameters for an engine

VIBRATORY PARAMETERS	VALUES
Stiffness k	151200000 N/m
Clean pulse ω_0	317.46 rd/sec
Depreciation ξ	0.04
Coefficient of damping c	38098.8 kg/S kg/S
Amplitude of the dynamic response of the PAN FEEDER structure at 171.76 rad / sec speed	34302.12 N

IV.2. Cases of two Engines Producing Horizontal and Vertical Vibrations

➲ **for the Horizontal Engine**

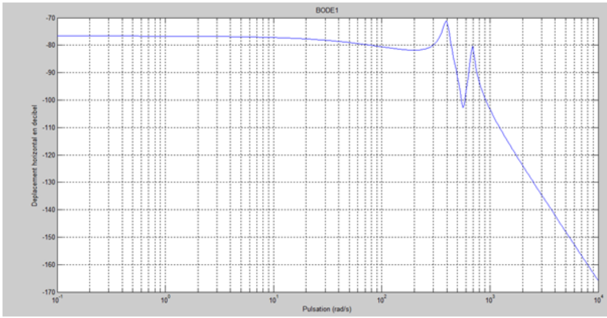

Figure 8: Frequency response of the FAN FEEDER structure for the case of the horizontal motor

➲ **For the vertical motor**

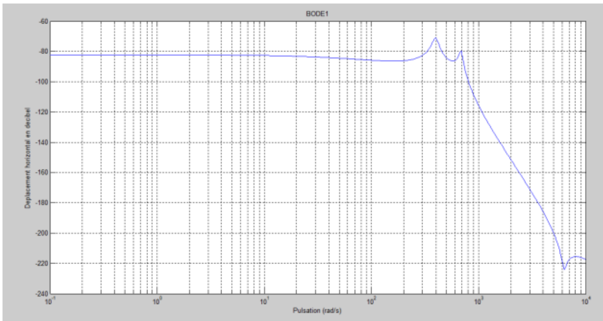

Figure 9: Frequency response of the PAN FEEDER structure for the case of the vertical motor

a) Values of five vibratory parameters

Table III.2 below shows the values of vibration parameters previously calculated for the case of two motors.

Table3: Vibration parameters for two motors

VIBRATORY PARAMETERS	VALUES
Stiffness k	1512.00000 N/m
Clean pulse ω_0	280.18 rd/sec
Depreciation ξ	0.04
Coefficient of damping c	43170.13 kg/S
Amplitude of the dynamic response of the PAN FEEDER structure at 171.76 rad / sec speed	68604.24 N

Table 3: shows the decibel displacement values corresponding to the different angular pulse values for the case of one motor and two motors, and this for different positions.

Table 4: The different values of displacements in dB relating to the corresponding pulsations

Pulsation value [rd/sc]	**Corresponding displacement [dB]**									
	Case of one motor								Case of twomotors	
	$\frac{\pi}{4}$	$\frac{\pi}{2}$	$\frac{3\pi}{4}$	π	$\frac{5\pi}{4}$	$\frac{3\pi}{2}$	$\frac{7\pi}{4}$	2π	Horizontal motor	Vertical motor
$\mathbf{10^0}$	-191	-182	-178	-170	-162	-158	-150	-148	-78	-81
$\mathbf{10^1}$	-191.5	-181	-176	-199	-161	-157	-149	-149	-77	-82
$\mathbf{10^2}$	-181	-176	-169	-162	-156	-148	-141	-136	-80	-83
$\mathbf{10^3}$	-202	-198	-192	-185	-178	-169	-165	-158	-106	-120
$\mathbf{10^4}$	-221	-219	-212	-205	-199	-198	-185	-179	-165	-204
$\mathbf{10^{2.2}}$	-151									
$\mathbf{10^{2.2}}$		-145								
$\mathbf{10^{2.2}}$			-139							
$\mathbf{10^{2.2}}$				-133						
$\mathbf{10^{2.2}}$					-127					
$\mathbf{10^{2.2}}$						-120				
$\mathbf{10^{2.2}}$							-113			
$\mathbf{10^{2.2}}$								-106		
$\mathbf{10^{2.6}}$									-71	
$\mathbf{10^{2.6}}$										-70

CONCLUSION

We have come to the end of our study in the field of mechanical vibrations.

In this work, it has been a question of checking the vibratory performances of the vibrating feeder when it works with a single motor producing the vertical vibrations and when it works with two motors (horizontal and vertical) in order to justify the necessity of use one or two drive motors.
To get there, we started:

- Model the PAN FEEDER structure for the two operating modes (the case of a single motor and the case of two motors). The mathematical models obtained allowed us to plot the different frequency responses for the different modes of operation of the structure;
- Then we calculated the five vibratory parameters of the PAN FEEDER structure operating on the one hand with a single motor and on the other hand with two motors.

We obtained the following results:

- For the case of an engine, the vibrations generated have a maximum displacement of -106 dB equivalent to $10^{-5.3}$ m at a pulse of $10^{2.2}$ rad / sec with a phase of 2π;
- In the case of two motors, the vibrations generated have a maximum displacement of -71 dB and -70 dB respectively equivalent to $10^{-3.5}$ m (for the horizontal motor) and $10^{-3.55}$ m (for the vertical motor) to the pulsation of regime of $10^{2.2}$ rad / sec.

After analysis and interpretation of the results obtained, we found that the vibrations generated by a single engine are lower than those generated by two engines. Which means in practice that the PAN FEEDER operating with a single engine would be less efficient than that operating with two engines.
In view of the above, we therefore suggest that CHEMAF use two engines to operate the PAN FEEDER in order to:

- To improve the value of the vibration amplitudes;
- To overcome the efforts of adherence of the ore to the structure;
- To accelerate the movement of minerals;
- And finally, increase the performance of PAN FEEDER, in addition to its performance.

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