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CONTRIBUTION TO MINIMIZING THE EFFECTS OF UNBALANCE ON A MOTOR-FAN

Lias REHAI, Ahmed BELLAOUAR , Rachid CHAIB, Mounir GAHGAH

Abstract: *In this work we have limited our study for the characterization of the influence of unbalance on the vibratory level of a motor- fan. In this context, we proceeded to create a mechanical imbalance, by adding a mass on the rotating part of the system. This causes a centrifugal force, which causes internal stresses, affecting the proper operation of the machine. The calculation of the FFT of each signal is performed by MATLAB software, which allows the temporal phenomenon to be properly presented in a frequency domain. The various measurements of the vibration amplitude will be analyzed by the Taguchi method, which helps to minimize the effect of unbalance on the motorized fan.*

Key words: *Motorized fan, unbalance, vibration, internal forces, Taguchi method.*

1. INTRODUCTION

Vibration analysis has become the main technique used in condition monitoring[1]. It aims to ensure rigorous monitoring of the behaviour of rotating machines in order to make a better diagnosis of faults in order to intervene at the right time, and this to guarantee the availability of the industrial system[2].

Unbalance is considered to be one of the main causes of vibration in rotating machines. The uneven distribution of the mass of a rotor around its kinematic line generates vibrations that propagate to the bearings, and consequently, will accelerate their damage[3].

These vibrations occur at the frequency of rotation of the rotating part of the system.

Depending on the size and speed of the machine, the vibration level increases with increasing size and speed[4].

In practice, rotors can never be perfectly balanced due to manufacturing errors such as non-uniform material density, manufacturing tolerances and material gain or loss in operation[5].The identification of such a problem will be done in a first step by the analysis of the global state of the machine, followed by a spectral analysis in order to value the magnitude of the internal forces[6] in order to be able to proceed to an analysis by the Taguchi method which will allow to have a good choice of the parameters which ensure the attenuation of the values of these internal forces, which manifest themselves through vibration signals, and therefore ensure a good balance.

For this purpose, an accelerometer (SCHENK VS-068/1/1/1/1/0) is used (figure 1).

Fig. 1. Accelerometer VS-068

It will be fixed on the rotor at a radial position, and it will be connected to a Hameg- HM507 oscilloscope which in turn is connected to a microcomputer which will read the signals in real time. Then we use the Fourier transform which is a method widely used today to

represent a time phenomenon in the frequency domain[4].
In this work we limit ourselves to studying the parameters that influence the unbalance, namely: mass, position and rotational speed on the vibration level. Then the data collected by the Taguchi method are analysed in order to model the vibration amplitude according to the functional parameters mentioned above, in order to remedy the effect of unbalance and to find an optimal operating regime for the machine.

2. EXPERIMENTAL SYSTEM

The experimental system is shown in Fig.2, and consists of an electric motor that rotates the fan blades, a VS-068 accelerometer (type of voltage B&K) attached to the stator, and an oscilloscope (HAMEG HM507), which is connected to a computer to visualize the vibration signals and process them using the Matlab tool. The imbalance must be created by using small masses (screws + nuts) that are fixed on the fan blades. The accelerometer is fixed in a radial position on the stator to properly detect system vibrations.

To know the behavior of the motorised fan system in the case of an unbalance, an imbalance must be created by fixing a small mass m (screw + nut) to the fan blades at a distance r. An unbalance force appears in the radial direction of the rotor at its rotational frequency, and is proportional to the unbalance mass m, the eccentric r and the square of the rotational speed [7].

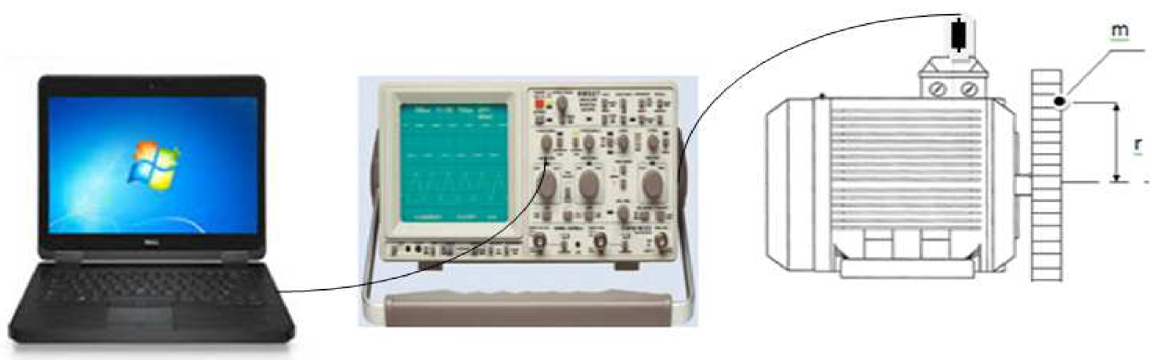

Fig. 2. Experimental system

The unbalance is defined as the product of the unbalance mass m by its eccentric r and is expressed in [gr.mm]. The value of this force is determined by the relationship:

$$F_{i} = m_i r_i w_i^2 \quad (1)$$

The vibration amplitude will be measured for several combinations of angular velocity (2 speeds), eccentricity radius (3 radii), and balancing mass (3 mass), a summary table will be presented following the experiments.
The values of r (mm) : $r_1 = 50$ ؛ $r_2 = 100$ ؛ $r_3 = 135$
The values of w (rpm):
$w_1 = 300$ ؛ $w_2 = 900$
The values of m (g):
$m_1 = 1{,}89$ ؛ $m_2 = 2{,}4$ ؛ $m_3 = 3{,}15$
Figure 3 shows the amplitude spectrum of the vibration signal when the eccentric **r** is varied.

Figure 4 shows the amplitude spectrum of the vibration signal when the mass m varies.

3. TAGUCHI ANALYSIS

The Taguchi method is a method developed in the 1950 by Genichi Taguchi (Japanese statician) and introduced in the USA and Europe in the 1980. Tagichi's experimental designs define controllable factors that minimize the effect of noise factors. The famous Taguchi method is a direct approach to optimizing quality, focusing on the process conditions that produce the smallest variations in quality [8].

Taguchi experimental designs jointly treat the mean and variability of the values of the measured characteristics [8].
In conventional experimental designs, the main objective is to identify the factors that

affect the average response and control them to desirable levels. In addition, Taguchi's experimental designs jointly address the mean and variability of the measured characteristic values through the use of Signal/Noise ratios.

The use of these performance indicators makes it possible to find the combination of the levels of the controlled factors, which is the most insensitive to noise factors[8].

The Taguchi method for high lighting experimental designs uses fractional experimental designs [9].

The minimum value of the vibration signal due to unbalance can be reached by optimal selection of the functional parameters of the motor fan, by implementing the Taguchi method and the analysis of variance (ANOVA analysis), these parameters have a considerable influence on the vibration signal level.

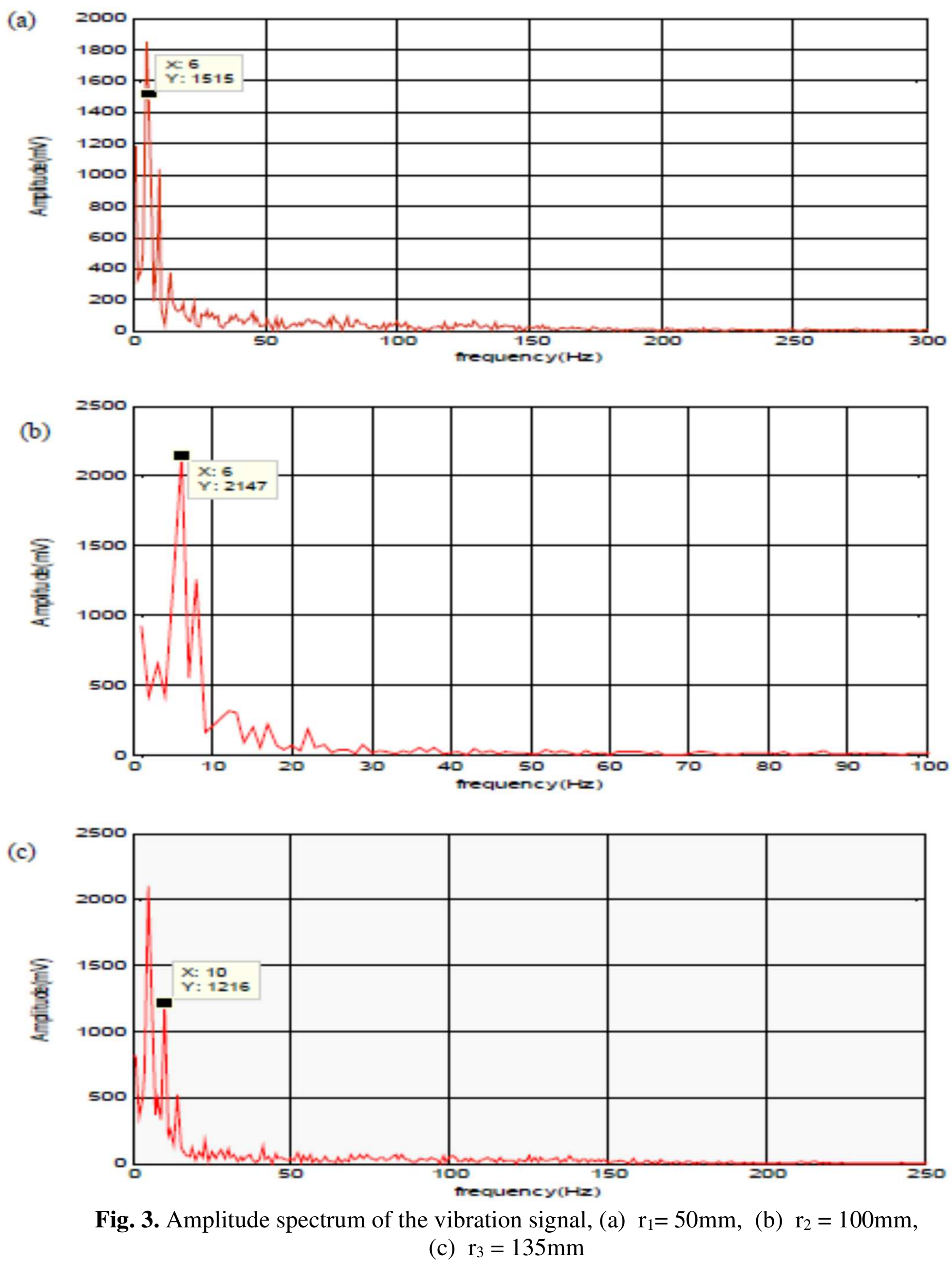

Fig. 3. Amplitude spectrum of the vibration signal, (a) r_1= 50mm, (b) r_2 = 100mm, (c) r_3 = 135mm

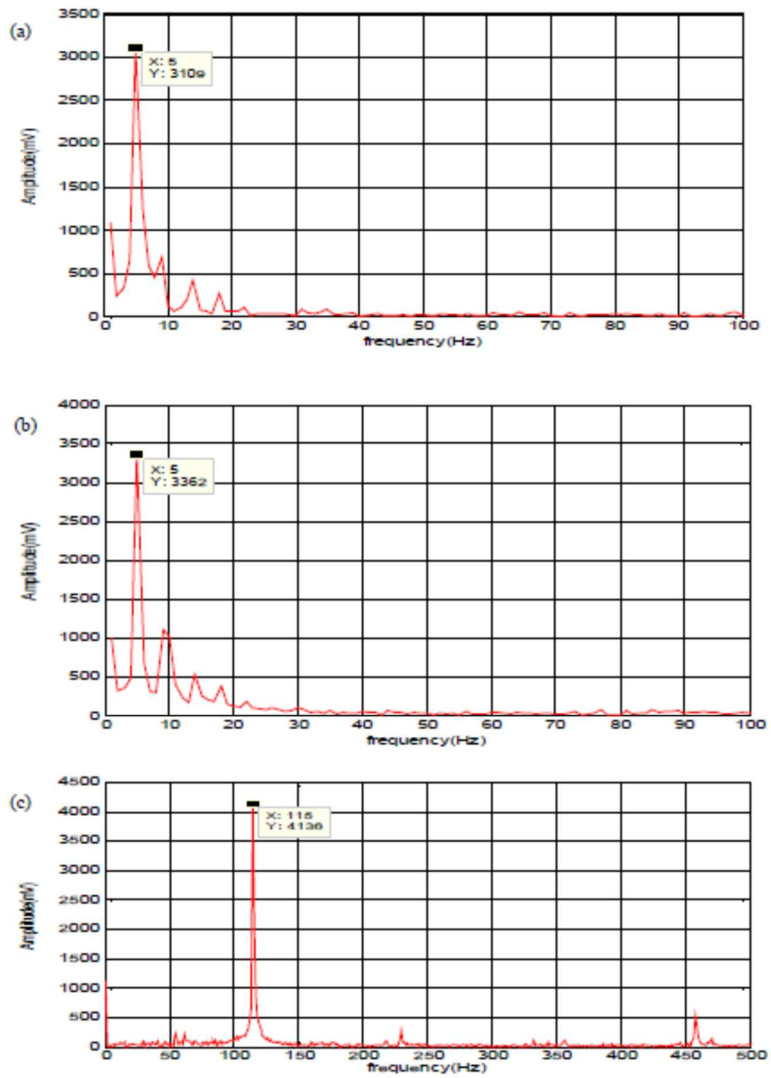

Fig. 4. Amplitude spectrum of the vibration signal, (a) m_1=1.89 g, (b) m_2=2.4g, (c) m_3=3.15g

4. CHOOSING THE FACTORS

The Taguchi method considers two categories of factors: controllable factors and noise factors. The controllable factors in our case are: speed of rotation, balance mass, and eccentricity, as shown in Table1, While the vibration is considered as noise.

Table1

Selected factors and levels.

Level	**Speed (rpm)**	**Mass (g)**	**Eccentricity r(mm)**
1	300	1,89	50
2	900	2,4	135
3	-	3,15	164

4.1 Signal-to-Noise Ratio (S/N Ratio)

Taguchi uses a performance statistic called signal-to-noise ratio (S/N) to measure the process robustness. This combines both the mean response and the variability of the response in a single performance measure [5].

There are three categories of quality characteristics in the signal-to-noise ratio analysis, namely; "nominal the best". "smaller the better" and "higher the better".

The values of the signal-to-noise ratio [S/N] of the amplitude of the vibration signal are calculated using the signal criterion "smaller the better" according to the equation:

$$\mu = -10log_{10}\left[\left(\frac{1}{n}\right) * S(y_i{}^2)\right] \quad (2)$$

For i=1, 2, 3 ,……

Here, μ represents the obtained S/N ratio; n is the number of observations for the particular product; and y is the respective characteristic.

To carry out the experiment series, the orthogonal table L18 is used, which is given in Table 2. The experiment matrix is composed of 3 columns that correspond to the selected factors; and 18 rows representing the experiment series on the determination of the amplitude of the vibration signal.

In the last two columns are reported, respectively, the experimental values of the vibration signal amplitude and the calculated values of the signal-to-noise ratio [S/N].

The algebraic value of the smallest ratio [S/N], corresponds to the best performance Characteristic, and therefore, the optimal level of the parameter is the smallest ratio level [S/N].

The smallest ratio [S/N] specific to each factor gives the best experimental result. The latter corresponds to the lowest rotational speed. The average ratios [S/N] correspond to each level of the factors for the vibration amplitude are given in Table 2.

The optimal operating conditions for the motorized fan that minimize unbalance are a rotation speed of 300 rpm (level 1), an eccentric r of 50 mm (level 1), and a mass of 1.89g (level 1). So the optimal combination of the input parameters is: (w_1, r_1, m_1.)

4.2 The ANOVA analysis

The ANOVA study was conducted to determine the influence of the main variables on the vibration signal and to determine the percentage contribution of each variable figure 5 and figure 6.
ANOVA was performed for S/N ratios using Minitab 17 software.

The results of the variance analysis of the vibration signal are given in Table 4, which shows the degrees of freedom (DF), the sum of the squares (SSd), the mean square (MS); the F test and the probability (Prob=0.080) provide information on the statistical significance of the source on the corresponding response.

Table 2

Orthogonal table of experimental results for vibration amplitude and ratio[S/N]

	w	r	m	Amplitude	FITSI
1	300	50	1.89	420.13	417.61
2	300	135	189	849.76	870.32
3	300	164	189	953.32	1024.77
4	300	50	2.40	538.86	508.61
5	300	135	2.40	1216.00	1201.94
6	300	164	2.40	1544.30	1438.49
7	300	50	3.15	655.56	642.42
8	300	135	3.15	1515.00	1689.61
9	300	164	3.15	2147.00	2046.89
10	900	50	1.89	1434.00	1491.29
11	900	135	189	3109.00	3047.79
12	900	164	189	3362.00	3578.83
13	900	50	2.40	1712.39	1807.12
14	900	135	2.40	4136.00	3604.24
15	900	164	2.40	4136.60	4217.38
16	900	50	3.15	2203.35	2271.58
17	900	135	3.15	4694.64	4422.56
18	900	164	3.15	4808.12	5156.42

Table 3

Response table for the signal/noise.

	Response Table for Means [S/N]; (db)		
Level	W	R	m
1	-59.70	-59.68	-62.36
2	-69.64	-66.59	-64.91
3	-	-67.75	-67.75
Delta	9.94	8.07	8.07
Rank	1	2	3

Table 4

Result of the analysis of variance of vibration signal

Source	DL	SSd	Contribution	Adj SS	F-Value	P-Value
Regression	6	36474976	98.35%	36474976	109.40	0.00
w	1	21684471	58.47%	25282	0.45	0.514
r	1	9596767	25.88%	204702	3.68	0.081
m	1	2836119	7.65%	45647	0.82	0.384
W*r	1	1775835	4.79%	1775835	31.96	0.000
W*m	1	234217	0.63%	234217	4.22	0.89
r*m	1	347567	0.94%	34.98	0.000	0.065
Error	11	611226	1.65%	347567	6.26	0.029
Total	17	37086202	100%	55566	-	-

In this analysis, the percentage (P %) contribution of each source factor to the total variability of responses is represented by the last column of Table 4; these values give the degree of influence of each factor on the studied response.

The results of the analysis of variance of the amplitude of the vibration signal, show that the rotational speed is the factor that represents the great effect on the total variation of the amplitude of the vibration signal; this explains 58.47% of the contribution. On the other hand, the second factor that affects the vibration signal is the eccentric (r) with a contribution of 25.88%. Finally, the mass ***m*** has a low contribution on a variation of the vibration signal with a percentage of 7.65%.

Fig. 5. Interaction plot for means

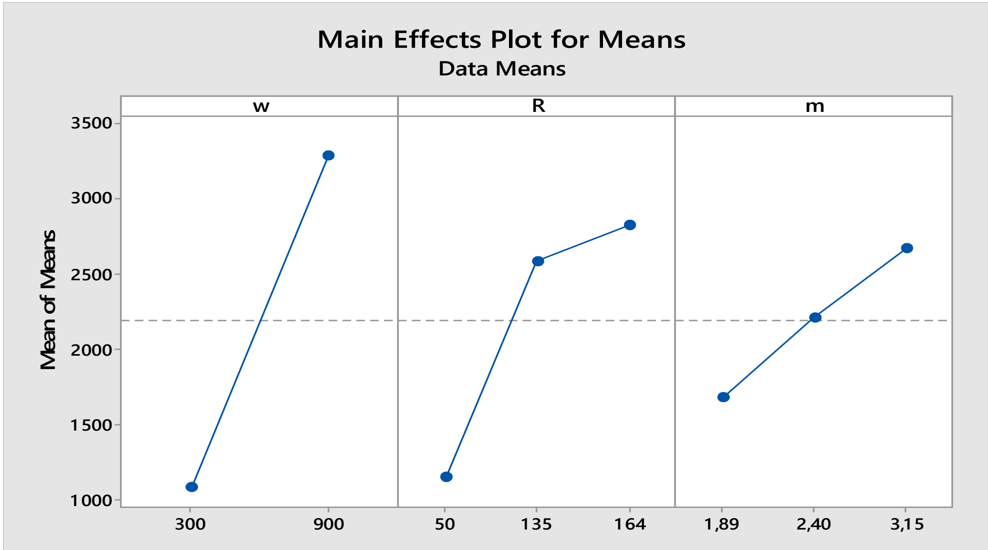

Fig. 6. Main effects plot for means

A regression analysis was used to develop the second order mathematical response surface model for the amplitude of the vibration signal, which is presented as follows:

$$A = 543 - 0.68w - 11.66r - 3 + 0.02164(w * r) + 0.735(w * m) + 5.55(r * m) \quad (3)$$

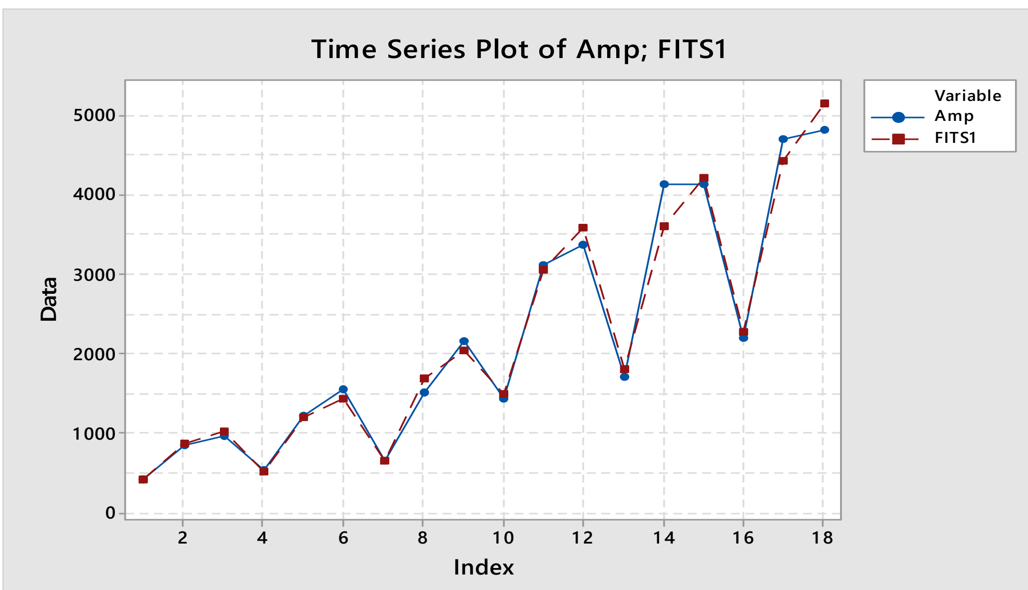

Fig. 7. Normal probability curve of the amplitude of vibration

Figure 7 shows the normal probability of model residues of the vibration amplitude of the motor fan. It is found that the residues adjust reasonably, which leads to the conclusion that the errors have a normal distribution and therefore the model developed is significant.

5. CONCLUSION

The work presented is part of the application of statistics and probabilities in the field of vibration analysis.

More specifically, the purpose of the work is to apply Taguchi's experimental plans to see the different relationships between the parameters that affect the amplitude of vibration due to the unbalance of the motor fan (w,r,m).

Taguchi's method uses a robust design that allows the most significant factors to be obtained at a very short experimental time and a reduced number of experiments.

A mathematical model is developed for the amplitude of vibration to understand the effect of different factors on the response.

The analysis of variance clearly shows that, in our case, the vibration amplitude is influenced, from a statistical point of view, much more by the rotational speed (58.47%) and the eccentricity (25.88%) while the balancing mass has a very small influence (07.65%).

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Contributia pentru minimizarea efectelor dezechilibrului pe un Motor -Fan

Rezumat: În această lucrare ne-am limitat studiul pentru caracterizarea influenței dezechilibrului asupra nivelului vibrator al unui motor. În acest context, am procedat la crearea unui dezechilibru mecanic, prin adăugarea unei mase pe partea rotativă a sistemului. Aceasta provoacă o forță centrifugă, care provoacă tensiuni interne, afectând buna funcționare a mașinii. Calculul FFT al fiecărui semnal se realizează prin intermediul software-ului MATLAB, care permite prezentarea corectă a fenomenului temporal într-un domeniu de frecvență. Diferitele de măsurători ale amplitudinii vibrațiilor vor fi analizate prin metoda Taguchi, care contribuie la minimizarea efectului dezechilibrului asupra ventilatorului motorizat.

Cuvinte cheie: ventilator motorizat - dezechilibrul - vibrații, forțe interne, echilibrare, metoda Taguchi

Lias REHAI, Department of Mechanical Engineering, Laboratory of research LRPCSI, 20 August 1955 University of Skikda, Algeria. lias21000@yahoo.fr, office phone**:** +213772645059

Ahmed BELLAOUAR, Department of Engineering transport and environment laboratory LITE, Mentouri University, Constantine, Algeria. bellaouar_ahmed@yahoo.fr, office phone: 0773750949

Rachid CHAIB, Department of Engineering transport and environment laboratory LITE, Mentouri University, Constantine, Algeria. r3chaib@yahoo.fr, office phone: +21331818705

Mounir GAHGAH, Department of Mechanical Engineering, Laboratory of research LRPCSI, 20 August 1955 University of Skikda, Algeria. office phone: +213664713492.