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ANALYSIS OF VIBRATION EFFECT ON FACTORY FOUNDATION IN A FLOUR MILL

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ABSTRACT

Thirteen roller machines, in operation at a flour mill, all on one floor, were analyzed for spectra transmission and propagation, using a vibration analyzer. The vibration analyzer was placed at 8 different positions around each roller machine, generating unique spectra curves symbolic of signals transmitted. It was observed that with exponential characteristics above 2 in the polynomial equations resulted in significant signal propagation requiring isolation of the machines necessary. Results indicates that out of the 7 machines requiring isolation, cork would be needed for 3 with maximum displacement of 0.19 to 0.20mm, while composite pad would be needed for 4 with a maximum displacement of 0.10 to 0.16mm. The study had shown that vibration effects could be successfully monitored on factory floors through the vibration analyzer application, thus, minimizing harzardous effects on factory workers and facilties.

Keywords: spectra transmission, vibration analyzer, signal propagation, isolation

NOMENCLATURE

Symbol	Meaning	Units
CPE	characteristic polynomial equation	-
SCC	spectra characteristic curve	-
ec	exponential characteristics	-
m_1	mass of vibrating factory floor	*kg*
m_2	mass of vibrating roller machine	*kg*
m_3	mass of vibrating analyzer	*kg*
k_1	spring constant relative to factory floor	kN/m
k_2	spring constant relative to factory floor and vibrating roller machine	kN/m
k_3	spring constant relative to roller machine and analyzer	kN/m
k_4	spring constant relative to factory floor and analyzer	kN/m
c_1	damping constant relative to factory floor	$kN\,s/m$
c_2	damping constant relative to roller machine and analyzer	$kN\,s/m$
x_1	displacement of m_1	m
x_2	displacement of m_2	m
x_3	displacement of m_3	m
ω	excitation frequency	rad/s
ω_n	natural frequency	rad/s
T_r	transmissibility	-

1.0 Introduction

Mechanical vibrations occur in all factories as long as there are operating machines. The machines and floor vibrate and may harmonize once their frequency approaches each other, or the natural frequency of one of the machines. Unwanted vibrations may be induced by large impulsive forces in machines such as hammers and presses; unbalanced reciprocating components such as engines, motors compressors, etc. (Kelly, 2000).The dynamic forces produced by machinery are often very large. However, the force transmitted to the foundation or supporting structure can be reduced by using flexible mountings with the correct properties (Beards, 1999).

Ground vibrations arising from man-made sources including construction activities, blasting, vehicle and rail traffic may interfere with surrounding residential and commercial activities (Hiramatsu *et al.*, 2006). Ground-borne vibrations can also cause structural damage to nearby buildings. The problems may occur as a result of large vibration response, from repeated occurrences of smaller amplitude vibrations, or from differential settlement induced by particle rearrangement. Ground-borne vibrations are often accompanied by air-borne noise and other physical disorders in the human body (Evans *et al.*, 2005). As a matter of fact, vibration has been proven to result in musculoskeletal disorders of both the hand and arm, the neck, and the back (Rasmussen, 2003).

Hiramatsu *et al.* (2006) suggested high levels of vibrations can occur in floor systems due to excitation from human activities such as walking and aerobics. Excessive vibrations typically occur in light weight floors, floor systems with low stiffness, where the floor dominant natural frequency is close to the excitation frequency, and floors with low damping. While the floor mass and stiffness are normally constant during the life of the structure and can be estimated with a high degree of accuracy, damping is more difficult to predict because it is mostly associated with non-structural components such as partitions, false floors, suspended ceilings and ducts as well as furniture such as filing cabinets and bookshelfs. Current trends in the building industry associated with using lightweight materials, long-span open-plan floors and adoption of the electronic office, give rise to the importance of understanding floor vibrations and specifically damping. Sun *et al.* (2007) gave a summary of factors affecting floor vibrations, and discussed available damping systems which can be used to reduce vibration levels in floor systems.

In analyzing the vibration of a machine, which is a complex mechanical system, it is useful to consider the sources of vibration energy and the paths in the machine that this energy takes. Energy always moves, or flows, from the source of the vibration to the energy absorber where it is converted into heat. In some cases, this may be a very short path, but in other situations, the energy may travel relatively long distances before being absorbed (Olusegun, 2004).

The most important absorber of energy in a machine is friction, which can be sliding friction or viscous friction. Sliding friction is represented by relative motion between parts of the machine, and viscous friction is known to occur in the oil film in a journal bearing. If a machine has very little friction, its vibration level tends to be fairly high, for the vibration energy builds up due to the lack of absorption. On the other hand, a machine with greater inherent friction will have lower vibration levels because the energy is absorbed quickly (Ljunggren, 2006).

Mechanical vibrations are responsible for machines not operating up to design standard, especially if they are also affected by floor vibration. The floor itself will now be capable of transmitting response signals to the machines. The vibration of the machine will begin to harmonize with the transmitting vibration from the floor. Then chatting occur which eventually leads to whirling or resonance and serious damage to the moving parts.

The work of Ljunggren (2006) demonstrated the complexity of floor vibration, both when it comes to reduction of vibration levels as well as its cost. To change the vibration properties of a floor, either the stiffness, the mass or the damping must be changed. To change the mass and/or the stiffness of an existing floor is not easy since it requires major modifications which is costly and unsafe.

This work is aimed at monitoring microfloor vibrations in a newly-constructed factory building which houses a variety of machines with performances that are deleteriously affected by floor vibrations. Mmeasurements of the vibrations will profer appropriate ways to reduce them at their sources.

2.0 Description of the Vibration Analyser

The locally designed and constructed vibration analyzer consists of a microphone, a preamplifier, a rectifier and a display meter as shown in Figure 1.

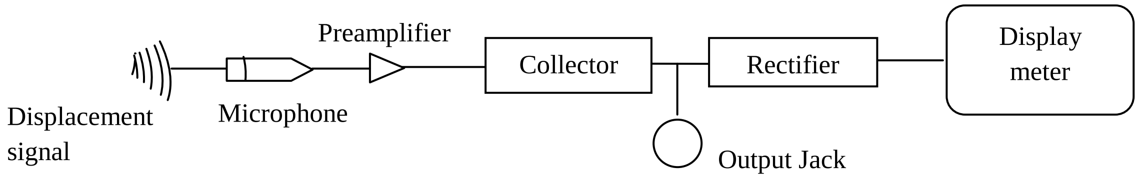

Figure 1: Components of the vibration analyzer

The vibration signals strike the diaphragm of the microphone, causing the diaphragm to move with the pressure fluctuations in the air. The microphone converts these pressure fluctuations into corresponding voltage fluctuations, which are then amplified and conditioned for further analysis by the preamplifier. In addition, at the microphone all sound wave energy is converted into an electrical signal that is boosted in magnitude at the preamplifier. The amplified signal is then passed through a collector which increase the signal. The rectifier converts the electrical signal from alternating current to direct current to cause the digital display meter to register the oscillation in millimetres.

3.0 Theorectical Analysis

The vibration analyzer which was constructed from locally sourced materials operates as a multiple degree of freedom system. The operation of the entire system was resolved to 3 mass system. The vibrating factory floor was represented as mass one (m_1), vibrating machine as mass 2 (m_2), and the vibration analyzer as mass 3 (m_3). The entire system is a 3-degree-of-freedom system as represented in Figure 2, while Figure 3 presented the free body diagram.

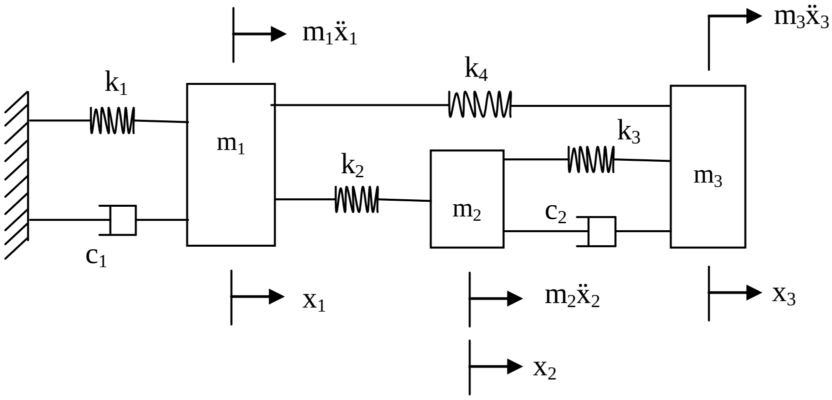

Figure 2: Schematic diagram of vibrating factory floor, machine and analyzer

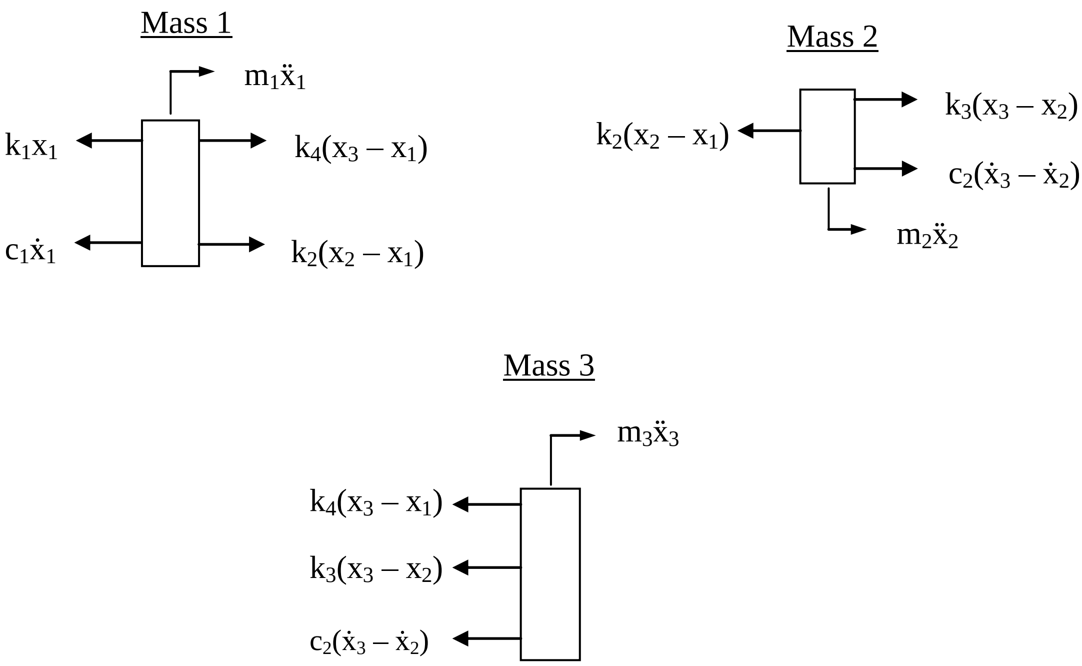

Figure 3: Free body diagram of the 3-degree-of-freedom system

The equations of motion are,

$$m_1\ddot{x}_1 + c_1\dot{x}_1 + (k_1 + k_2 + k_4)x_1 - k_2x_2 - k_4x_3 = f_1(x) \quad (1)$$

$$m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_3) + (k_2 + k_3)x_2 - k_2x_1 - k_3x_3 = f_2(x) \quad (2)$$

$$m_3\ddot{x}_3 + c_2(\dot{x}_3 - \dot{x}_2) + (k_3 + k_4)x_3 - k_3x_2 - k_4x_1 = f_3(x) \quad (3)$$

The matrix equation of motion is

$$m\ddot{x} + c\dot{x} + kx = F \quad (4)$$

which is expressed according to (eFundo Inc., 2009) as

$$\begin{vmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{vmatrix} \begin{vmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{vmatrix} + \begin{vmatrix} c_1 & 0 & 0 \\ 0 & c_2 & 0 \\ 0 & 0 & c_2 \end{vmatrix} + \begin{vmatrix} k_1 + k_2 + k_4 & -k_2 & -k_4 \\ -k_2 & k_1 + k_2 & -k_3 \\ -k_4 & -k_3 & k_3 + k_4 \end{vmatrix} \begin{vmatrix} x_1 \\ x_2 \\ x_3 \end{vmatrix} = \begin{bmatrix} f_1(t) \\ f_2(t) \\ f_3(t) \end{bmatrix} \quad (5)$$

4.0 Methodology

The dynamic force of the vibrating factory floor was $f_1(x)$ in equation (1) and was responsible for the relative displacement of the floor. Likewise $f_2(x)$ and $f_3(x)$ were the dynamic forces of the Buhler roller machines and the vibration analyzer and gave rise to the relative displacement of the two respectively.

A locally designed vibration analyzer was used to measure the vibrations of machines on the factory floors to determine the oscillations on the floors. Each reading was taken three times at eight different machine positions shown on Figure 4. The readings were taken at ten seconds intervals for sixty seconds round the machines. The values of time and displacement (oscillations) were used to generate the spectra and characteristic polynomial equations (CPE), which were used to determine the possible positions of high floor response and subsequent isolations. The readings were inputed into a computer for spectra analysis and produced the CPE shown in Appendix 1.

Damping is of prime importance in noise and vibration control (Matter *et al.*, 2009). The magnitudes of response were used to determine the type of isolator suitable for damping all abnormal oscillations at the various positions on the floor.

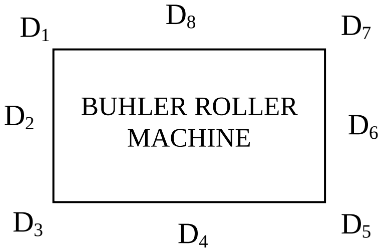

Figure 4: Roller machine positions from where vibration displacement were taken

5.0 Result and Discussion

Figures 5 to 17 shows the displacement and time readings recorded using the locally constructed vibration analyzer. The readings were for eight locations around the floor area of each of the thirteen Buhler roller machines tested in a flour mill. When the characteristic polynomial equations (CPE) were of three exponential characteristics, there was a tendency for the response to continue rather than dampen.

The spectra characteristic curve (SCC) for Roller Machine 1, Figure 5 was found to have responded evenly with a maximum crest of 0.21mm at position D_3 and a minimum trough of 0.08mm at Roller position D_5. No damping was recommended for Roller machine 1, as the CPE for that system did not exceed 2 exponential characteristics (ec). Roller Machines 3, 4, 6, 7 and 9 also had similar response to Roller Machine1 and did not response beyond the 2ec signal. This was because both internal response from machines as well as external ones from surrounding machines through the factory floor, did not affect the machines significantly as indicated by the amplitude of oscilation shown by the displacement-time curves. The maximum displacements for Roller Machines 3, 4, 6, 7 and 9 were 0.22, 0.22, 0.18, 0.21, and 0.23mm respectively. The minimum displacements were 0.07, 0.06, 0.04, 0.05 and 0.04mm respectively.

Relatively, the SCC of Roller Machine 2, Figure 6 was more pronounced than that of Roller Machine 1, Figure 5. The CPE for Roller Machine 2 exceeded 2ec. There was a tendency for the SCC to build up because of transfer of signal from other machines through the factory floor. This phenomena could lead to the growth of the signals to a catastrophic level, a process known as "chatting". Roller Machines 5, 8, 10, 11, 12 and 13 exhibit similar behaviour as Roller Machine 2. The SCC are shown on Figures 9, 12, 14, 15, 16 and 17 and to be pronounced.

Whereas Roller Machines 1, 3, 4, 6, 7 and 9 have no need for isolation, Roller Machines 2, 5, 8, 10, 11, 12 and 13 required isolation from the factory floor through which their SCC were propagated. The selection of isolators to match the displacement in mm and the machine position at which the isolator is to be placed are shown in Table 1.

The condition for isolation for conventional isolator design was considered in this study, which required that the value of the transmissibility T_t (the ratio of the force reaching the floor compared to the force applied by the machines) be greater than one (T_r>1) when $\omega/\omega_n < \sqrt{2}$ for the force transmitted to the floor to be considered as large. When $T_r < 1$ and $\omega/\omega_n < \sqrt{2}$, the machine required no isolation.

6.0 Conclusion

The locally made vibration analyzer was used to generate spectra characteristic curves at the flour mill factory floor where Roller Machines were mounted. The analysed SCC produced characteristic polynomial equations. It was observed that when the CPE was a regular 2 exponential characteristic signal, it was not necessary to isolate the factory floor from the machine vibrations, as the signals were not likely to propagate significantly through the factory floor. However, when the exponential characteristic signal exceeded 2, the SCC tends to propagate as a result of the influence of the signal from other machines through the factory floor. Isolation of the factory floor from the machine was done whenever the CPE was a 3 exponential signal. Cork and Composite pad were found to be adequate for the isolation of the machines. The study had shown that vibration effects could be successfully monitored on factory floors through the vibration analyzer application, thus, minimizing harzardous effects on factory workers and facilties.

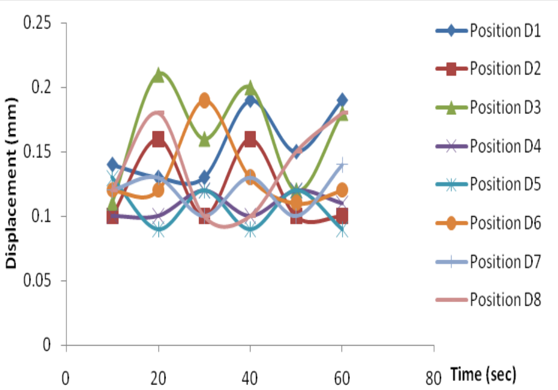

Figure 5: Displacement-time readings on roller machine 1

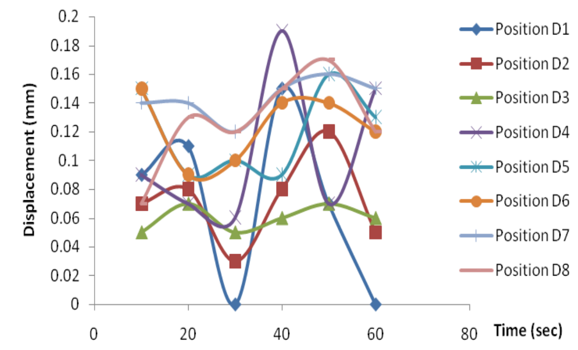

Figure 6: Displacement-time readings on roller machine 2

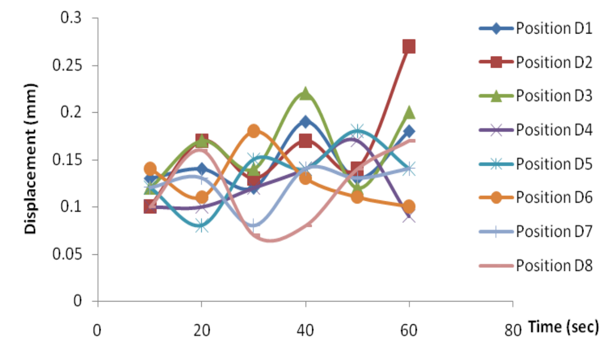

Figure 7: Displacement-time readings on roller machine 3

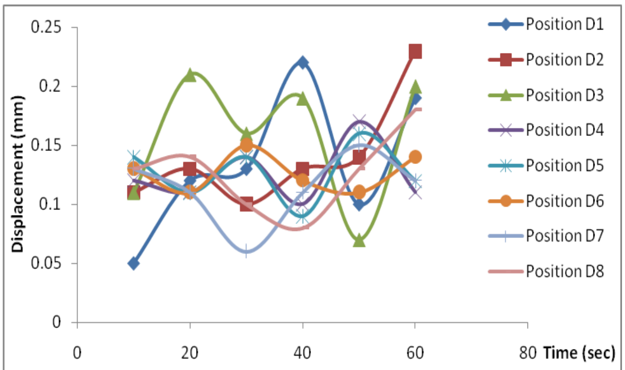

Figure 8: Displacement-time readings on roller machine 4

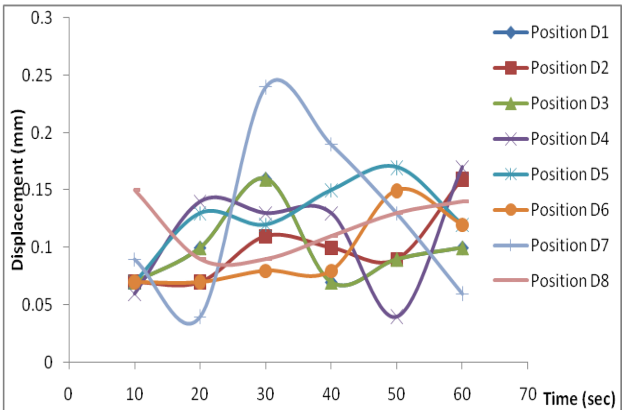

Figure 9: Displacement-time readings on roller machine 5

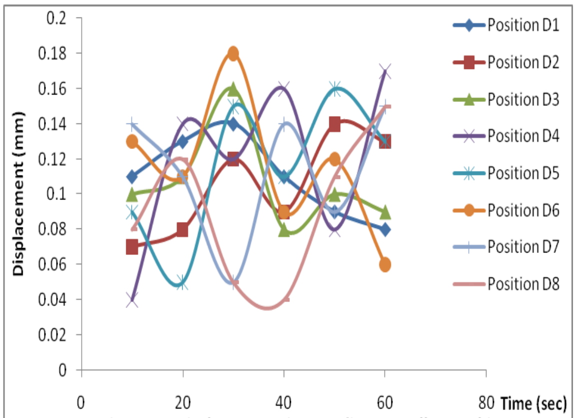

Figure 10: Displacement-time readings on roller machine 6

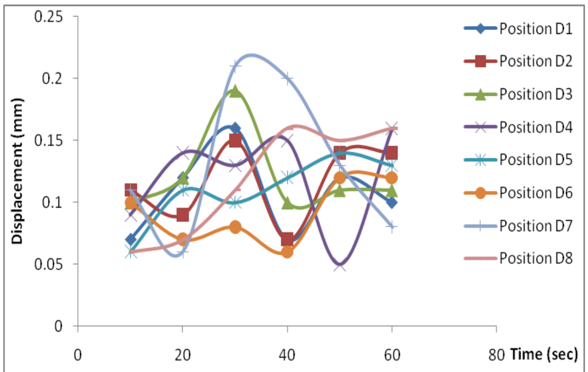

Figure 11: Displacement-time readings on roller machine 7

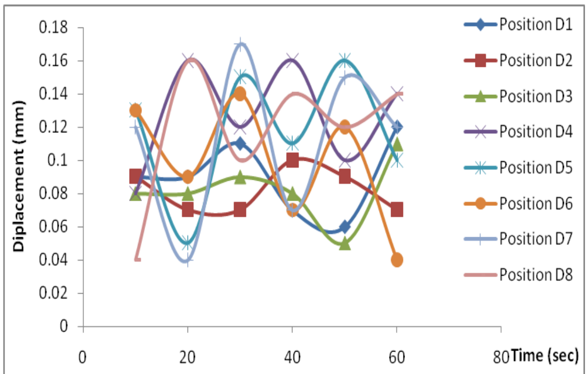

Figure 12: Displacement-time readings on roller machine 8

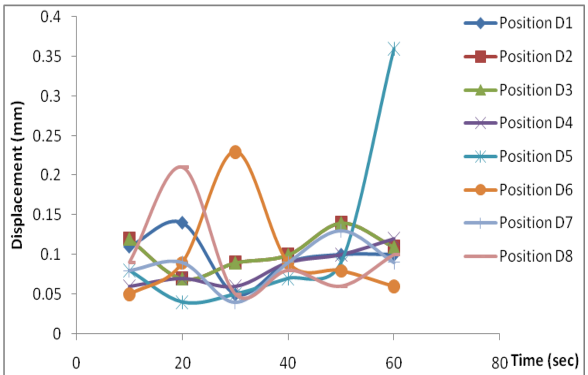

Figure 13: Displacement-time readings on roller machine 9

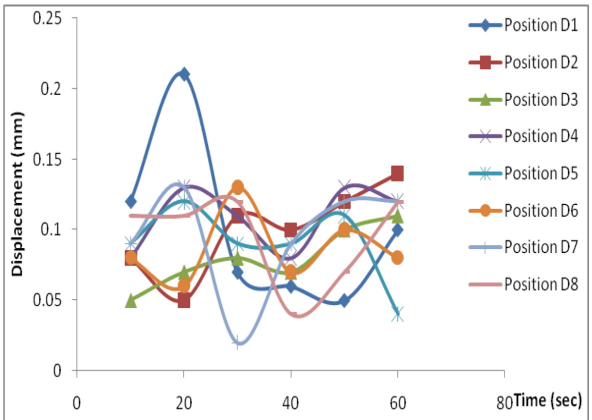

Figure 14: Displacement-time readings on roller machine 10

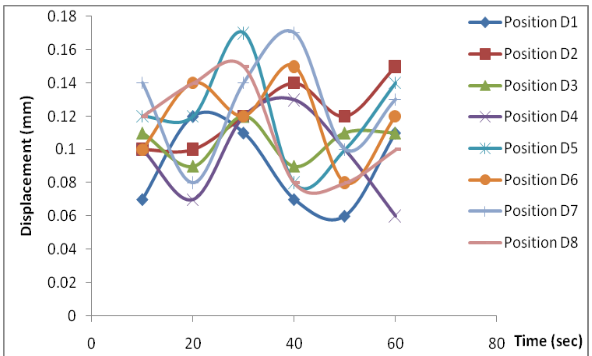

Figure 15: Displacement-time readings on roller machine 11

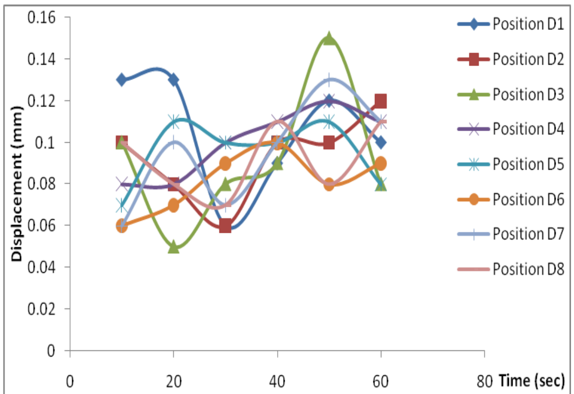

Figure 16: Displacement-time readings on roller machine 12

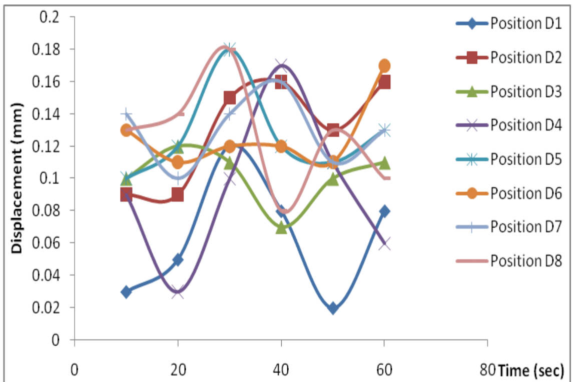

Figure 17: Displacement-time readings on roller machine 13

Table 1: Roller Machine Isolator Selected and Position where fixed

Roller machine number	Machine displacement -Crest to Trough (mm)	Isolator selected	Factory floor Position where Isolator was placed
1	-	None required	-
2	0.19	cork	D_4
3	-	None required	-
4	-	None required	-
5	0.20	Cork	D_7
6	-	None required	-
7	-	None required	-
8	0.13	Composite pad	D_7
9	-	None required	-
10	0.19	Cork	D_1
11	0.11	Composite pad	D_7
12	0.10	Composite pad	D_3
13	0.16	Composite pad	D_5 & D_8

7.0 Acknowledgement

The authors acknowledge Mr O. Shittu of the Flour Mill where the test were done and the crew that assisted in the experimentation. We also acknowledge the workshop staff of the University of Ilorin where our design of the vibration analyzer was manufactured.

8.0 References

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APPENDIX 1

FLOOR VIBRATION EQUATIONS

Statements of Equations of the Machine Vibrations transmitted to the Foundations at the immediate Vicinity of the Machines.

Roller Machine 1

D_1: $y = 5E-08x^5 - 8E-06x^4 + 0.0005x^3 - 0.0138x^2 + 0.176x - 0.65$

D_2: $y = 4E-08x^5 - 8E-06x^4 + 0.0005x^3 - 0.017x^2 + 0.2472x - 1.13$

D_3: $y = 8E-08x^5 - 1E-05x^4 + 0.0009x^3 - 0.027x^2 + 0.3803x - 1.75$

D_4: $y = -4E-08x^5 + 6E-06x^4 + 0.0004x^3 + 0.0114x^2 - 0.1499x + 0.79$

D_5: $y = -4E-08x^5 - 7E-06x^4 + 0.0004x^3 + 0.0131x^2 - 0.1834x - 1.02$

D_6: $y = -5E-08x^5 + 8E-06x^4 - 0.0006x^3 + 0.0181x^2 - 0.2498x + 1.31$

D_7: $y = 3E-08x^5 - 5E-06x^4 + 0.0003x^3 - 0.0104x^2 + 0.144x - 0.57$

D_8: $y = 2E-08x^5 - 4E-06x^4 + 0.0003x^3 - 0.0105x^2 + 0.1674x - 0.76$

Roller Machine 2

D_1: $y = 1E-07x^5 - 2E-05x^4 + 0.0016x^3 - 0.0476x^2 + 0.6439x - 2.94$

D_2: $y = 2E-08x^5 - 5E-06x^4 + 0.0003x^3 - 0.0111x^2 + 0.1595x - 0.71$

D_3: $y = 9E-09x^5 - 2E-06x^4 + 0.0001x^3 - 0.0044x^2 + 0.0668x - 0.29$

D_4: $y = 1E-07x^5 - 2E-05x^4 + 0.0012x^3 - 0.0343x^2 + 0.4392x + 1.89$

D_5: $y = -4E-08x^5 + 7E-06x^4 - 0.0004x^3 + 0.0128x^2 - 0.1799x - 1.03$

D_6: $y = 1E-08x^5 - 2E-06x^4 + 9E-05x^3 - 0.0019x^2 + 0.0098x + 0.17$

D_7: $y = 2E-08x^5 - 3E-06x^4 + 0.0002x^3 - 0.0068x^2 + 0.0929x - 0.3$

D_8: $y = 1E-08x^5 - 3E-06x^4 + 0.0002x^3 - 0.0066x^2 + 0.1042x - 0.48$

Roller Machine 3

$D_1:\quad y=7E-08x^5-1E-05x^4+0.0007x^3-0.0213x^2+0.281x-1.17$

$D_2:\quad y=6E-08x^5-1E-05x^4+0.0007x^3-0.0209x^2+0.2936x-1.33$

$D_3:\quad y=9E-08x^5-2E-05x^4+0.001x^3-0.0305x^2+0.4098x-1.81$

$D_4:\quad y=-1E-08x^5+2E-06x^4-0.0001x^3+0.0037x^2-0.0494x+0.33$

$D_5:\quad y=-5E-08x^5+9E-06x^4-0.0006x^3+0.018x^2-0.2544x-1.36$

$D_6:\quad y=-4E-08x^5+8E-06x^4-0.0006x^3+0.0182x^2-0.2587x+1.4$

$D_7:\quad y=5E-08x^5-9E-06x^4+0.0006x^3-0.0187x^2+0.2556x-1.09$

$D_8:\quad y=2E-08x^5-5E-06x^4+0.0004x^3-0.0127x^2+0.1985x-0.93$

Roller Machine 4

$D_1:\quad y=9E-08x^5-2E-05x^4+0.001x^3-0.0293x^2+0.3915x-1.79$

$D_2:\quad y=3E-08x^5-5E-06x^4+0.0004x^3-0.0111x^2+0.1537x-0.63$

$D_3:\quad y=9E-08x^5-2E-05x^4+0.001x^3-0.0302x^2+0.4194x-1.92$

$D_4:\quad y=-6E-08x^5+1E-05x^4-0.0006x^3+0.0188x^2-0.2497x+1.28$

$D_5:\quad y=-6E-08x^5+1E-05x^4-0.0007x^3+0.0211x^2-0.2843x+1.48$

$D_6:\quad y=-2E-08x^5+5E-06x^4-0.0003x^3+0.0102x^2-0.1469x+0.85$

$D_7:\quad y=2E-08x^5-5E-06x^4+0.0003x^3-0.0104x^2+0.1425x-0.54$

$D_8:\quad y=-8E-09x^5+1E-06x^4-5E-05x^3+0.0006x^2+0.0027x-0.08$

Roller Machine 5

$D_1:\quad y=7E-08x^5+1E-05x^4-0.0008x^3-0.0237x^2+0.3134x-1.51$

$D_2:\quad y=-9E-09x^5+2E-06x^4-0.0002x^3+0.0052x^2-0.0768x+0.45$

$D_3:\quad y=-7E-08x^5+1E-05x^4-0.0008x^3+0.0237x^2-0.3134x+1.51$

$D_4:\quad y=5E-08x^5-8E-06x^4+0.0005x^3-0.0158x^2+0.2208x-1.02$

$D_5:\quad y=1E-08x^5-3E-05x^4+0.0002x^3-0.0066x^2+0.1042x-0.48$

$D_6:\quad y=-3E-08x^5+5E-06x^4-0.0003x^3+0.0083x^2-0.1059x+0.55$

$D_7:\quad y=-8E-08x^5+2E-05x^4-0.0011x^3-0.0354x^2-0.5121x+2.61$

$D_8:\quad y=-8E-08x^5+2E-07x^4-2E-05x^3+0.0012x^2-0.0288x+0.34$

Roller Machine 6

$D_1:\quad y=-1E-08x^5+2E-06x^4-0.0001x^3+0.0039x^2-0.0483x-0.32$

$D_2:\quad y=-4E-08x^5+8E-06x^4-0.0005x^3+0.0149x^2-0.1972x+0.98$

$D_3:\quad y=-6E-08x^5+1E-05x^4-0.0007x^3+0.0222x^2-0.293x+1.46$

$D_4:\quad y=7E-08x^5-1E-05x^4+0.0008x^3-0.0232x^2+0.3255x-1.55$

$D_5:\quad y=-8E-08x^5+1E-05x^4-0.0009x^3+0.028x^2-0.3904x+1.97$

$D_6:\quad y=-8E-08x^5+1E-05x^4-0.001x^3+0.0298x^2-0.4046x+2.04$

$D_7:\quad y=8E-08x^5-1E-05x^4+0.0009x^3-0.0277x^2+0.363x-1.52$

$D_8:\quad y=2E-09x^5-9E-07x^4+0.0001x^3-0.0048x^2+0.0875x+0.41$

Roller Machine 7

$D_1:\quad y=-7E-08x^5+1E-05x^4-0.0008x^3+0.0231x^2-0.2954x-1.39$

$D_2:\quad y=-8E-08x^5+1E-05x^4-0.001x^3+0.0292x^2-0.3935x+1.96$

$D_3:\quad y=-7E-08x^5+1E-05x^4-0.0008x^3+0.025x^2-0.3337x+1.65$

$D_4:\quad y=6E-08x^5-1E-05x^4+0.0006x^3-0.0182x^2+0.2449x-1.07$

$D_5:\quad y=1E-08x^5-2E-06x^4+0.0001x^3-0.00052x^2+0.0829x-0.38$

$D_6:\quad y=-4E-08x^5+6E-06x^4-0.0004x^3+0.0116x^2-0.1575x+0.85$

$D_7:\quad y=-4E-08x^5+8E-06x^4-0.0006x^3+0.0203x^2-0.3064x-1.66$

$D_8:\quad y=2E-08x^5+3E-06x^4+0.0002x^3-0.0041x^2+0.0489x+0.15$

Roller Machine 8

$D_1:\quad y=-2E-08x^5+3E-06x^4-0.0002x^3+0.0075x^2-0.1033x+0.58$

$D_2:\quad y=1E-08x^5-3E-06x^4+0.0002x^3-0.0045x^2-0.0546x+0.14$

$D_3:\quad y=7E-09x^5-9E-07x^4+4E-05x^3-0.0007x^2+0.005x+0.07$

$D_4:\quad y=6E-08x^5-1E-05x^4+0.0007x^3-0.0224x^2+0.3154x-1.46$

$D_5:\quad y=-8E-08x^5+1E-05x^4-0.001x^3+0.0305x^2-0.432x-2.24$

$D_6:\quad y=-8E-08x^5+1E-05x^4-0.0009x^3+0.0267x^2-0.3644x+1.86$

$D_7:\quad y=-1E-07x^5+2E-05x^4-0.0015x^3+0.0469x^2-0.6512x-3.25$

$D_8:\quad y=6E-08x^5-1E-05x^4+0.0007x^3-0.0232x^2+0.3418x+1.68$

Roller Machine 9

$D_1:\quad y=5E-08x^5-9E-06x^4-0.0006x^3-0.0201x^2+0.287x+1.29$

$D_2:\quad y=-2E-08x^5+4E-06x^4-0.0002x^3+0.0078x^2-0.1145x+0.7$

$D_3:\quad y=-2E-08x^5+4E-06x^4-0.0002x^3+0.0078x^2-0.1145x+0.7$

$D_4:\quad y=2E-08x^5-3E-06x^4+0.0002x^3-0.0064x^2+0.0879x-0.36$

$D_5:\quad y=2E-08x^5-3E-06x^4+0.0001x^3-0.0032x^2+0.0274x-0.01$

$D_6:\quad y=-1E-07x^5+2E-05x^4-0.0013x^3+0.0409x^2-0.5512x+2.62$

$D_7:\quad y=3E-08x^5-5E-06x^4+0.0004x^3+0.0116x^2-0.1664x-0.73$

$D_8:\quad y=9E-08x^5-2E-05x^4+0.0011x^3-0.0363x^2+0.5301x+2.55$

Roller Machine 10

$D_1:\quad y=6E-08x^5-1E-05x^4+0.0007x^3-0.0246x^2+0.3668x+1.73$

$D_2:\quad y=-3E-08x^5+6E-06x^4-0.0004x^3+0.0132x^2-0.189x+1.01$

$D_3:\quad y=-2E-08x^5+3E-06x^4-0.0002x^3+0.0046x^2-0.0563x+0.29$

$D_4:\quad y=-2E-08x^5+3E-06x^4-0.0002x^3+0.0044x^2-0.0391x-0.19$

$D_5:\quad y=-7E-19x^5-4E-07x^4+6E-05x^3-0.0027x^2+0.0493x-0.19$

$D_6:\quad y=-7E-08x^5+1E-05x^4-0.0008x^3+0.0241x^2-0.3302x+1.65$

$D_7:\quad y=6E-08x^5-1E-05x^4+0.0008x^3-0.0267x^2+0.3797x-1.76$

$D_8:\quad y=-5E-08x^5+9E-06x^4-0.0006x^3+0.0165x^2-0.217x+1.11$

Roller Machine 11

$D_1:\quad y=-5E-09x^5+9E-07x^4-5E-05x^3+0.001x^2-0.0004x+0.02$

$D_2:\quad y=1E-08x^5-2E-06x^4+0.0001x^3-0.0028x^2+0.0317x\ 0.03$

$D_3:\quad y=-3E-08x^5+6E-06x^4-0.0004x^3+0.0121x^2-0.1668x+0.91$

$D_4:\quad y=-7E-09x^5+2E-06x^4-0.0001x^3+0.005x^2-0.0825x-0.54$

$D_5:\quad y=-6E-08x^5+1E-05x^4-0.0008x^3+0.0232x^2-0.3121x-1.58$

$D_6:\quad y=5E-08x^5-9E-06x^4+0.0006x^3-0.0168x^2+0.2289x-0.99$

$D_7:\quad y=2E-08x^5-2E-06x^4+8E-05x^3-0.0003x^2-0.0248x-0.36$

$D_8:\quad y=-3E-08x^5+6E-06x^4-0.0004x^3+0.0117x^2-0.1511x+0.8$

Roller Machine 12

$D_1:\quad y=3E-08x^5-5E-06x^4+0.0004x^3-0.012x^2+0.171x+0.7$

$D_2:\quad y=3E-08x^5-5E-06x^4+0.0003x^3-0.0089x^2+0.1154x-0.42$

$D_3:\quad y=-3E-08x^5+6E-06x^4-0.0004x^3+0.0118x^2-0.1666x+0.92$

$D_4:\quad y=-6E-09x^5+1E-06x^4-7E-05x^3+0.0023x^2-0.0328x-0.24$

$D_5:\quad y=8E-10x^5-4E-07x^4+4E-05x^3-0.0019x^2+0.0373x-0.15$

$D_6:\quad y=7E-09x^5-1E-06x^4+5E-05x^3-0.0012x^2+0.0141x-1E-11$

$D_7:\quad y=2E-08x^5-3E-06x^4+0.0002x^3-0.0082x^2-0.1236x-0.57$

$D_8:\quad y=3E-08x^5-6E-06x^4+0.0004x^3-0.0104x^2+0.1308x-0.48$

Roller Machine 13

$D_1:\quad y=-2E-08x^5+4E-06x^4-0.0003x^3+0.0092x^2-0.1326x+0.67$

$D_2:\quad y=-2E-09x^5+9E-07x^4-9E-05x^3+0.0037x^2-0.061x-0.41$

$D_3:\quad y=-2E-08x^5+4E-06x^4-0.0002x^3+0.0067x^2-0.0805x+0.44$

$D_4:\quad y=2E-08x^5-3E-06x^4+0.0002x^3-0.0031x^2+0.0123x-0.14$

$D_5:\quad y=-4E-08x^5+8E-06x^4-0.0005x^3+0.0164x^2-0.2208x+1.13$

$D_6:\quad y=3E-09x^5-3E-07x^4+5E-06x^3+0.0004x^2-0.013x-0.22$

$D_7:\quad y=1E-08x^5-2E-06x^4+6E-05x^3-0.0005x^2-0.0128x-0.27$

$D_8:\quad y=-8E-08x^5+1E-05x^4-0.0009x^3+0.0269x^2-0.3543x-1.76$