Advanced Logistic Systems Vol. 13 No. 1 (2019) pp. 55-67, https://doi.org/10.32971/als.2019.012

MECHANICAL VIBRATION AND SHOCK MEASUREMENT OF MATERIAL FLOW DEVICES AND SYSTEMS

ISTVÁN SZENTMIKLÓSI [1], BÉLA ILLÉS [2]

Abstract: The article deals with the measurement and analysis of the vibration of material flow devices and systems. This work has been done to find out if and in what form kinetic energy arises in comprehensive material flow processes. In the first chapter the theory of vibration measurement from periodic vibration to transient effects will be described using their physical and mathematical foundations. At the beginning of the article the results of the large-scale measurements are presented. A special focus is on the natural frequency of the individual material flow devices. It has to be examined whether it is a certain useful frequency of technical units such as trucks, conveyor belt, etc. exist over the entire supply chain. In the second chapter, the theoretical basics of metrology are described, then the results will be presented and then the results will be summarized and evaluated. At the very end, an outlook is given about the further steps of the work.
Keywords: Material flow devices, vibration measurement, shock, acceleration, Power Spectral Density, SignalExpress

1. INTRODUCTION

Modern mobile, non-stationary IoT devices require continuous power supply [1]. Their energy needs must be ensured. A further requirement is that the unit does not use any external charge or replacement for human or other resources during its lifetime to meet economic needs. This can be accomplished in several ways. One possible way to accomplish this is to convert the kinetic energy generated during transportation, loading into electricity, to store it and to make it available for electronics.

To do this, it is necessary to get acquainted with the means of the movements generated by the transport used in the field of logistics. They pass on eg. vibrations caused by the quality of the road.

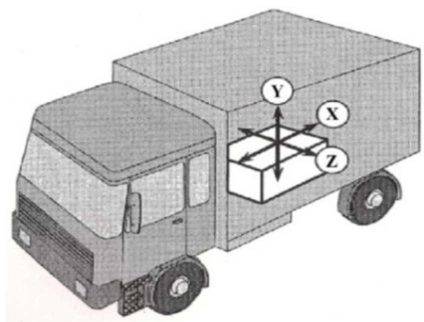

Figure 1. Direction of force in material flow devices [2]

[1] MSc., University of Miskolc
quality2000@citromail.hu
[2] University professor, University of Miskolc
altilles@uni-miskolc.hu
H-3515 Miskolc-Egyetemváros, Hungary

During transportation, the track or due to the quality of the road, according to the actual traffic event, due to the characteristics of the means of transport, horizontal (in the x and z direction shown in Fig. 1) and vertical (in the y direction shown in Fig. 1) forces occur. The magnitude of these forces is proportional to the quality of the road, the type of the vehicle, its technical conditions and the speed of the delivery, etc. During material flow processes, in the transport medium, in addition to static kinetic energy, dynamic kinetic energies occur in the form of vibrations and shocks. The purpose of this work is to present the methods of measuring these vibrations and to present concrete measurement results. This article reports on the kinetic conditions of material flow systems under normal conditions, which forms the basis of my work and on which my later research is based.

2. THEORY OF VIBRATION MEASUREMENT

2.1. Periodic vibration

Periodic vibration may be looked upon as an oscillating motion of a particle, or body, about a reference position, the motion repeating itself exactly after certain periods of time. The simplest form of periodic vibration is the so- called harmonic motion which when plotted as a function of time, is represented by a sinusoidal curve, Fig.2. Here T is the period of vibration, i.e. the time elapsed between two successive, exactly equal conditions of motion.

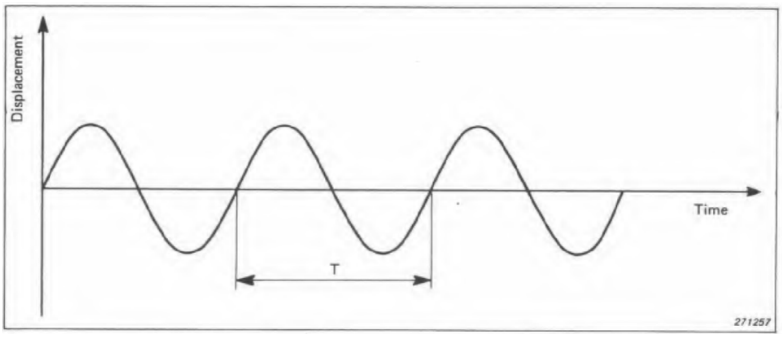

Figure 2. Example of a pure harmonic (sinusoidal) vibration signal

The frequency of the vibration is given by:

$$f = \frac{1}{T} \tag{1}$$

If the vibration has the form of a pure translational oscillation along one axis (x) only, the instantaneous displacement of the particle (or body) from the reference position can be mathematically described by means of the equation:

$$x = X_{peak}\, sin\left(2\pi \frac{t}{T}\right) = X_{peak} sin(2\pi f t) = X_{peak} sin(\omega t) \tag{2}$$

where

$\omega = 2\pi f$: angular frequency
X_{peak}: Maximum displacement from the reference position
t: time

As the velocity of a moving particle (or body) is the time rate of change of the displacement, the motion can also be described in terms of velocity (v):

$$v = \frac{dx}{dt} = \omega X_{peak} cos(\omega t) = V_{peak} cos(\omega t) = V_{peak} sin(\omega t + \frac{\pi}{2}) \quad (3)$$

Finally, the acceleration (a) of the motion is the time rate of change of the velocity:

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -\omega^2 X_{peak} sin(\omega t) = -A_{peak} sin(\omega t) = A_{peak} sin(\omega t + \pi) \quad (4)$$

A further descriptive quantity, which does take the time history into account, is the average absolute value, defined as (see also Fig.3):

$$X_{Average} = \frac{1}{T}\int_0^T |x| dt \quad (5)$$

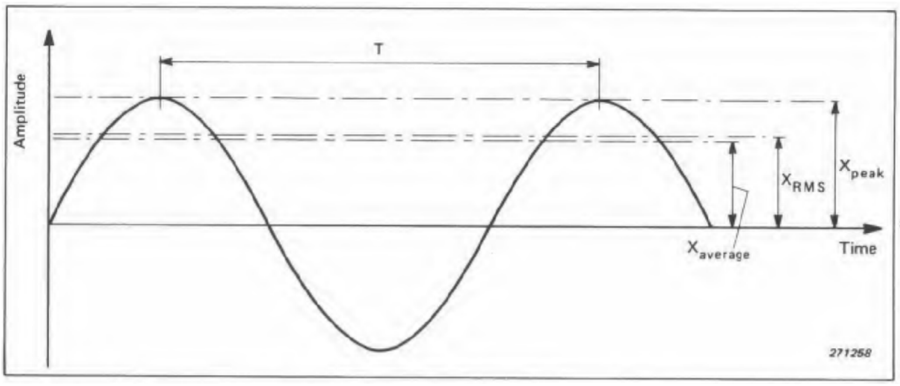

Figure 3. Example of a harmonic vibration signal with indication of the peak, the RMS and the average absolute value

A much more useful descriptive quantity which also takes the time history into account, is the RMS (root mean square) value (Fig.3):

$$X_{RMS} = \sqrt{\frac{1}{T}\int_0^T x^2(t) dt} \quad (6)$$

The major reason for the importance of the RMS-value as a descriptive quantity is its simple relationship to the power content of the vibrations [3].

2.2. Transient phenomena and shocks

Transient phenomena and mechanical shocks are, like random vibrations encountered relatively often in daily life. They may originate from such widely different releases of energy as rough handling of equipment, explosions and supersonic motion. However, common for this type of energy release is its short duration and sudden occurrence. A simple shock may be defined as a transmission of kinetic energy to a system which takes place in a relatively short time compared with the natural period of oscillation of the system, while transient phenomena (also termed complex shocks) may last for several periods of vibration of the system. Shocks and transient vibrations may be described in terms of force, acceleration, velocity or displacement and for a complete description it is necessary to obtain an exact time history record of the quantity in question. In many cases the ultimate goal is not the waveform itself, but rather a means to estimate the effect that the corresponding shock or transient vibration would have on a certain mechanical system. A more useful method of description might be found in the form of Fourier analysis. If the time function for a shock is $x(t)$ then its Fourier transform is given by [3]:

$$F[x(t)] = \int_{-\infty}^{\infty} x(t) \in^{-j\omega t} dt = X(\omega) \tag{7}$$

and the inverse Fourier transform , frequency to time domain, of $X(\omega)$ is

$$F^{-1}[X(\omega)] = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega) \in^{j\omega t} d\omega = X(t) \tag{8}$$

Let's look at the connection between energy and performance.

Parseval's theorem relates the representation of energy, $\omega(t)$, in the time domain to the frequency domain by the statement

$$\omega(t) = \int_{-\infty}^{\infty} f_1(t) f_2(t) dt = \int_{-\infty}^{\infty} F_1(f) F_2(f) df \tag{9}$$

where *f(t)* is an arbitrary signal varying as a function of time and *F(t)* its equivalent Fourier transform representation in the frequency domain.

$$\omega(t) = \int_{-\infty}^{\infty} f^2(t) dt = \int_{-\infty}^{\infty} F(f) F^*(f) df = \int_{-\infty}^{\infty} |F(f)|^2 df \tag{10}$$

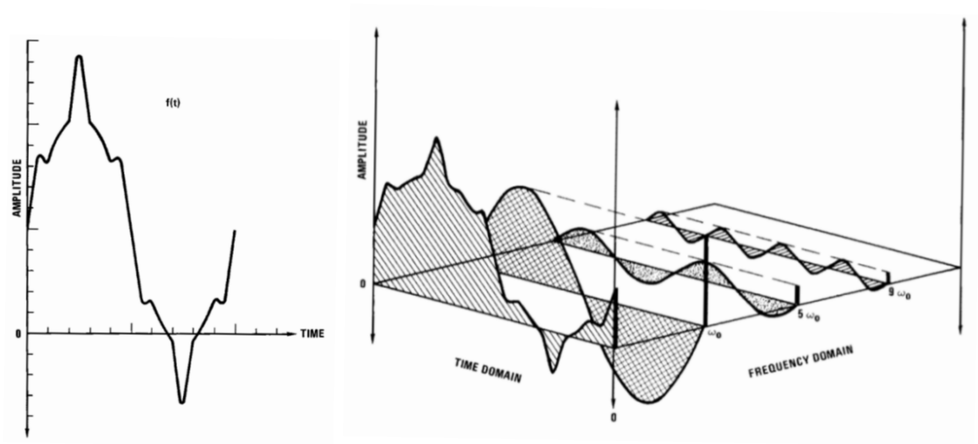

Figure 4a. An signal $f(t)$, Figure 4b. Combined Time Domain and Frequency Domain Plots [4]

This simply says that the total energy in a signal *f(t)* is equal to the area under the square of the magnitude of its Fourier transform. $|F(f)|^2$ is typically called the energy density, spectral density, or power spectral density function and $|F(f)|^2 df$ describes the density of signal energy contained in the differential frequency band from f to f + dF [4]. For periodic signals, equation (11) can be used to define the average power, P_{AVG}, over a time interval t_2 to t_1 by integrating [f(t)]² from t_1 to t_2 and then obtaining the average after dividing the result by $t_2 - t_1$ or

$$P_{AVG} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} f^2(t)dt = \frac{1}{T} \int_0^T f^2(t)dt \tag{11}$$

where T is the period of the signal. Having established the definitions of this section, energy can now be expressed in terms of power, P(t),

$$\omega(t) = \int_{-\infty}^{\infty} [f(t)]^2 dt = \int_{-\infty}^{\infty} P(t)dt \tag{12}$$

with power being the time rate of change of energy

$$P(t) = \frac{d\omega_t}{dt} \tag{13}$$

As a final clarifying note, $|F(f)|^2$ and $P(t)$, as used in equations (12) and (13), are commonly called throughout the technical literature, energy density, spectral density, or power spectral density functions, PSD. Further, PSD may be interpreted as the average power associated with a bandwidth of one hertz centred at f hertz.

2. MEASUREMENT RESULTS

For the measurements was used the test setup consisting of equipment NI-9234 Sound and Vibration module with three connected acceleration sensors which was assembled to a load unit to measure the acceleration in all three directions x, y, z. See Figure 5.

Figure 5. Load Unit with assembled acceleration sensors

The data were acquired and analyzed by using the mathematical methods described in Chapter 1 by the data-logging software NI-SignalExpress [5]. The vibrations were measured in acceleration and then converted by the software into PSD. It is helpful to indicate for the fast evaluation of the characteristics that 0 dB = 1 W, -10 dB = 100 mW, -20 dB = 10 mW and -30 dB = 1 mW at the given frequency.

2.1. Conveyor belt of driverless truck under laboratory conditions

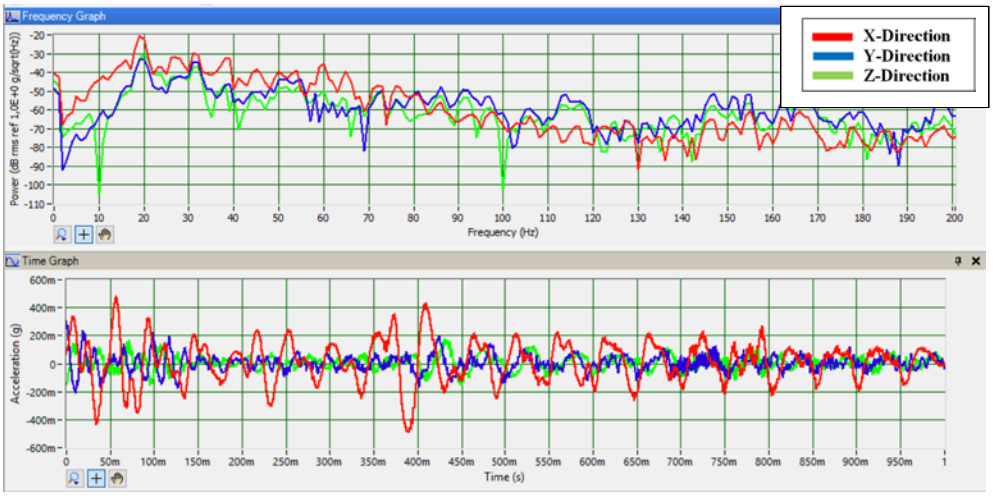

Figure 6. Conveyor belt of driverless truck. PSD and acceleration

The greatest amplitude force is from X - direction. Harmonic vibration movement occurs at 19 Hz.

2.2. Driverless truck under laboratory condition

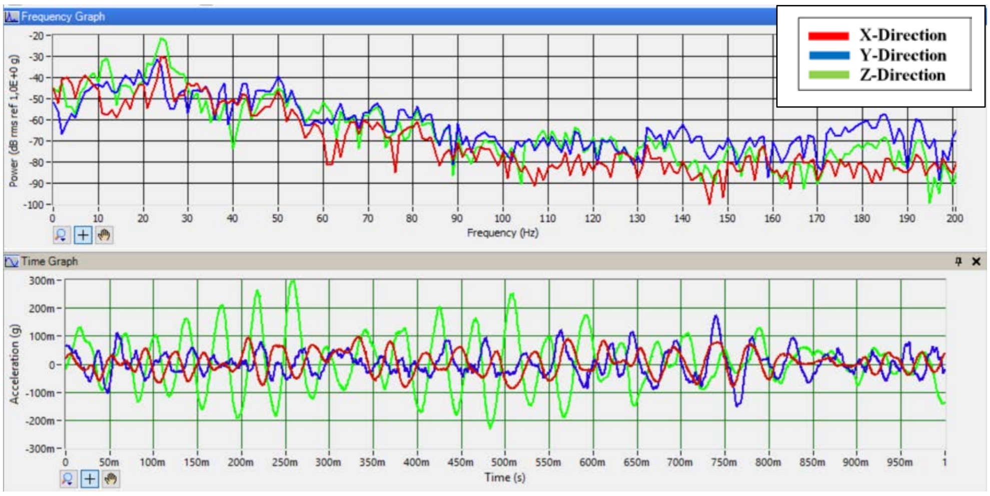

Figure 7. Driverless truck. PSD and acceleration

The greatest amplitude force is from direction Z. Harmonic vibration movement occurs at 24 Hz.

2.3. Mitsubishi robotic arm

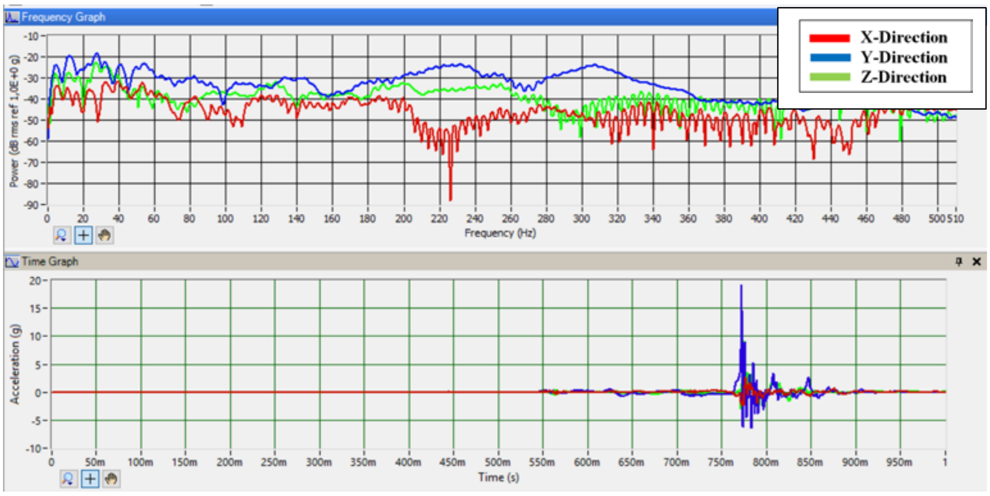

Figure 8. Mitsubishi robotic arm. PSD and acceleration

The greatest amplitude force is from Y-direction. There is no harmonic vibration movement, shock force occurs, with an acceleration of 19 g in the Y-direction. The shock extends over the entire spectrum of the frequency band.

2.4. Roller track

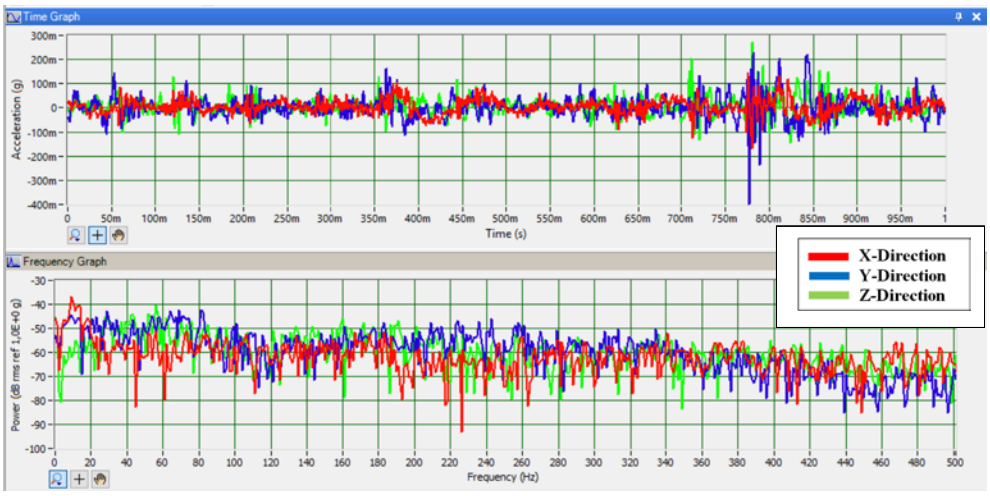

Figure 9. Roller track. Acceleration and PSD

There is no strong force from any direction in the flow of material on the roller track.

2.4.1. Roller track brake

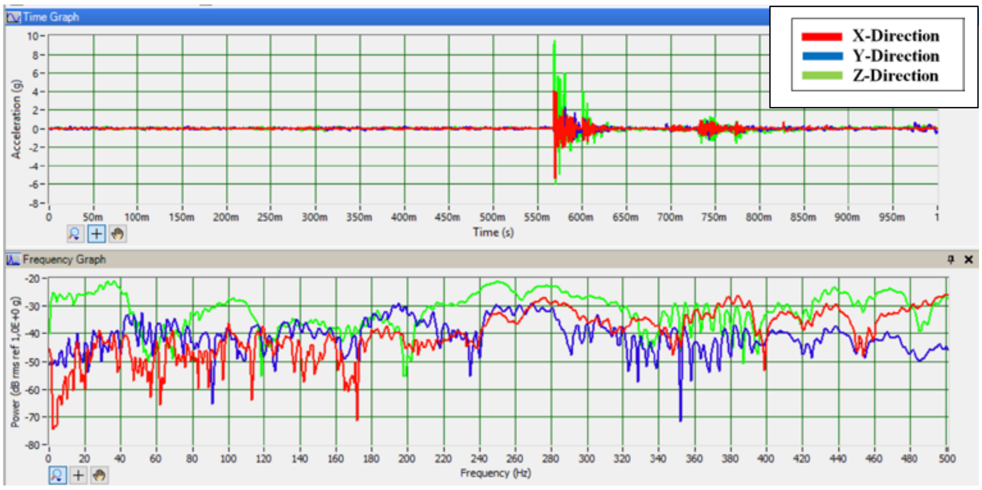

Figure 10. Roller track brake. Acceleration and PSD

During the flow of material on the roller track, the load stop brake generates shock force. There is no pronounced power force from one direction to the other, the shock is in the whole spectrum of the frequency band.

2.4.2. Roller track turntable

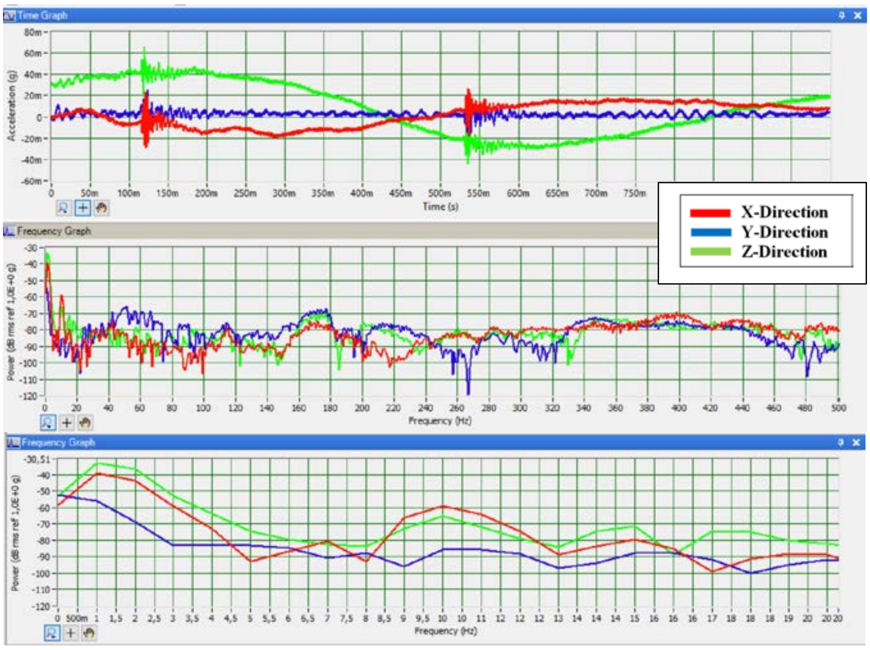

Figure 11. Roller track turntable. Acceleration and PSD, PSD 0 – 20 Hz

During the flow of material on the roller track, the transfer device creates a long-term but low amplitude accelerator force. There is no pronounced power force from one direction to the other, the shock is in the whole spectrum of the frequency band. Amplitude peak are at 1.5 Hz and 10 Hz.

2.5. Forklift (Yale GDP 20 TF) outside

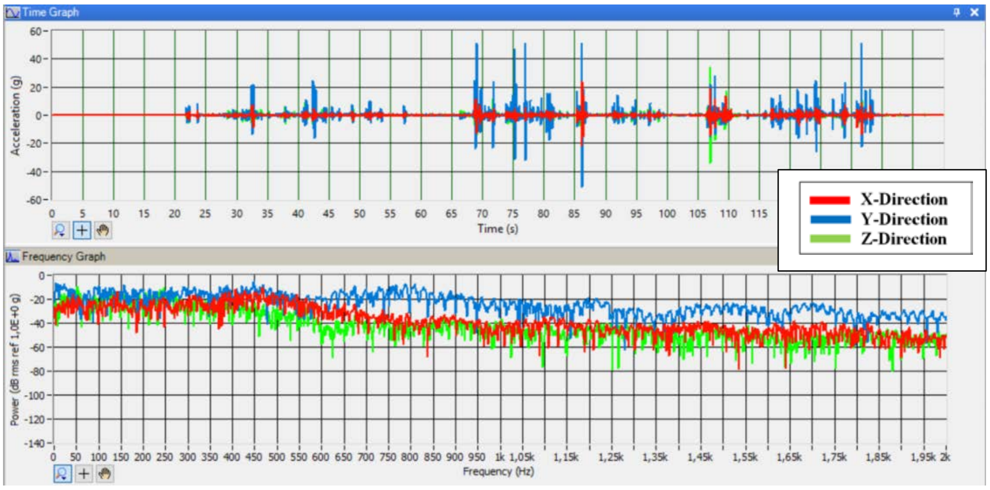

Figure 12. Forklift. Acceleration and PSD

2.6. Truck (Nissan Vanette) free-wheel

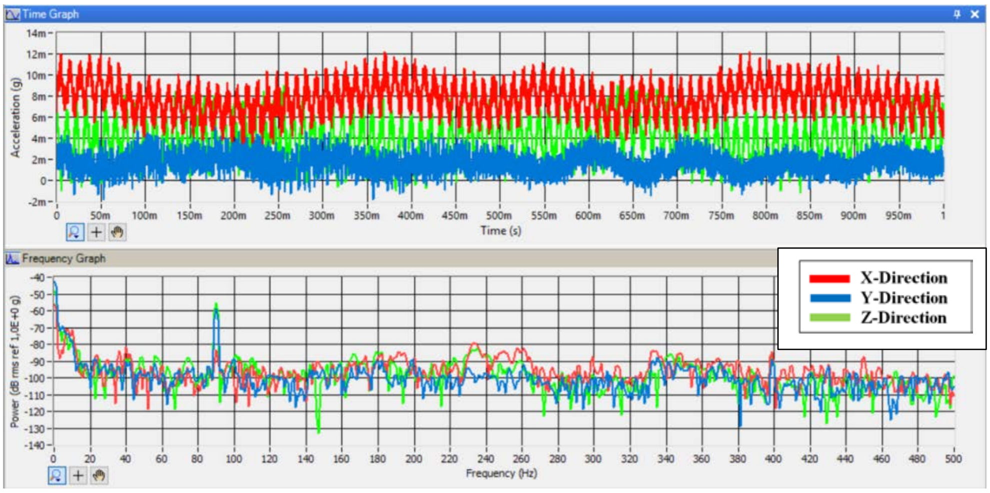

Figure 13. Truck free-wheel. Acceleration and PSD

2.6.1. Truck in the city with 50 km/h in good road surface

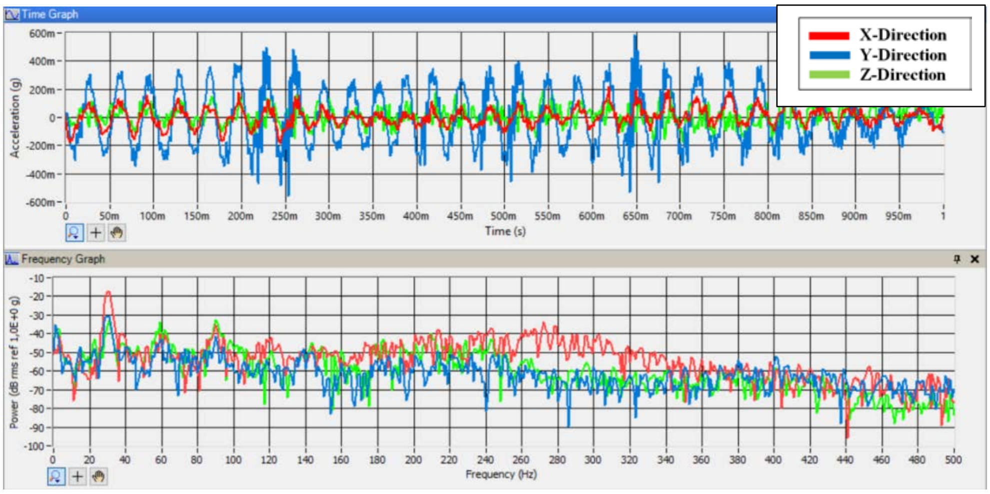

Figure 14. Truck in city with 50 km/h in good road surface. Acceleration and PSD

2.6.2. Truck in the city with 50 km/h in bad road surface

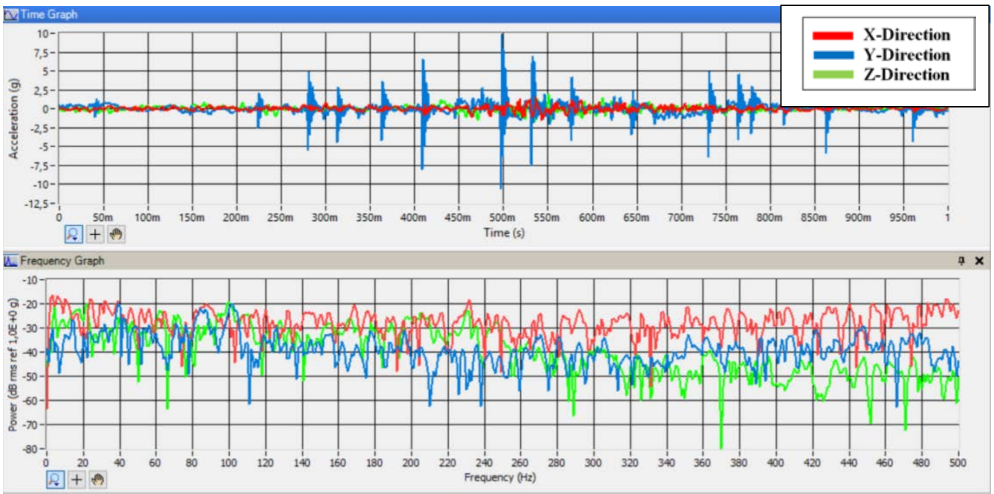

Figure 15. Truck in the city with 50 km/h in bad road surface. Acceleration and PSD

2.6.3. Truck on the highway with 90 km/h in good road surface

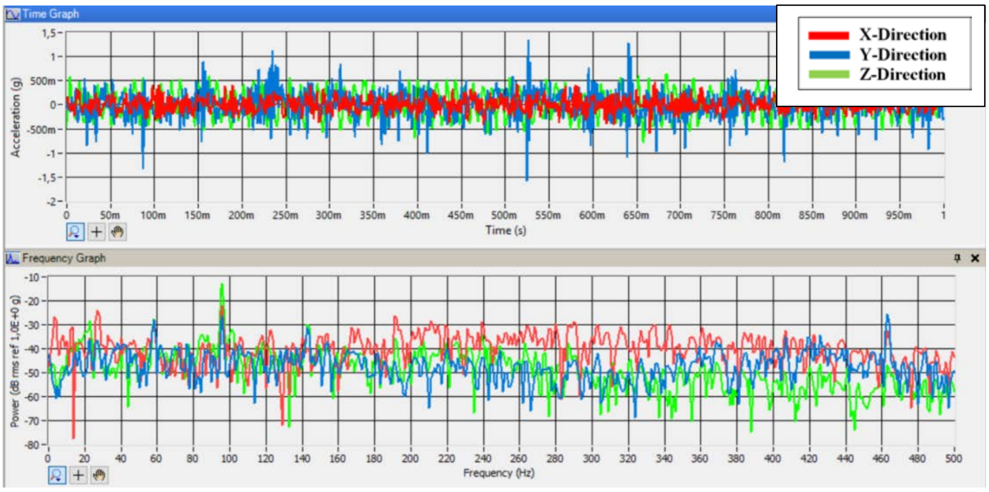

Figure 16. Truck on the highway with 90 km/h in good road surface. Acceleration and PSD

2.6.4. Truck on the highway with 90 km/h in bad road surface

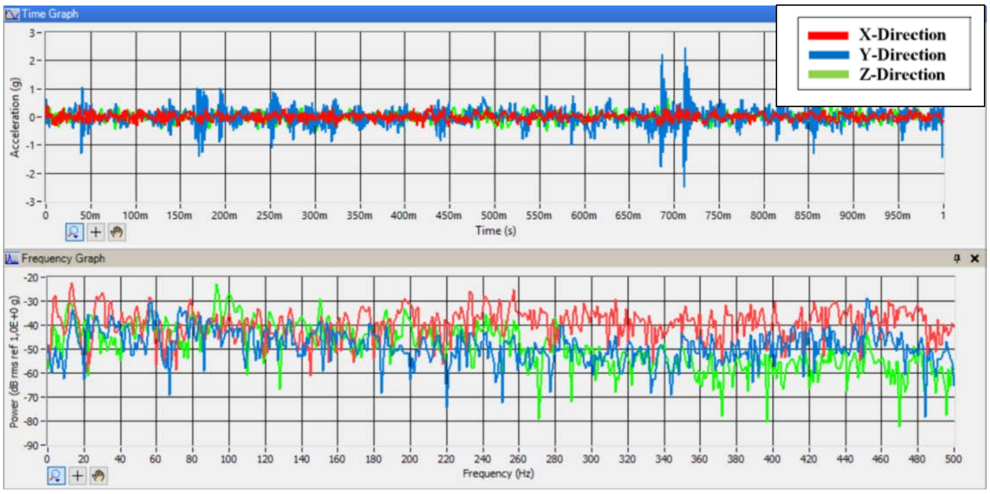

Figure 17. Truck ont he highway with 90 km/h in bad road surface. Acceleration and PSD

3. EVALUATION OF MEASURED VALUES

Table I.

Comparison of measured acceleration values

Device	***Natural Frequency***	***Power natural frequency X-direction***	***Power natural frequency Y-direction***	***Power natural frequency Z-direction***
Conveyor belt	19 Hz	-21 dBW	-32 dBW	-27 dBW
Truck, driverless	23 Hz	-30 dBW	-30 dBW	-21 dBW
Roller track	-	-	-	-
Truck, free-wheel	90 Hz	- 87 dBW	- 60 dBW	- 55 dBW
Truck in city, good road	30 Hz	- 18 dBW	- 30 dBW	- 32 dBW
Truck on highway, good road	95 Hz	- 22 dBW	- 27 dBW	- 13 dBW
Truck on highway, bad road	91 Hz	-	-	- 22 dBW

Table II.

Comparison of measured shock values

Device	***Axis***	***Peak Acceleration***	***Peak Duration***
Robotic arm	Longitudinal	19 g	2 ms
	Vertical	2,5 g	2 ms
	Lateral	9 g	2 ms
Roller track brake	Longitudinal	4 g	1 ms
	Vertical	4 g	3 ms
	Lateral	16 g	10 ms
Roller track transfer device	Longitudinal	20 mg	1 s
	Vertical	-	-
	Lateral	40 mg	1 s
Forklift Yale	Longitudinal	22 g	5 ms
	Vertical	51 g	10 ms

	Lateral	12 g	5 ms
Truck in City, Bad Road Surface	Longitudinal	1 g	10 ms
	Vertical	10 g	3 ms
	Lateral	1 g	10 ms
Truck on Highway, Good Road Surface	Longitudinal	0,2 g	2 ms
	Vertical	1,35 g	2 ms
	Lateral	0,45 g	5 ms
Truck on Highway, Bad Road Surface	Longitudinal	0,3 g	10 ms
	Vertical	2,3 g	4 ms
	Lateral	0,25 g	10 s

4. CONCLUSIONS

In material flow processes, due to the complexity and diversity of processes, used devices, quality of the used devices and determining circumstance it can be stated that there is no specific harmonic vibration movement that would be widely suitable for energy generation. In material flow processes, high-amplitude collisions and shock-like forces can be observed and measured. Although not periodic, they occur in a predetermined place and time in each process. These transients are very energy rich and happen when going off, lane change, braking, stopping, changing direction, etc., wherever static motion is changed. Upon evaluation of the data obtained, it becomes clear that the kinetic energy is abundant. The challenge is to find a procedure a non-conventional method to convert this non-periodic shock energy of x,y,z directions into electrical energy. In my later work such a system will be described.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691942.

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