Vibration Impact on People Transported by Mining Belt Conveyors

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Abstract

The paper presents the description and results of experimental research whose purpose was to analyze the vibration influence the miner's body during riding on a belt conveyor for transporting coal. The transport of people on mining belt conveyors is a commonly used method to increase mining efficiency and improve a mine's profitability. The paper presents an assessment of safety and comfort parameters used in transporting people, the effect of strong vibrations on the human body and its internal organs, the measuring system used to record the accelerations during the experiment and the measurement results. The recorded data enabled a dynamic analysis of the movement and an assessment of safety and comfort of transported miners on the basis of defined indicators. The data included the accelerations from the moment of getting on the conveyor belt to the moment of going down onto the platform. The tests were carried out for two different belt conveyor speeds, which allowed to assess how conveyor speed affects safety and comfort of people transported on the mining belt conveyor.

Keywords: belt conveyor, accelerations, safety and comfort of transporting people

1. Introduction

Many experiments described in the literature have confirmed that vibrations impact on the nervous system [1-4] and the circulatory system [5]. These vibrations may have effect on the systems' organs malfunction as well as mental and physical disorder. High vibration amplitudes in long periods of time can cause irreversible changes in the human body and even on internal organs. We are then dealing with a vibration disease (so-called Vibration Syndrome) [2, 6]. There are some studies where the human body is considered as a single mass (uniform mass) for frequency vibrations below 2 Hz [8, 9]. In this frequency band they are not harmful to humans and do not pose a significant threat. Impact of vibrations at a frequency range from 3 to 4 Hz induce strong vibrations on the abdominal organs and at a frequency range from 7 to 8 Hz there is chest resonance. Vibration frequencies of head's organs are around 20 to 30 Hz and eyeballs at around 60 to 90 Hz. Strong vibrations in the narrow frequency range from 2 Hz to 100 Hz may cause adverse (hazardous in extreme situations) consequences for the human body.

Like all mechanical structures, the human body has resonance frequencies where the body exhibits a maximum mechanical response. Human body responses to vibration cannot be explained solely in terms of a single resonance frequency. There are many resonances in the body, and the resonance frequencies vary among people and with posture [10]. Approximate resonance frequency values of human body organs and possible disease symptoms observed during long exposure are presented in Table 1. When people are transported(e.g. by mining belt conveyors), it is beneficial that the vibration energy is evenly distributed in the frequency band from 2 Hz to 20 Hz, in which the resonant frequencies of most human organs are contained. An adverse phenomenon for the transported person is the effect of high amplitude peaks in a narrow band of the frequencies, which can cause resonant vibration of an organ or group of organs. Presented research concentrated on factors impacting miners comfort during transport by belt conveyors for the velocity above 2.5 m/s.

Table 1. Resonant frequencies of human organs [12]

Name of organ	Frequency Hz	Possible disease symptoms observed
Head	4 – 5, 17 – 25	Pains, dizziness, imbalances, larynx pressure, nausea, forced rotation movement of the head, speech impediment, general psychophysical fatigue
Head with neck	20 – 30	
Eyeballs	40 – 90	
Abdominal organs	4.5 – 10	Sensation of internal organs vibration, pain, nausea, feeling of fullness, urinary and bowel urgency, weakness and fatigue, reluctance to performing work
Stomach	2 – 3	
Chest organs	5 – 9	Respiratory distress, dyspnea, tachypnea, sensation of restlessness, pulse acceleration, blood pressure changes, heart beat, speech disorders,
Lungs	4 – 11	
Heart	4 – 6	
Lower torso	4 – 6	Joint and muscle pains, lumbar and cervical spine pain, increased muscle tension, fatigue
Pelvis	5 – 9	
Spine	10 – 12	
Hips	5	Joint and muscle pains, increased muscle tension, numbness and tingling of muscles
Calves	20	
Arm	16 – 30	Joint pains, increased muscle tension, muscle pains, involuntary muscular contractions resulting in additional hand movements
Forearm	4 – 6	
Hand	20 – 30	

2. Indicators for assessment of comfort and safety

The raw data from accelerometer recorded during experiments (the acceleration versus time) are difficult to unequivocal interpret and analyze. Therefore, the data analysis techniques used are, described by indicators and estimators to obtain better results.

The RMS (Root Mean Square) indicator is most often used to estimate the impact of vertical vibrations on the human body. The root-mean-square acceleration versus time gives a measure of the oscillatory content in the acceleration data. For the period of time considered, this quantity gives an indication of the time-averaged energy in the signal [11, 14]. The RMS value of acceleration is defined as (1).

$$a_{\mathrm{RMS}}=\left[\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} a^2(t)\mathrm{dt}\right]^{\frac{1}{2}} \tag{1}$$

where: $a(t)$ is the time history of the vertical acceleration recorded as a function of time t and expressed in m/s^2, and T is the duration of the measurement in seconds.

Table 2 presents the relation of the frequency-weighted a_{RMS} acceleration and subjective response scale (degree of comfort) of ISO 2631-1 standard[12] and BS 6841standard [3].

Table 2. The scale of discomfort based on a_{RMS} [3, 5]

Frequency-weighted R.M.S. acceleration in units of m/s^2	Subjective response
Less than 0.315	Not uncomfortable
0.315 – 0.63	A little uncomfortable
0.5 – 1.0	Fairly uncomfortable
0.8 – 1.6	Uncomfortable
1.25 – 2.5	Very uncomfortable
Greater than2.0	Extremely uncomfortable

Simultaneously, the a_{RMS} underestimate the effects of transient shocks (instantaneous sudden amplitude growths), due to which neither of these methods makes it possible to take into account the impact of such shocks on the human body [13]. Therefore, an index referred to as a_{RMQ} (Rot Mean Quad) has been introduced, which was proposed by M. J. Griffin [2], described in BS 6841 [3], and defined as follows (2).

$$a_{\mathrm{RMQ}}=\left[\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} a^4(t)\mathrm{dt}\right]^{\frac{1}{4}} \tag{2}$$

The a_{RMQ} is a preferred measurement for exposure to jolts, shocks and intermittent vibration because it is sensitive to peaks in acceleration levels. [13].

3. Methodology and system of measurement

In order to perform acceleration measure and data acquisition, the dedicated mobile measuring device was designed. The measuring recorder was built based on the 32-bit RISC (Reduced Instruction Set Computing) microcontroller with the ARM Cortex-M3 core. The user interface consists of a mini-keyboard and LCD (Liquid Crystal Display).

The recorder allows accelerations measurement from three digital sensors and saves data to an SD card. Saving to a file in text form allows to easily transfer data to any computer. The three-axis MEMS (Micro Electro Mechanical Systems) accelerometers were used to measure acceleration. The use of integrated digital sensors allows to easily and quickly change the settings of measurement parameters such as resolution, bandwidth, sensitivity, and range. Data reading from each sensor was carried out via the I2C (Inter-Integrated Circuit) serial interface. The recorders were placed in miners' backpacks during recording or data acquisition.

Table 3. Parameters of the measuring system

Parameter	Value	Unit
Sampling frequency	512	Hz
Measurement range	16	g
Sensor sensitivity	3.9	mg/LSB
Non-linearity	0.5	%
RMS noise level	1	LSB
Maximum sensor bandwidth	3200	Hz
Accelerometer low pass filter	250	Hz
Power supply (6 x AA batteries)	9	VDC

The accelerations of the body part of miner transported by belt conveyor were recorded during the experimental tests. Data recording has begun just before the moment of getting on the conveyor belt and has finished when the person going down onto the platform. Each of the measuring systems allows the acquisition of acceleration data from three independent channels (sensors).The first two sensors enabled the measurement of vibrations on the miner's legs. They were mounted on shoes, beside the ankles. The third sensor was attached to the belt or placed on the back, at the height of the breastbone. This arrangement of sensors allowed to study the dynamics of miner's movement. Additionally, it allows the detection of dangerous cases such as strong shocks, loss of balance or falling.

4. Experiments

An analysis compares data from three channels (right leg, left leg, belt or back). The recorded data consist of accelerations from three orthogonal axes. Figure 1 presents the accelerations from the moment of getting on the conveyor belt to the moment of going down onto the platform with described stages of the ride.

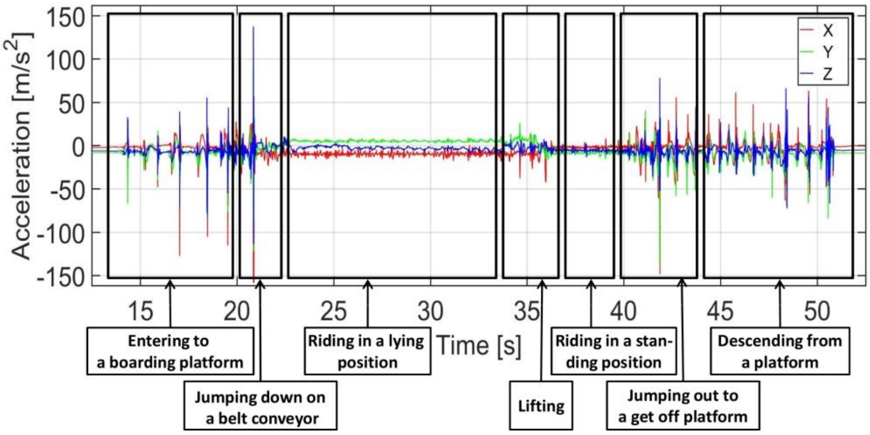

Figure 1. Accelerations recorded during transport with velocity 2.5 m/s

Curves colours are assigned to the respective sensor axes (X - red, Y - green, Z - blue). The axes of the coordinate system were dependent on the orientation of mounting the sensor on the body and current miner's body position. In order to determine the spatial orientation, they should be transformed individually for each case by determining the direction of the constant component (gravitational acceleration).

5. Results

Based on the recorded acceleration data from the miners' rides, an FFT(Fast Fourier Transform) frequency analysis was performed.

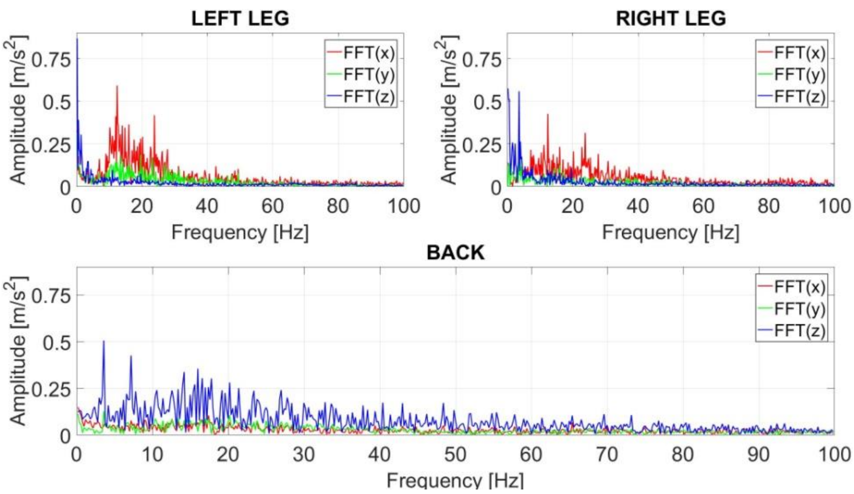

Figure 2. Acceleration spectra of vibration recorded during transport with velocity 2.5 m/s, lying position

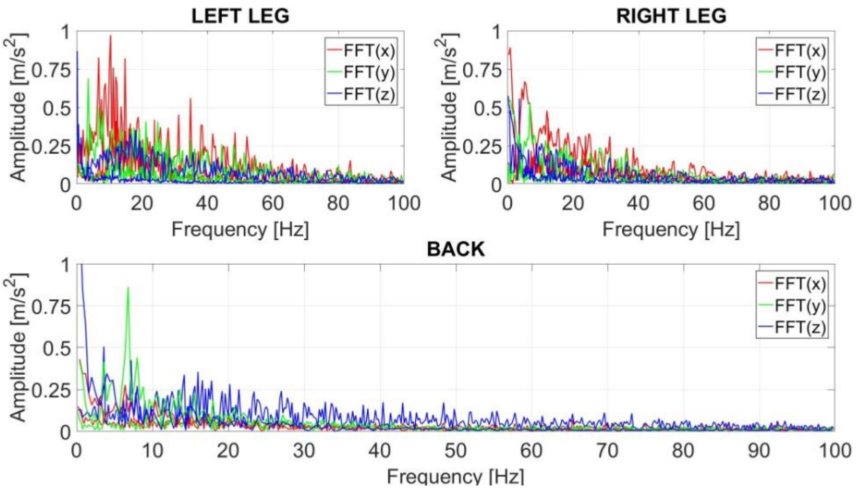

Figure 3. Acceleration spectra of vibration recorded during transport with velocity 2.5 m/s, standing position

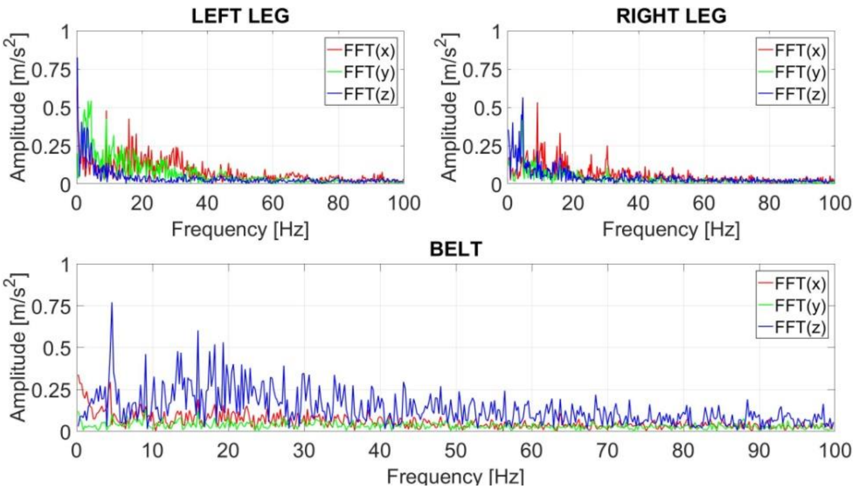

Figure 4. Acceleration spectra of vibration recorded during transport with velocity 3.3 m/s, lying position

The graphs above (Figure 3-4) show a comparison of the accelerations' spectra for transport of people with the speed 2.5 m/s and 3.3 m/s in the lying position and for the speed 2.5 m/s in the lying and standing position. The results of FFT transform shows that a resonant band occurs in the vibrations range around 5 Hz, which corresponds to the human heart, head and chest organs resonant frequency. The body posture is the factor that impacts the possibility of dangerous vibrations of internal organs during transport more than belt movement velocity.

Table 4. Parametrization results of vibrations registered during transport of people by mining conveyors (bandwidth: 2-250 Hz)

Person	Lying position, *max* (*x*, *y*, *z*)			Standing position, *max* (*x*, *y*, *z*)			Lying position, *max* (*x*, *y*, *z*)			Standing position, *max* (*x*, *y*, *z*)		
	LL	**RL**	**B/B**	**LL**	**RL**	**B/B**	**LL**	**RL**	**B/B**	**LL**	**RL**	**B/B**
	a_{RMS} [m/s^2] (transport velocity 2.5 m/s)						a_{RMQ} [m/s^2] (transport velocity 2.5 m/s)					
B1	1.76	2.32	1.33	9.32	9.32	3.25	3.57	5.13	2.33	14.50	20.39	4.10
B2	2.53	1.95	2.89	4.26	1.59	2.45	3.64	2.95	6.22	8.33	2.43	3.49
B3	1.03	1.09	2.56	6.53	8.74	2.90	1.49	1.66	1.78	11.38	14.93	4.35
	a_{RMS} [m/s^2] (transport velocity 3.3 m/s)						a_{RMQ} [m/s^2] (transport velocity 3.3 m/s)					
B1	2.41	2.67	3.37	8.50	14.68	5.87	4.92	4.21	4.31	17.65	35.74	8.53
B2	2.60	2.12	4.67	6.47	6.54	2.51	3.79	3.01	9.53	11.62	14.11	3.46
B3	2.50	2.12	1.84	8.69	4.37	3.51	3.87	3.58	3.33	17.19	8.42	4.65
LL – left leg, RL – right leg, B/B – back/belt,												

6. Conclusions

Based on the results of the research conducted it can be assumed that the acceleration measurement data allow safety and comfort assessment of transported people.

The vibration frequency analysis enables the risk evaluation of harmful influence on human body organs and vitals. An increased speed of belt conveyor has no negative impact on comfort of transported miners according to a_{RMS} and a_{RMQ} indicators (Table 4). Frequency analysis shows that increased energy of vibrations (resulting from the increase of speed of a belt conveyor) has a linear distribution in the research range. The results of FFT transform shows that a resonant band occurs in the vibrations range around 5 Hz, which corresponds to the human heart resonant frequency. Therefore, some medical examinations for miners using belt conveyors for transport should be conducted (with special emphasis on possible heart diseases). The future steps of the research will include experiments with changing the speed of a moving belt by a few percent (increase and decrease of the speed) and carrying out the experiments on another conveyor belt. That may lead to a decrease in the amplitude of a resonant band. The body posture is the factor that impacts the possibility of dangerous vibrations of internal organs during transport the most.

The transport in a standing position may induce strong vibrations on a chest and abdominal cavity (or abdominal organs). That is the consequence of high bands on the frequency spectrum in the range from 4 to 6 Hz. It is suggested to minimize the time of transport in the standing position. Based on the data provided in table 3 it can be assumed that an increase of velocity of the belt conveyor does not have any major effect on comfort during the transport. A moderate discomfort can be statistically confirmed for all the analyzed cases.

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