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A Preliminary Studies of the Impact of a Conveyor Belt on the Noise Emission

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Abstract: This article performs a comparative analysis of noise generated by conveyor belts with different design parameters. The study was conducted for belts with the same tensile strength, differing in the physical parameters of the cover rubber. Noise emission measurements were performed on a laboratory belt conveyor. The test on the stand allowed for the determination of the noise emission as a function of variable operating parameters: the tensioning force and linear speed of the belt. Research results indicated a significant impact of speed on the emitted noise. The effect of belt tension on noise emission is small, and it is definitely less significant than the effect of linear speed. The results also show that it is possible to select a conveyor belt that emits less noise under the same operating conditions. The analysis of the results allowed us to determine the impact of the physical parameters of the belt covers on the emitted noise.

Keywords: conveyor belt; belt conveyor; noise; rubber mixture; cover rubber; conveyor belt properties

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1. Introduction

Conveyor transport is constantly being developed as a high-performance industrial transport system for bulk materials. The areas of enhancement mainly include the improvement of performance of the following parameters: efficiency, reliability, and energy intensity. Research and development projects are conducted for such means as increasing the energy efficiency of conveyor components, start-up dynamics, and for adapting its design to difficult installation conditions [1], as well as for reducing transport energy consumption by controlling the feed (management of loading) of conveyors [2]. Developmental fields also include linear speed control [3,4], improvement of conveyor modeling methods [5,6], implementation of new drive solutions, and, also, the use of conveyors for long-distance transport [7,8]. The optimization solutions also apply to conveyor components, including numerous research works on, and implementation of, belts [9,10] and energy-saving idlers [11]. These improvements lead us to a more efficient, cost effective, and reliable conveyor transport system. Improving transport in the area of its component technics is not the only direction for change. At times, environmental considerations, such as reducing emissions and the carbon footprint, are even more important [12–18]. The issue of emissions, including noise emissions, becomes increasingly important when belt transport is located in close proximity to inhabited areas [19]. In addition to the negative factors that exist during open-pit operations, the exceeding of noise emission standards is a source of social conflict [20]. For this reason, it is justified to work on optimizing this field of transport regarding emissivity, and, in particular, noise emissions. The number of noise reduction methods are limited; therefore, developing new solutions is a major engineering challenge [21,22]. Studies have attempted to systematize knowledge about conveyor noise and classify noise sources [23–27]. It is important to consider the conveyor not as a linear noise source, but as a collection of point sources [28]. This approach makes it possible not only to identify and understand the causes of noise generation of individual conveyor elements, but also to reduce some of them.

Conveyor noise depends on many factors, and its nature is complex and difficult to predict. The dominant sources of belt conveyor noise are components resulting from the rotation of pulley bearings, occurring especially on new routes [27,29]. A separate problem is posed by point sources such as drives, return stations, or transfer points, but in this case the reduction of noise emission is facilitated by the possibility of using acoustic barriers and soundproofing elements [30]. Current research focuses primarily on the analysis of bearing noise pertaining to conveyor rotating components [31]. The number of publications on the effect of the belt used, and its properties on conveyor noise, are limited [32]. According to topical literature, the research carried out to determine the noise of rubber belts, commonly used to transfer movement and power in industrial machines or car engines, is worth noting [33]. Due to the quality requirements of customers, methods to determine and reduce noise have become one of the major engineering problems of synchronous belt drives [33]. In accordance with conducted studies, the main sources of noise associated with the belt-pulley interaction come from vibration of material structure, and friction [33,34]. Characteristic of belt transmissions are constant sounds associated with transverse vibrations of the belt and cyclic impacts from the meshing of the belt and pulley [35–40]. The measured amplitude of the sound pressure from the impacts ought to be proportional to the width and speed of the belt. In the case of belt drives, here is an unavoidable displacement of the belt relative to the drive wheel due to the slip rate [41]. The slipping of the belt on a drive pulley causes frictional noise [33]. A similar noise generation mechanism occurs on the drive pulleys of conveyors, where the drive is transmitted to the belt by friction force [42]. In the case of multi-groove belts and multi-V-belts, the phenomenon of air pumping also occurs [33,43]. The noise is caused by the flow of air as a result of the meshing of the belt and pulley. An analogous phenomenon takes place in automobile tires, where the change in sound pressure occurs between the tire tread and the road surface [44–47]. Additionally, in the case of tire/surface contact, the impact of air resonance in the tread grooves, vibration of the tread rubber, turbulence, slip-stick, Helmholtz resonance, as well as adhesion of rubber and surface, is also relevant [48]. Among the factors that have the largest impact on the noise level generated, one finds the pressure of the tire itself, the shape of the tread, the type of surface, the construction, and the rubber parameters [49–51]. Similar phenomena may occur when it comes to belt conveyors. The noise of air pumping takes place at the extreme points of contact between a belt and pulleys or idlers, and between idler supports; this is where the belt's transverse vibrations of the highest amplitude occur [52,53]. Air resonance can be created in the tread grooves of the pulley lagging, and the resulting amount of noise generated depends on the shape of the lagging tread [54]. This is due to the fact that the shape of the tread affects the friction conditions and stresses at the belt-pulley interface [55]. One of the mechanisms for generating belt vibrations is friction contact with the drive pulley, while turbulence is largely due to manufacturing inaccuracies of rotating elements, deformation over time, or variable load [56,57]. Additionally, adhesion of rubber/rubber or rubber/steel causes this effect [58,59]. The noise caused by the belt and idler's contact is a noteworthy issue as well. As a result of turning the viscose and elastic belt on the idler, energy is dissipated, and part of it is lost to acoustic phenomena [53,60]. Energy losses are compensated by an increase in the belt tension, which is defined as the resistance of denting the belt into the idler [54,55]. Consequently, the idler shell also vibrates [61]. The presented review of previous studies suggests that each of these components should depend on the individual parameters of the belt, and this is true especially on the hardness of the rubber compound used and the design of the carcass. The type of polymer used, and its properties affect the absorption efficiency and noise reduction [62,63]. Among polymers, epoxy resins and polyester have good damping properties, but the way the sound wave propagates in each of these materials varies. Changing the chemical composition through the introduction of additives will affect the vibration damping effect [64]. Regarding conveyor belts, individual polymers in their pure form are not used—it is always a mixture [65]. As a result, it is possible to flexibly control the chemical composition of the rubber mixture in order to obtain the best damping properties while maintaining the operational requirements expected by the user.

This article presents the impact of the belt's type on the emitted noise. Belts with different design parameters of cover rubber were examined, and the ability to emit noise was assessed. In order to make a reliable analysis and reduce the impact of factors interfering with the measurements, it was decided to perform tests in the conveyor. An analysis of the measurements made was carried out to answer the following question: which belt, installed on a laboratory conveyor, generates more noise? The results were compared with the belt specifications. A description of the test subject (two samples of the conveyor belt) and the test procedure is included in the following sections.

2. Materials and Methods

In the initial preparations for the research, a set of parameters was selected, based on a literature review, that should affect the acoustic properties of the belt. Among several parameters, two belts with different parameters pertaining to the cover rubber mixture were analyzed for the purposes of the pilot studies presented in the article. In standard laboratory tests, the material parameters of the samples prepared were determined [66–73]. Noise measurements were then performed, the data were analyzed, and the results were compared. The following steps in the entire test cycle are presented in the flowchart (Figure 1).

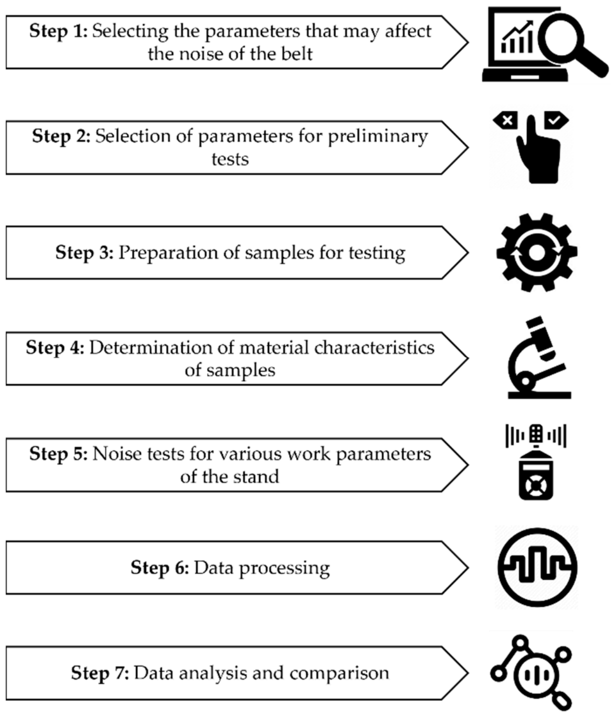

Figure 1. Steps of the test procedure.

The study of the cover rubber mixture properties' influence on the noise of the conveyor was carried out on a laboratory belt conveyor. A ≈5 m long stand was used, enabling the installation of a ≈12 m long belt loop (Figure 2a). Accurate measurements of the belt speed were made possible by the encoder installed on the drive drum shaft (Figure 2b). The tensioning force of the belt was set by a hydraulic tensioning mechanism and the force in the belt was recorded using two strain gauges (Figure 2c). One idler support was placed in the return belt. The location of the individual idlers was constant. The laboratory idlers were selected based on the analysis of the shell wear status and the condition of the bearings, in order to ensure that the noise they generated was similar to each other, and to ensure that the noise of the station as a whole did not significantly increase.

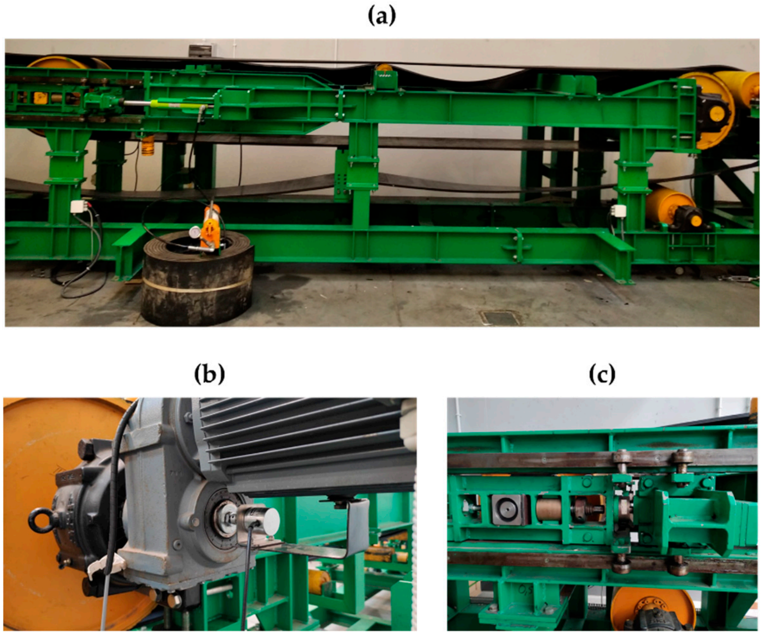

Figure 2. Measuring rig: (**a**) general view; (**b**) encoder on the drive pulley shaft for measuring belt speed; and (**c**) strain gauge for measuring the tensile force of the belt.

Two conveyor belts, of one manufacturer, with a carcass of steel cables were analyzed. The cross-section of the belt, with a view of the carcass, is shown in the next figure (Figure 3a). For the purposes of this research, the standard lining rubber mixture is described by the A symbol, while the new mixture with potentially better damping (vibration) properties, and the ability to dissipate less energy, is described by the B symbol. In laboratory tests, the tensile strength of the cover rubber, elongation at break, abrasion strength, and hardness were determined (Figure 3b). All parameters of the two belts, and the standards of the tests performed, are listed in the table below (Table 1). Their comparison allowed for the indication of material and strength differences between the tested belt samples, as these may affect the obtained noise emission results.

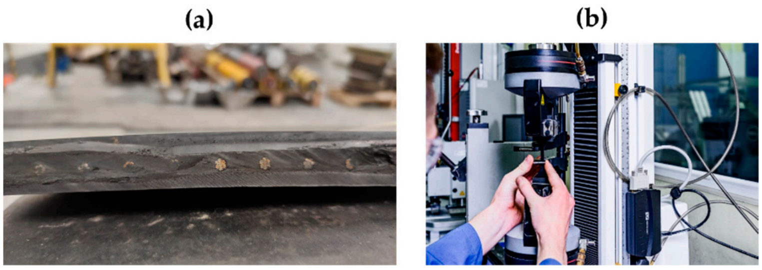

Figure 3. Analysis of the tested belt parameters: (**a**) cross-section with a view of the steel carcass in the form of steel cables with a diameter of 3.5 mm; and (**b**) tests of the rubber's strength to breaking point in laboratory conditions.

The possibility of comparing the test results of two types of belts also depended upon maintaining the same standards and methods of splicing the belt. To ensure those, the splices were made on the test rig by the same company, using a hot vulcanizing method, in order to maintain the best strength properties. The use of various mixtures of rubber covers causes the belts to differ in the hardness of the covers and in the strength parameters (tensile strength and elongation at break). For this reason, it is these parameters that will be treated as factors determining the obtained result.

Table 1. Summary of the parameters of the conveyor belts used for the tests.

	Characteristic	Unit	Standard	Value	
			1. Basic Information		
1.1	Type of belt	-	-	A—standard	B—new properties
1.2	Belt width	mm	ISO 15236-1	400	400
1.3	Strenght of belt	N/mm	ISO 7622-2	800	800
1.4	Top cover thickness	mm	ISO 7590	8.0	8.0
1.5	Bottom cover thickness	mm	ISO 7591	5.0	5.0
1.6	Total belt thickness	mm	ISO 7592	16.7	16.7
1.7	Cord pitch	mm	Sempertrans	15.0	15.0
1.8	Steel cord diameter	mm	-	3.7	3.7
			2. Cover rubber		
2.1	Tensile strenght	MPa	ISO 37	25	21
2.2	Elongation at break	%	ISO 38	550	520
2.3	Abrasion resistance	mm^3	ISO 4649	60	60
2.4	Hardness	Shore A	ISO 7619-1	62	58
			3. Adhesion		
3.1	Top cover to core rubber	N/mm	ISO 8094	20	20
3.2	Bottom cover to core rubber	N/mm	ISO 8095	18	18
			4. Cord pull-out strength from ready belt		
4.1	Before ageing	N/mm	ISO 7623	90	90
4.2	After reheatin (150 min. at 145 °C)	N/mm	ISO 7624	75	75

2.1. Background Acoustics, Reference Standards and Methodology

Due to the short distance between the test conveyor and the wall, it was decided that additional soundproofing, in the form of acoustic panels, should be used, preventing reflected interference. All objects between the conveyor and the measuring equipment were eliminated. The research was performed late in the evening, after the lab workers left the building. At that time, the operation of ventilation devices, and the power supply of other devices, were limited. Measurements were made at 3 points and the final result was averaged. The distance from the conveyor was constant at 4 m. The measuring equipment was placed on a tripod at a height of 1.7 m.

The room maintained a constant temperature of ≈23 °C. Noise measurements required the determination of the environmental correction factor K_2, which takes into account the testing room's suitability. According to EN ISO 3746:2010, the environmental correction factor for this type of test ought not to be greater than 7 dB [74]. In the case of the research, a lower value of K_2 = 5.14 dB was obtained.

For each measurement series, background impact was carried out using measuring equipment. Background influence was eliminated individually for each measurement performed. In accordance with EN ISO 11201:2010, the correction factor K_1 for background effect has been determined from the following relation [75]:

$$K_1 = -10\, lg\left(1 - 10^{-0.1\Delta L_{eq}}\right) \tag{1}$$

where:

ΔL_{eq}—difference in sound pressure level when the machinery is switched on or off.

The average background noise level for all measurement series was ≈51 dB. The results were also adjusted by an A curve corresponding to the characteristics of the human hearing threshold curve. It allows for the reflection of low sensitivity to low frequencies for measurements with low sound levels. The maximum recorded station noise was <82 dB. Background noise over time and background noise spectrum are further shown in the figure below (Figure 4).

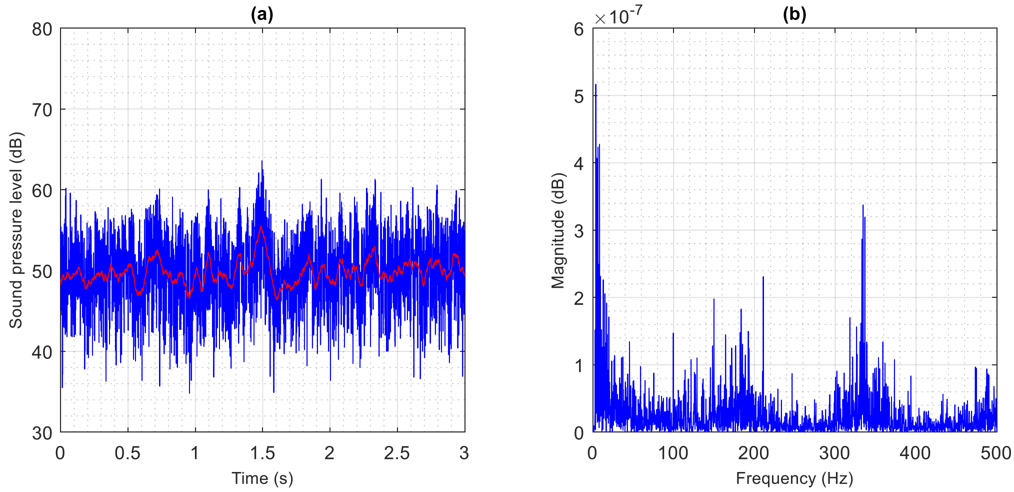

Figure 4. Laboratory room acoustic background measurements: (**a**) background noise over time; and (**b**) spectrum.

The appropriate equivalent sound pressure level is defined as:

$$L'_{eq} = L_{eq} - K_1 \tag{2}$$

where:

L_{eq}—measured sound pressure level.

2.2. Measuring Apparatus

A certified (according to IEC 61672-1:2013) noise and vibration level meter SVAN 979, with accuracy class 1 [76], was used for the measurements. A GRAS 40AZ measuring head with a sensitivity of 50 mV/Pa was utilized, enabling measurement in the frequency range from 0.5 Hz to 20 kHz. Measurements for signal analysis were made using NI data acquisition card and LabVIEW software, sampled at a frequency of 1000 Hz. The sound level was measured using dedicated SVANPC++ software, enabling simultaneous correction according to the A curve. In this case, it was sampled at a frequency of 100 Hz. Earlier analysis of the signal has shown that this frequency is sufficient.

3. Results

Comparative analysis of two variants of the acoustic signal allows for the illustration of the similarities and differences between the noise generated by the two belts. Information on signal amplitude, cross-correlation, and characteristic frequencies will make it possible to better determine the appropriate measurement methodology and the ranges of future studies. Spectral analysis based on known belt noise frequency ranges can be used to select individual components related to individual material characteristics. Comparative analysis was based on acoustic signals recorded for the same belt speed of ≈1.4 m/s (Figure 5). The figure shows short, 3-s slices of long-time signals (data frames), used in the next step for spectral analysis. The presented trends are visible in the full range of analyzed belt speeds. The visual assessment of the course of acoustic signals over time allows the researchers to conclude that the signal for standard belt A is definitely more diverse, with a greater range of recorded amplitude. The square average signal of belt A is 0.046 Pa, while belt B is 0.039 Pa. The greater variation of the standard belt signal can be assessed by a standard deviation of 0.0098 Pa (for belt B 0.0051 Pa), and it is more than four times the variance of the signal sample.

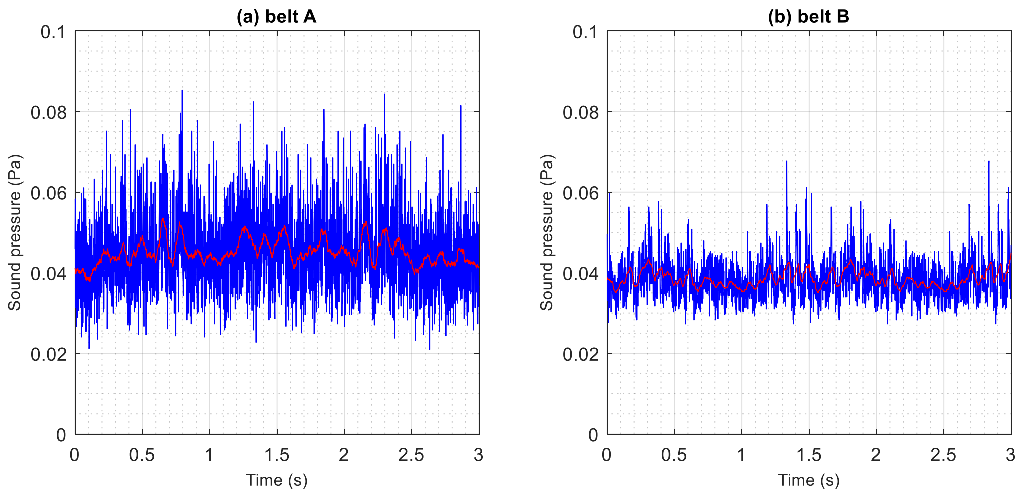

Figure 5. Acoustic signal over time: (**a**) for belt A; and (**b**) for belt B.

The distribution of samples around the mean value is shown in the chart below (Figure 6).

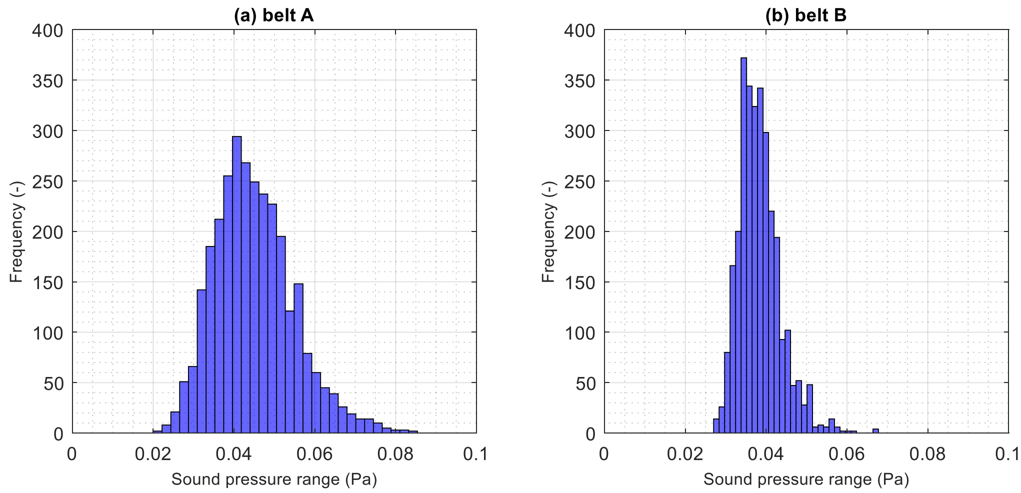

Figure 6. Histogram: (**a**) for belt A; and (**b**) for belt B.

Positive values of kurtosis (kurtosis > 3), indicate a leptocurtic distribution. This means that there are many extreme values located in the signals, deviating from the mean value. The very structure of value distribution around the mean for both types of belts is similar. According to what could be observed on the time function graphs, the acoustic signal of standard belt A has a higher dispersion of values, while the signal of belt B is more condensed. However, there are more extreme cases in it. Spectral analysis allows for the determination of similarities and differences also in the domain of component frequencies. The graph shows two variants of the acoustic signal spectrogram (Figure 7). Previous research suggests that the frequencies associated with the conveyor belt should be located in the lower frequency range [26,32,52,77,78].

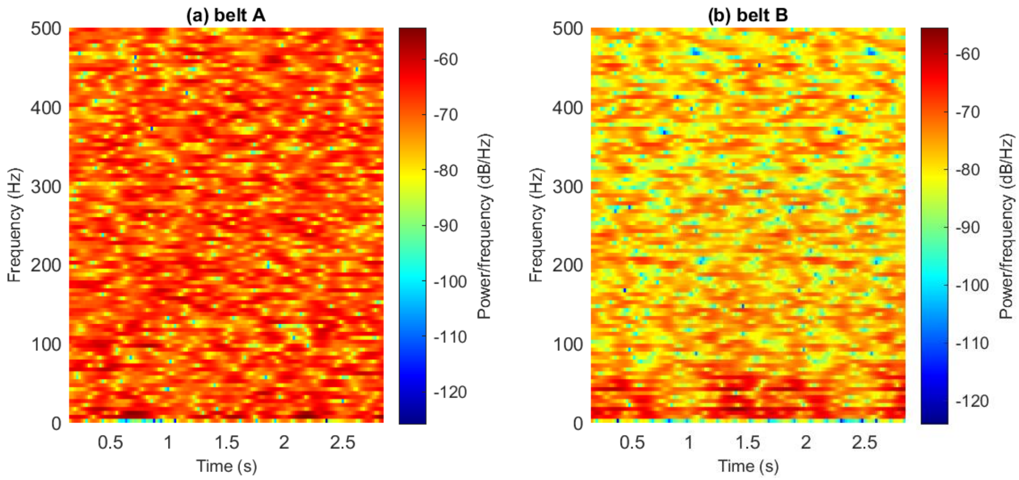

Figure 7. Spectrogram: (**a**) for belt A; and (**b**) for belt B.

In both cases, the dominant frequencies are located in the low range up to 100 Hz. Spectrograms are very diverse, despite many design similarities and the same operating conditions, two belts differing in cover material generate different dominant frequencies and different signal strength densities for the same frequencies. These differences result from different conditions of cooperation with rotating elements of the conveyor. In the case of belt A, the total signal strength is distributed practically over the full range of the analyzed frequencies, in belt B's case, 99% of the signal strength is settled within frequencies up to 200 Hz (40% of the frequency range possible to be obtained), with particular density in the range up to 100 Hz (Figure 8).

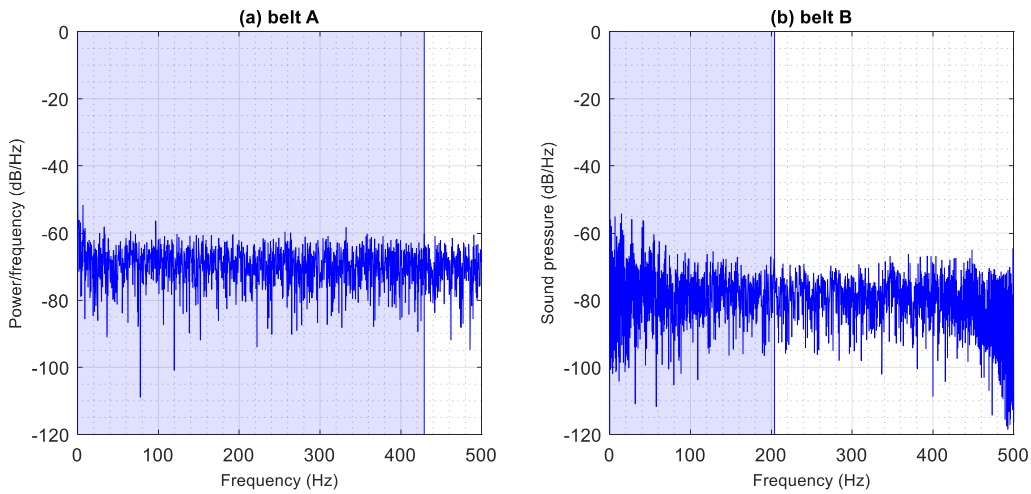

Figure 8. Field of 99% acoustic signal strength in the range of frequencies analyzed: (**a**) for belt A; and (**b**) for belt B.

As shown in Figure 8, the frequencies important for the B-belt signal strength are located below 200 Hz. In the case of the A-belt, the characteristic frequencies are located in a fuller range of the tested range. The cross-correlation of the two signals indicates their significant, mutual correlation (Figure 9). The obtained cross-correlation coefficient between the two signals is definitely more than 0.9, regardless of the operating parameters of the station. The mean value of the correlation coefficient as a function of belt speed is 0.98, while the mean value as a function of the tensile force of the belt is 0.97. Comparative analysis requires a larger number of compared samples, but at this stage, due to the rigorous conditions of conducting the research, it can be concluded that the resulting differences are only due to the difference in composition of the cover rubber.

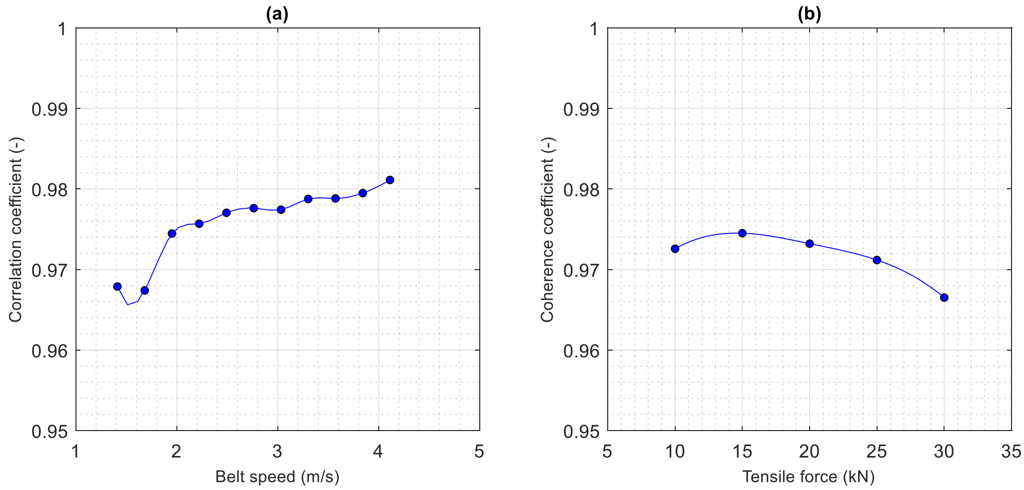

Figure 9. Cross-correlation coefficient between the noise signals of two belts, A and B as a function of the analyzed operating parameters: (**a**) belt speed; and (**b**) tensile force of the belt.

According to the graph of the signal spectrum (Figure 10a), the highest density of significant frequencies is in the range up to 100 Hz. The spectral consistency of the two signals shows that A and B belts have several common frequencies, correlated at >0.6 (≈6 Hz, ≈28 Hz, ≈60Hz, ≈282 Hz, ≈490 Hz) (Figure 10a). In the highly correlated frequency range, the phase shift is significant, from −128° to 178° (Figure 10b).

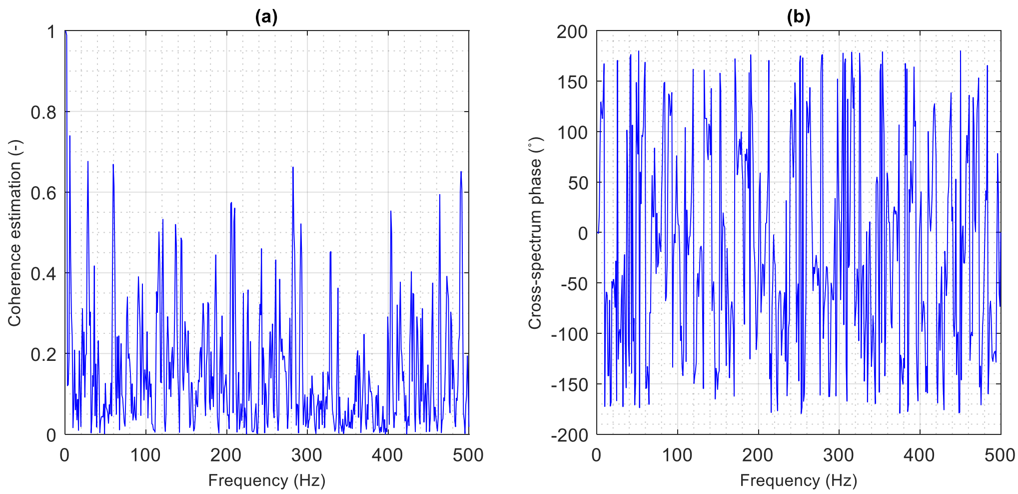

Figure 10. Signal comparison: (**a**) spectral coherence; and (**b**) spectral phase shift analysis.

The selected frequencies characteristics of each belt are shown in the following graph (Figure 11). For characteristic frequencies, in most cases, the spectral coherence coefficient is low (<0.6), which may suggest that these values depend on individual material characteristics.

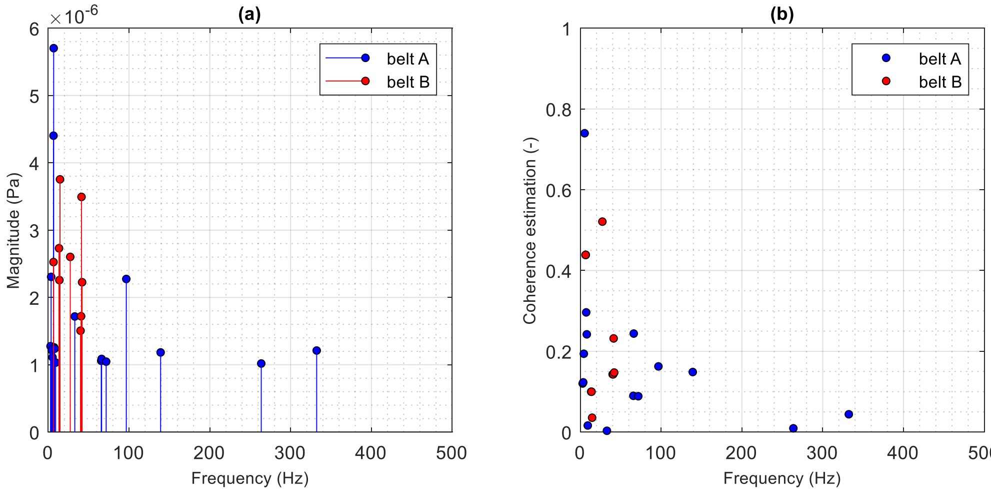

Figure 11. Characteristic frequencies of two belts: (**a**) selected in the spectrum; and (**b**) spectral coherence coefficient as a function of the frequencies characteristic of each belt.

4. Discussion

The noise analysis of the station was performed in two variants, depending on the basic operating parameters of each conveyor: the speed of the belt, and the tensile force of the belt.

4.1. Belt Noise Depending on the Tensile Force

The tensile force of the belt is particularly important in the case of belt conveyor resonance, causing the machine to work with increased noise emission [52]; this article verified its effect on conveyor noise, depending on the belt used. Figure 12 shows the sound pressure level emitted by the station as a function of tensile force for two different belts.

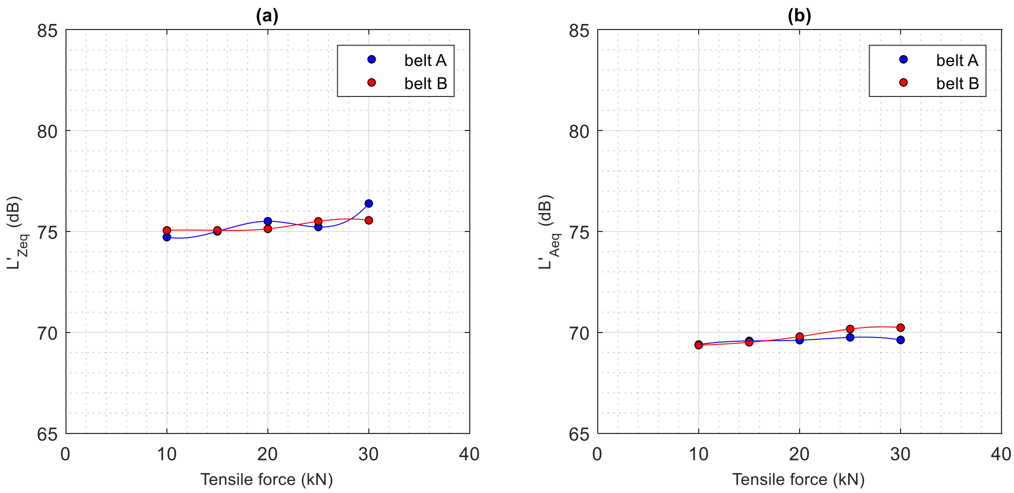

Figure 12. Sound pressure level as a function of the tensile force of the belt: (**a**) equivalent sound pressure level; and (**b**) equivalent sound pressure level according to correction curve A.

It is impossible to determine a trend of changes in the sound pressure level as a function of the tensile force of the belt. Based on the aforementioned graphs, it can be concluded that no significant effect of the tensile force on the emitted noise was observed. The average difference in the full range of test forces is 0.3 dB (Figure 13). These differences are not correlated with one type of belt, so an assumption was made that they result directly from the measurement error of the meter. In further analysis, the value of 0.3 dB was taken as the measurement error level, above which it becomes possible to form conclusions regarding the difference in the level of noise emitted.

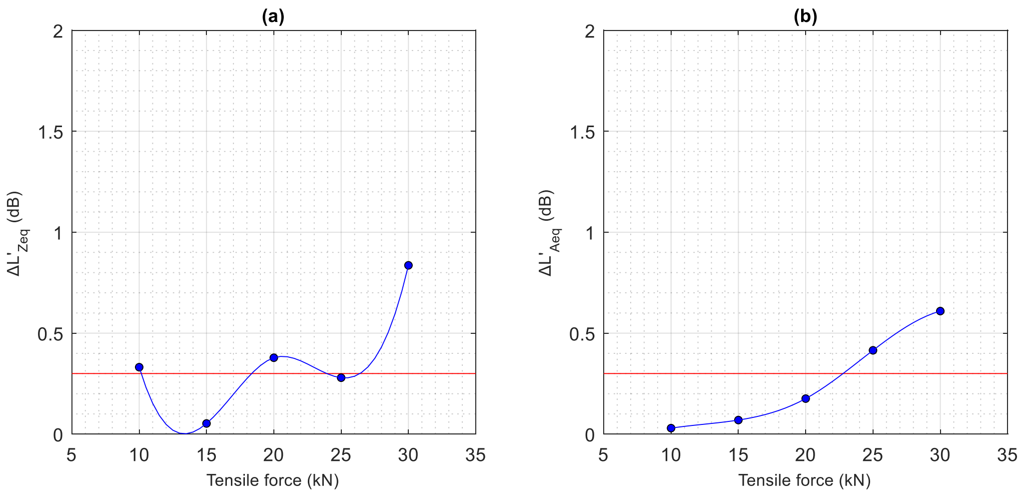

Figure 13. Difference in sound pressure level between belt A and belt B as a function of the tensile force of the belt: (**a**) without correction curve; and (**b**) according to curve A.

4.2. Belt Noise Depending on Speed

The figure below shows the average sound pressure level of a laboratory conveyor for two types of installed belts as a function of their speed (Figure 14).

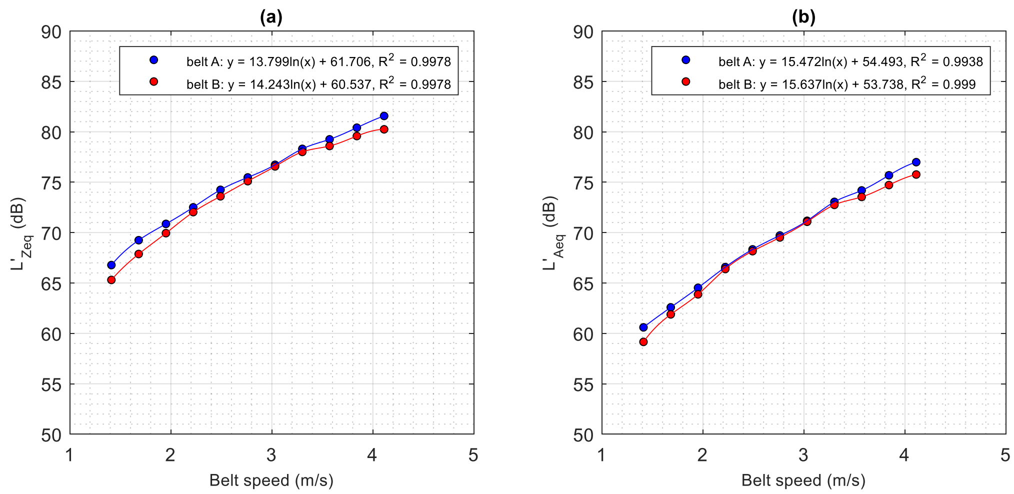

Figure 14. Sound pressure level as a function of belt speed: (**a**) equivalent sound pressure level; and (**b**) equivalent sound pressure level according to correction curve A.

The noise of the laboratory conveyor increased with the linear speed of the belt. Approximation was carried out using a logarithmic curve with significant values of the correlation coefficient. The measurement results clearly indicate a lower noise level of belt B in the full speed range. The average difference in noise levels was 0.78 dB (more than the assumed measurement error rate). The biggest differences, reaching up to 1.47 dB, were recorded for extreme speeds. The smallest variation was noted in the middle of studied speed range. The resulting differences are shown as a function of the belt speed (Figure 15).

Background noise displayed the largest impact with low sound levels and low belt speeds. Its importance decreases with increasing speed. Over the full speed range, for each point measured, the background correction factor K_1 is less than the measured sound difference between belt A and belt B. This is a test of the reliability of the measurements obtained with such small differences in sound level.

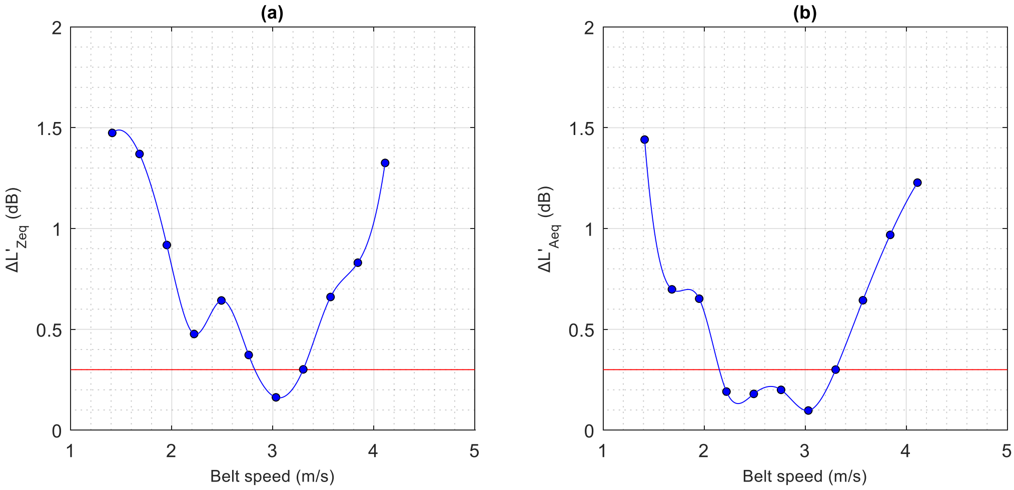

Figure 15. Difference in sound pressure level between belt A and belt B as a function of belt speed: (**a**) without a correction curve; and (**b**) according to curve A.

5. Conclusions

This article presents the methodology of noise emitted by conveyor belts. The scope of research included an analysis regarding the noise emission of two belts, differing only in the composition of the rubber cover mixture. The determined material characteristics confirmed that the differences between the tested samples occur only at the level of the properties of the cover rubber (hardness, tensile strength, and elongation at break). Belt noise was tested on a single test rig as a function of tensile force and belt speed. The effect of the tensile force on the noise generated by the laboratory conveyor is insignificant. Velocity studies indicate that the sound pressure level increases nonlinearly with the increase in this parameter. Linear speed studies indicate that the sound pressure level increases nonlinearly with the increase in this parameter. In the range of analyzed speeds, an average increase of 15 dB was recorded, with background noise at the level of 50 dB (increase in belt speed by 2.7 m/s); this is the parameter that has the greatest impact on conveyor noise, and therefore, if it is necessary to reduce emissions, the possibility of limiting the speed of the conveyor belt should be considered primarily. Belt tests have shown a significant correlation between the composition of the belt cover rubber and noise emissions. The average difference in noise level between the two belts was 0.8 dB (in the variable speed range) in favor of the belt with a new mixture used, with rubber hardness reduced by 4 according to the Shore hardness scale. The most significant differences were located at extreme speeds, and these reached up to 1.5 dB. The research reliability is confirmed by the exceeding apparatus and measurement error, as well as the constant conditions for conducting research according to the scale of the object. Differences were observed not only in the level of emitted noise, but also in the spectral structure of the sound signal. The belts generated different characteristic frequencies, but with a high correlation of signals. Particular frequency concentration is visible in the area of infrasound. Low frequencies in mining are very dangerous, and they lack legal references and standards [79].

Based on conducted research, it seems reasonable to conclude that the hardness of the rubber is associated with the greatest impact on the resulting differences in noise emissions. For this reason, further research will focus on the analysis of the belt/idler interaction, with particular emphasis on the phenomenon of denting the belt into the roller. Future studies are planned to carry out tests on a larger number of samples, with more diverse parameters, in order to make the optimization of the rubber compound properties possible, with the goal of producing "silent belt".

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