

The analysis of influential parameters on calibration and feeding accuracy of belt feeders

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Highlights


- Measurements on a belt feeder with variable speed and belt tension.
- PLC controlled belt feeder with data monitoring, visualization and processing.
- Material calibration under operating conditions is the most accurate calibration method.
- Existing mathematical models for estimating measurement errors do not cover all factors.
- The speed and tension of the belt must be kept within certain limits during feeding.

Abstract

Continual material feeding represents a process of great importance for process industries. Feeding with belt feeders represents one of the most common methods. Belt feeders are devices that require little space, they are not expensive and, most importantly, they do not interrupt material flow while feeding. Calibration of belt feeders, as well as other measuring devices, is a prerequisite for measuring and achieving a defined level of measurement accuracy. On the other hand, the defined level of measurement accuracy is often difficult to achieve in practice due to the multitude of factors that affect the operation of belt feeders. Existing mathematical models indicate a number of influential factors on measurement accuracy. The paper presents the measurement procedure performed on a belt feeder in laboratory conditions, with variable speeds and belt tensions and the known raised position of the measuring idler. Based on the obtained results, appropriate conclusions were made about the influences on calibration and measurement accuracy.

Keywords

flat belt feeder, calibration methods, measurement errors.

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1. Introduction

Given the technological importance and complexity of measuring material flow, accelerated industrial development imposes the need for increase the level of accuracy of existing measuring devices. Material flow measurement occurs in many industries. Transport of certain material amount in a specified time interval between loading and unloading points is the transport task of belt conveyors [15]. Belt feeders, as shown on Figure 1, represent belt conveyors on which a design change has been made by placing one or more support idlers on the measuring bridge. Thus, during transport, the quantity, i.e., the flow of transported material can be measured.

The weight of the material on the belt is transferred to the load cell - directly or via a lever system. In practice, the integration principle of flow determination is most often applied. The principle is based on the specific load with which the material and the belt act on the measuring bridge of the scale, so that the flow is calculated according to:



Fig. 1. Belt feeder

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$$m_{vm} = \int_{t_1}^{t_2} \frac{Pv}{gr} dt \quad (1)$$

where:

- m_{vm} – the mass of the measured material [kg];
- P – force on the load cell due to the weight of material on the belt [N];
- v – belt speed [m/s];
- g – gravitational acceleration [m/s²];
- r – scale span [m].

Belt feeders consist of a large number of components, which during operation cause vibrations that are most often present in the low frequency range. Such low frequency components overlap with useful signals and it can be difficult to eliminate their influence, especially at higher speeds. The conventional way to eliminate these interferences is by low-pass filtering of load cell signals. In [21], a linear discrete low-pass filter with a time variant is shown. It can maintain the measurement error rate in an acceptable range over a wide range of speed.

The operation of belt feeders in certain working environments is influenced by strong vibrations that affect the accuracy of measurements. In [14], dampers are shown which, in addition to canceling the influence of vibrations, also collect vibration energy, which increases the efficiency of the belt feeder.

Optical measurement technologies can also be used to measure material flow on belt feeders. A modern method for measuring the flow of bulk material on a belt feeder by laser scanning is presented in [23]. The presented measuring system is able to form a three-dimensional cloud of points by scanning the cross section of the material on the belt. With further processing of the cloud of points, the material flow can be calculated.

Completely defining the level of accuracy of belt feeders requires determination of their technical and metrological characteristics along with understanding the influence of certain factors that exist in certain parts of the measuring system [1]. The basis for this is the calibration process, i.e., the comparison of measurement values given by the measuring device with the values of the calibration standard of known accuracy.

Maintenance activities are key to ensuring the reliability of operation and measurement with belt feeders. Conventional maintenance methods are defined on the basis of empirical, immutable data. In order to increase the reliability of work when measuring with belt feeders, modern methods for diagnostics and error detection have been developed. The basic approach to online error detection is shown in [16] and is based on two steps: the first step is to extract the fault data from the weigher sensors, and the second step is to classify the fault pattern based on the extracted fault data in the previous step. A new approach to monitoring work diagnostics and online fault detection, in order to increase the reliability of equipment for continuous bulk materials weighing equipment and thus belt feeders, is presented in [17]. It is based on an improved DBSCAN (Density-Based Spatial Clustering of Applications with Noise) clustering and Bayesian regularization neural network. In [18], an innovative framework for monitoring the parameters and collecting information on operating conditions is presented, which changes depending on the real-time operating conditions and the results of the reliability assessment. This approach is important for the reliability of work, and thus the validity of measurements, primarily of idlers at the measuring point of belt feeders, since during the work, the predicted failure rates of idlers are corrected and updated.

2. Influential factors on the feeding accuracy of belt feeders

There are four accuracy classes of belt weighers according to [20]: 0.2, 0.5, 1 and 2 %. The maintenance of the nominal accuracy of the measurement can be an issue, due to various factors such as material

flow, belt speed, accrued creep of the belt, etc. On the other hand, when the belt weigher is used for warehousing operations, transshipment in harbors and for the purpose of coal transport at power plants, the error can rise above 5% [3]. The belt weigher accuracy depends on conditions that are present during its operation and on aspects of the conveyor system structure [7]. During measurements on belt feeders, it comes from the interaction between the transported material and the elements of the feeder, primarily the belt and support idlers. The results of laboratory tests and computer simulations, using the method of discrete elements, presented in [12], have led to the development of improved methods for calculating the load on idlers and energy losses due to belt deflection, which are influential parameters on measurement accuracy. Perhaps the major problem associated with the use of conveyor belts originates from the adverse affection that powders have on the belt [5]. Generally speaking, the force measured by a load cell is influenced by factors divided into four categories:

- structural stability and stiffness of the measuring bridge;
- the construction of the belt feeder;
- the possibility of measuring the signal from the material on the belt – belt effects;
- calibration of the measuring system in conditions similar to working conditions.

With regard to the structural stability and stiffness of the measuring bridge, the support of the measuring bridge must ensure that only the force normal to the conveyor belt is transmitted to the load cell, excluding any lateral forces. It is necessary to ensure minimal deflection of the measuring bridge and torsional stability. It is necessary to be able to adjust the vertical position of support idlers around measuring idlers in order to achieve their proper alignment.

Also, it is important to provide that the measuring range is as large as possible so that the scale signal includes as much material on the belt as possible. Increasing the length of the measuring area leads to an increase in the accuracy of measurement with belt feeders, which is achieved by increasing the number of idler assemblies, with one or more idlers, which form the measuring bridge. If the idler assemblies are mechanically or electrically independent, then the belt feeder has a multi-channel system for measuring bulk materials [9]. The analysis of the optimal choice of the location of the measuring scale and the corresponding influence on the accuracy of the measurement, taking into account the total length of the belt feeder and the stiffness of the belt, is presented in [6]. All supports should be designed so that it is easy to check their condition and perform the necessary lubrication to avoid the influence of friction. The construction of the belt feeder should ensure the most even (continual) flow of material on the belt. It is necessary to provide centric loading of material on the belt and protection from weather impacts. The inclination of the feeder must be taken into account in order to prevent material slippage during transport. The belt tensioning system should be automatic in order to provide a constant tensioning force.

It is necessary that the belt does not serve as a support for the material, but only as a mean of transport. However, the conveyor belt has certain characteristics that allow it to partially accept the weight of the material.

Different stresses have impact on the conveyor belt while it transports the material. Those stresses cause deterioration of the belt [10]. These so-called effects of the belt have the greatest influence on the measurement accuracy, together with the vertical position of the measuring idler in relation to the adjacent support idlers.

There are three types of errors that cause improper weighing while using conveyor-type weighers according to [8]. The first type occurs due to force-measuring sensor sagging and represents a systematic error. The second type has roots in parameters of the conveyor itself – the belt tension in the weighing area, the resistance to motion of the belt, the dynamical characteristics of the transported material and the belt, the distance between the loading and unloading point and unbalanced deformation of the belt on conveyors placed under a cer-

tain angle. These errors can be successfully minimized with a proper calibration procedure. The third type is consisted of errors that occur randomly due to various deviations of characteristics of the physical function of a conveyor-type weigher.

It has been experimentally determined that the belt behaves as a continuous and horizontal elastic beam supported by equally spaced supports. The combined action of the tensile force and stiffness-to-bending (IE) in the conveyor belt on misaligned measuring idlers leads to inaccurate signals from the scale. Mathematical models have been developed for ideal systems that have supports and measuring idlers at equal distances, with n rollers on a measuring platform, a uniform belt, etc. One such model, according to [11], defines the force P detected by the scale according to the following:

$$P = \frac{nQL}{0.102\cos\theta} + \frac{TD}{500L} + \frac{3EID}{12500L^3} \text{ [N]} \quad (2)$$

where:

- n – number of idlers on the measuring platform;
- Q – material mass per unit length [kg/m];
- L – spacing between idlers [m];
- T – tension in the belt at scale location [N];
- E – modulus of elasticity of belt carcass material [MPa];
- I – moment of inertia of carcass cross-section [cm⁴];
- D – vertical misalignment between measuring idlers and adjacent support idlers [mm];
- θ – angle of conveyor inclination [deg].

The calibration procedure should take into account factors that affect the force detected by the scales that also exist during calibration. Assuming that the EI value does not change with the change in tensile force, the net value of the error (%Er) that occurs during operating conditions can be expressed as follows:

$$\%Er = \frac{2.4D(T_R - T_C)\cos\theta^*}{nQL^2} - \frac{T_R - T_C^{**}}{10000EA} - \frac{(T_R - T_C)W_b^{***}}{10000EAQ} \quad (3)$$

where:

- * – tension effect on misalignment;
- ** – speed measurement error;
- *** – error due to change in the belt weight per unit length due to stretch;
- T_R, T_C – tension force in the belt at the scale under working conditions and during calibration [N];
- A – cross-sectional area of the carcass [m²];
- W_b – belt mass per unit length [kg/m].

The second mathematical model according to [4] is based on the principle of a simple beam. The force detected by the scale P can be expressed as:

$$P = \frac{nQL}{0.102\cos\theta} \pm \frac{0.2KDT\cos\theta^{**}}{L} \quad (4)$$

$$K = \frac{1}{1 - \frac{\tanh(G)}{G}}; \quad G = 5L \sqrt{\frac{T\cos\theta}{EI_p}} \quad (5)$$

where:

- * – the true belt load on the scale;
- ** – measurement error caused by the beam effect of the belt;
- K – belt stiffness factor (od 1 do ∞); $K=f(L, T, E, I_p)$
- I_p – planar moment of inertia of a cross-section of the belt about its centroidal axis [cm⁴];

- the sign „-“ is used for downward displacement and the sign „+“ is used for an upward displacement of measuring idlers.

The modulus of elasticity of the belt carcass is determined according to [22].

It was experimentally determined that the modulus of elasticity of the belt carcass made from textile and nylon ranges from 275 ÷ 345 MPa, from rayon ranges from 690 ÷ 1050 MPa, and from steel cords is 7000 MPa. The measurement error caused by the behaviour of the belt as a simple beam can be represented as a percentage of the total load detected by the scale:

$$E\% = \frac{0.2DKT\cos\theta}{nQL / 0.102\cos\theta} \cdot 100 \quad (6)$$

The value $E\%$ varies depending on the support configuration of the scale. If the total vertical misalignment is consisted of the load cell deflection (D_1) and structural deflection and initial installation misalignment (D_2), then $E\%$ can be expressed as:

$$E\% = 0.0204 \frac{KT}{nQL^2} (D_1 + D_2) [\%] \quad (7)$$

The measurement error is directly proportional to the product of the belt tensile force and the vertical misalignment of measuring idlers (DT). As the troughing angle of support idlers increases, the belt becomes stiffer and the simple beam effect increases thus increasing the measurement error.

When loading the material on the belt, the direction of its movement does not coincide with the direction of movement of the belt. Therefore, it takes a certain amount of time, i.e., a certain distance for the material to reach the speed of the belt. In order for the material to reach the speed of the belt before it reaches the measuring range of the scale, the minimum required distance between the loading place and the scale is calculated according to:

$$X|_{v_x=v} = \frac{v^2 - v_0^2}{2 \cdot g \cdot \left[f \cdot \cos\theta - \sin\theta + \frac{0,25 \cdot W \cdot c}{A_m \cdot \rho} \right]} \quad (8)$$

where:

- v_0 – initial material speed [m/s];
- c – cohesion [kg/m²].

3. Experimental setup

In order to examine the influence of certain factors listed in the previous section, tests were performed on a horizontal belt feeder with a flat belt with lateral sides, which is located in the laboratory at the Faculty of Technical Sciences in Novi Sad (Figure 1). The belt feeder is controlled by the PLC and a variable frequency drive (VFD). The basic characteristics are:

- belt width 540 mm with the height of lateral sides of 70 mm;
- feeder length: $L = 3000$ mm;
- AC motor power: $P = 0.75$ kW;
- belt speed: $v = 0.2405$ m/s at 50 Hz of power supply of VFD;
- max. material flow: 26 m³/h.

With the development of the IT system and its application in transport systems, it is possible to collect a lot of valuable information for technical, operational and diagnostic purposes. This enables adequate identification of the flow distribution of transported bulk material [19, 13]. Control and measuring devices have been added to the basic con-

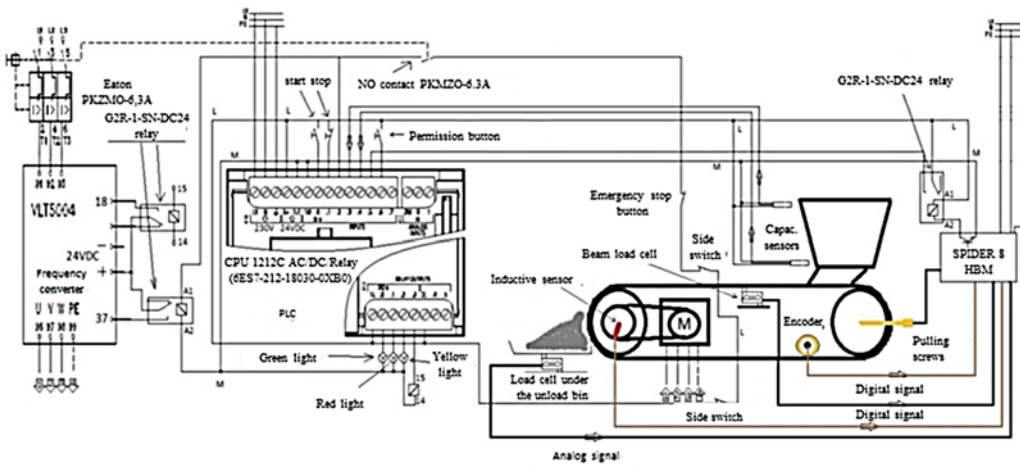


Fig. 2. Belt feeder drive automation scheme

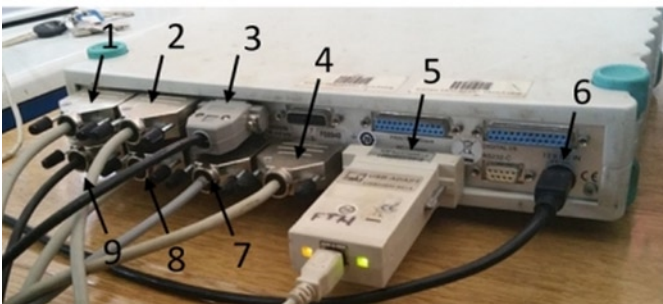


Fig. 3. Connectors on the SPIDER 8 – left tensioning (1) and right tensioning (2) mechanism, laser sensor (3), the unload bin (4), communication with the PC (5), power (6), scale (7), encoder (8), inductive sensor (9)

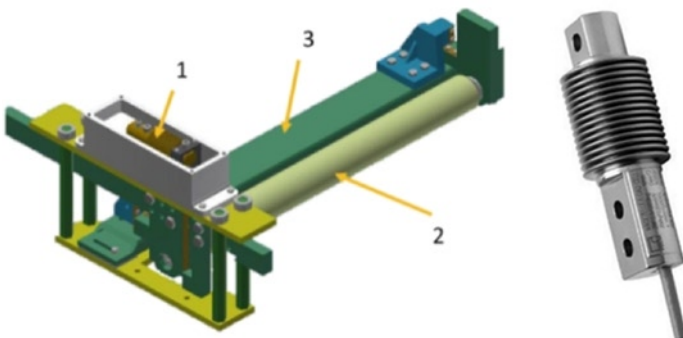


Fig. 4. The construction of the measuring idler set (a) and the load cell (b)

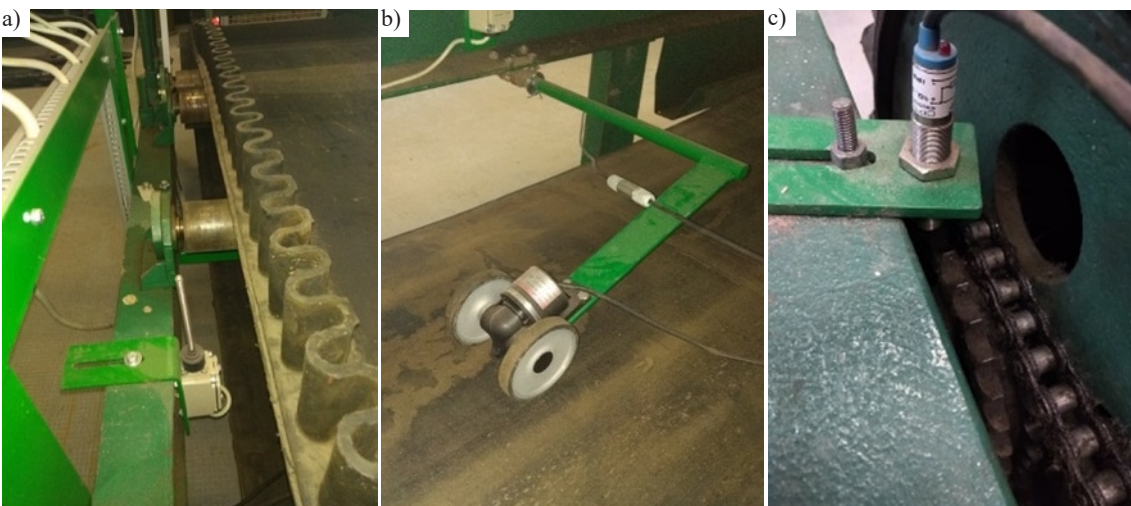


Fig. 5. Side switch (a), rotary encoder (b) and the inductive sensor (c)

figuration of the belt feeder. The scheme of automation of the belt dispenser drive is shown on Figure 2.

HBM SPIDER 8 universal measurement amplifier has been used as an acquisition device. Figure 3 shows the connectors of measuring instruments on the SPIDER 8. Catman® Professional PC software has been used for data recording, visualization and processing.

The feeder has one measuring idler set, Figure 4a. It is consisted of an idler (2) which transfers the force via a lever system to the load cell (1), type HBM Z6 FC3/100 kg, Figure 4b, and the fixed part (3) which

is attached to the conveyor structure. The scale span is 400 mm, and the distance from the loading zone is 1.3 m.

The drive is frequency-regulated by a Danfoss VLT 5000 Series type 5004 frequency inverter and it is controlled by a PLC Simatic S7-1212C AC / DC / Rly. The PLC controls the digital inputs of the frequency converter via its digital outputs. Also, all necessary protective and control equipment (switches, emergency stop button, relays, etc.) are applied in accordance with the needs of the feeder operation.

Side switches HY-M909, Figure 5a, were used to control the position of the belt. They detect lateral movement of the belt. For measurement of belt speed, a rotary encoder type PSC MC AB T24 has been used. It has been placed on the return back side of the belt, Figure 5b. The encoder is constantly in contact with the belt via a system of levers. Above the sprocket, as part of the drive mechanism, an inductive sensor is placed to provide information on the number of revolutions of the drive pulley, Figure 5c.

For the exact position of the belt detection, with the goal to account its inhomogeneity and to set the zero, a reference laser position sensor SPSR-115/230, Figure 6a, has been used. The laser sensor (1) emits a laser beam (2) to the lateral side of the belt. A reflective mark (3) is glued to the belt, which reflects the beam back to the sensor, and, at that moment, the sensor gives an output voltage signal. This way, it is possible to drive a triggered measurement with the measurement start at the same point, i.e., at the same position of the belt.

The material from the belt feeder was unloaded to the unload bin supported by the load cell type HBM RSC S-type / 5000 kg. Tensioning of the belt, i.e., the tensioning pulley, has been done using

two threaded spindles. These spindles have been instrumented with strain gauges (1, Figure 6b). In order to make an elastic element of the force transducer threaded spindles have been machined by removing the thread at the top, and strain gauges in full Wheatstone bridge, Figure 6b, have been applied on a previously prepared surface.

Testing of individual parts, as independent measuring elements, has been performed in

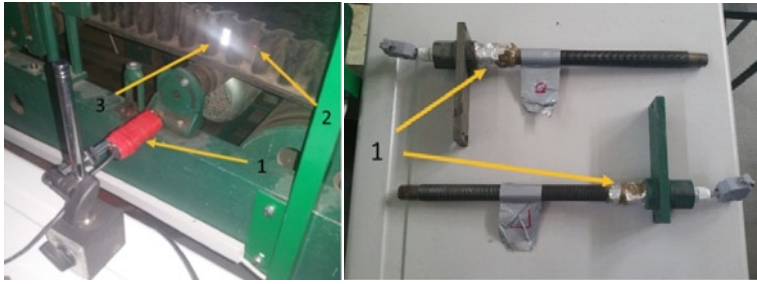


Fig. 6. Laser position sensor during work (a) and tension spindles (b)

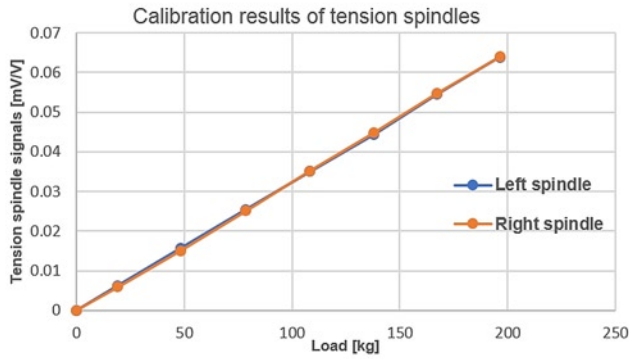


Fig. 7. Calibration results of tension spindles



Fig. 8. Measuring environment

laboratory conditions. Calibration of force transducers made from threaded spindles has been performed on a Toyoseiki AT-L-118B tensile testing device. Calibration has been performed at several points, and the results showed that there is an acceptable linearity, Figure 7. The calculated sensitivities were entered into the software.

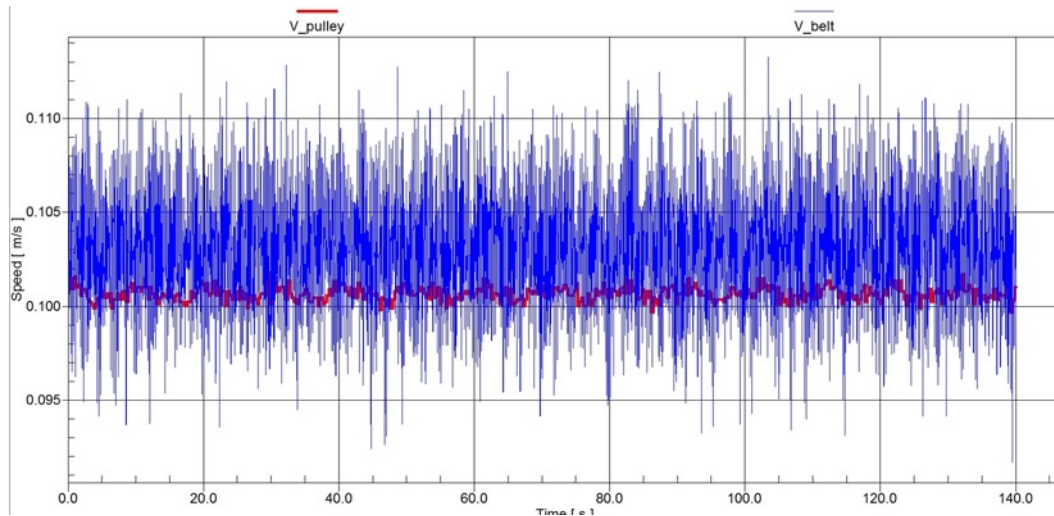


Fig. 9. Comparison of rotary encoder and inductive sensor signals

The load cell under the unload bin has a known measuring characteristic of 2 mV/V. Its characteristics has been checked by use of a set of calibration weights. An adequate measuring environment was then established, Figure 8.

First, it was checked whether the measurement of the belt speed was adequate, by comparing the signals of the rotary encoder and the inductive sensor that counts the sprocket teeth. The circumferential speed of the pulley was calculated on the basis of the frequency of detection of the teeth of the driven sprocket, and the linear speed of the belt was calculated on the basis of the frequency of detecting the slits of the rotary encoder. The results are shown on Figure 9.

Based on the measurements, the average value of the belt speed, based on the encoder signal, was 0.102 m/s; while the average value of the circumferential pulley speed, based on the inductive sensor signal, was 0.101 m/s, which is a negligible error. It was also noticed that the value of the belt speed, based on the encoder signal, has an oscillating sinusoidal shape. The signal was analysed in the frequency domain using Fast Fourier Transformation and it was determined that a peak corresponding to the moment when the chain link touches the sprocket tooth occurs in the frequency spectrum.

The control of the belt position laser sensor was performed by recording the signal of 6 cycles, Figure 10. The beginning of the circuit was marked by the signal of the laser sensor. Based on the obtained results, it was concluded that the cycles of movement of the empty belt coincide.

4. Measurements on the belt feeder

Calibration of the measuring system is the most important activity that needs to be performed in order to assess the accuracy. Based on the obtained results, it is necessary to perform automatic correction of measurement results [2]. There are three ways to calibrate the measuring system – with material, chain and dead weight. Dead weight calibration is a simple and fast procedure that does not take into account the errors caused by the dynamics of the movement of the belt, so it is not reliable. Chain calibration is a more precise method where the chain simulates a real continuous load on a belt. The minimum chain length should cover two support idlers in front of and behind the measuring idler. For the reliable calibration procedure, the line weight of the chain needs to be close to the line weight of the material to be transported. Material calibration is the most accurate method because it is performed in real conditions. This method is a direct test of the entire measurement system. The material transported over measuring idlers is collected and statically measured. This determines the calibration standard.

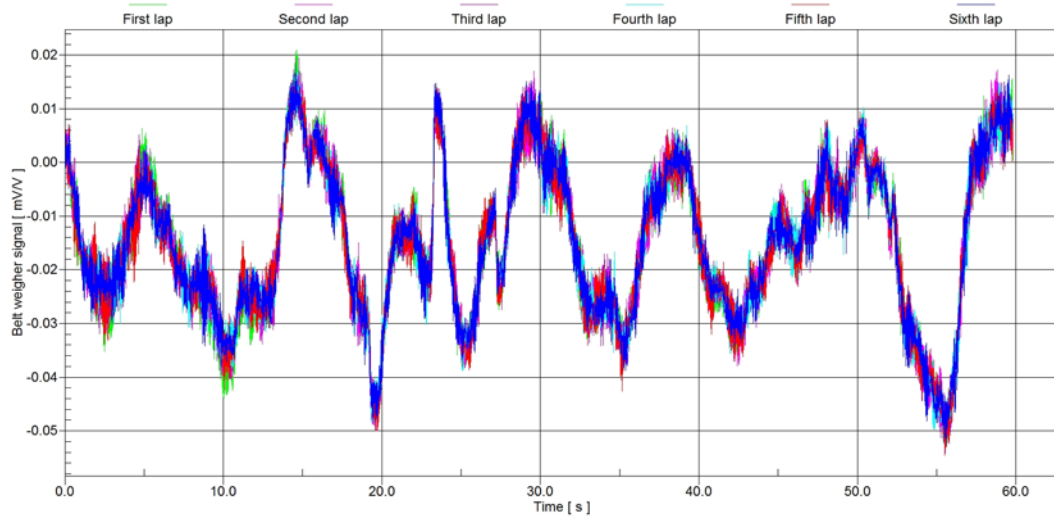


Fig. 10. Overlapping of 6 signals from the empty belt

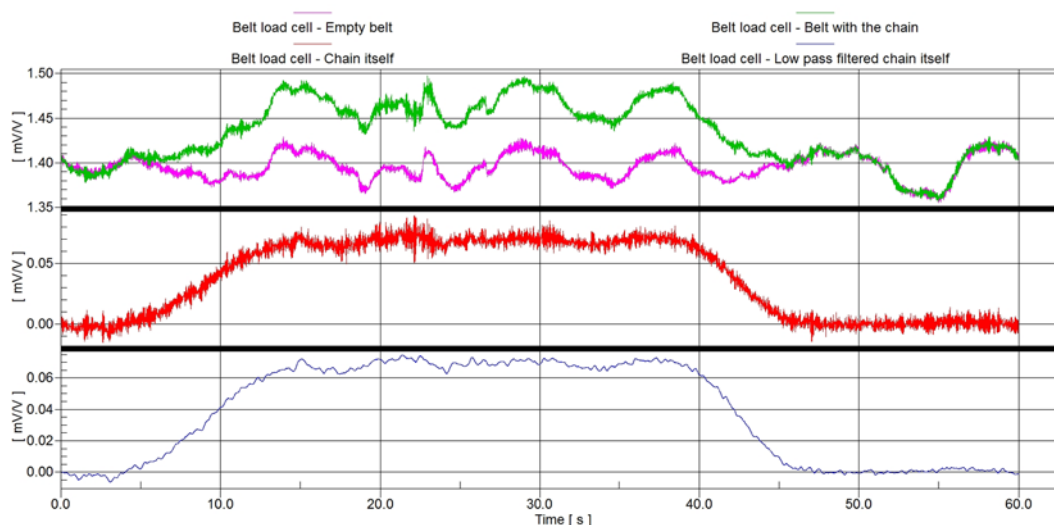


Fig. 11. Chain calibration results

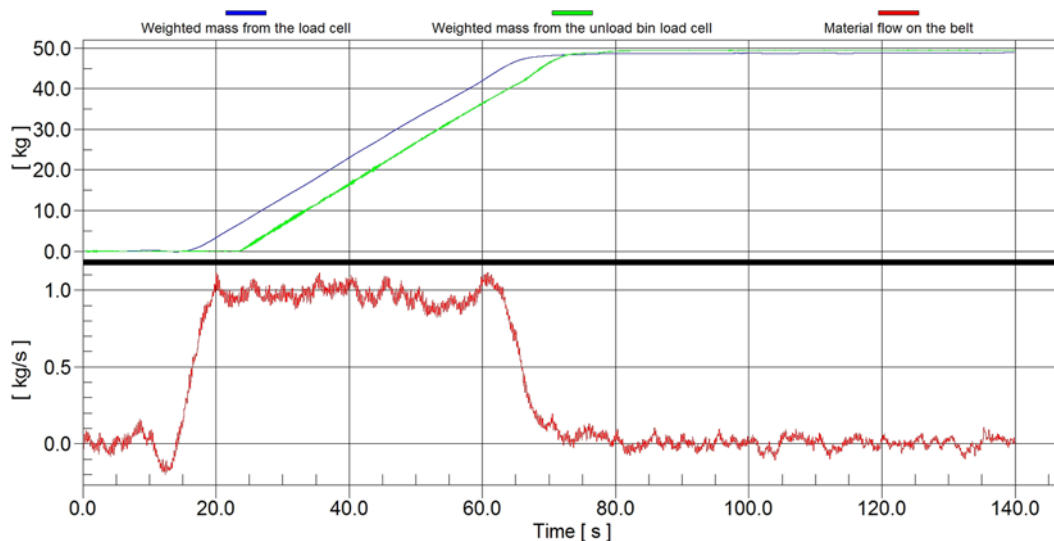


Fig. 12. Measurement results at tension I and the belt speed 0.102 m/s

In order to be able to detect and evaluate the influences on the calibration, test was performed for 9 variants - 3 values of belt tension and 3 values of speed. Measurements were performed for three levels of belt tension:

- tension I – minimum tension at which the belt did not slip on the drive pulley and at which the belt did not move laterally, tension force - 3.256 N;

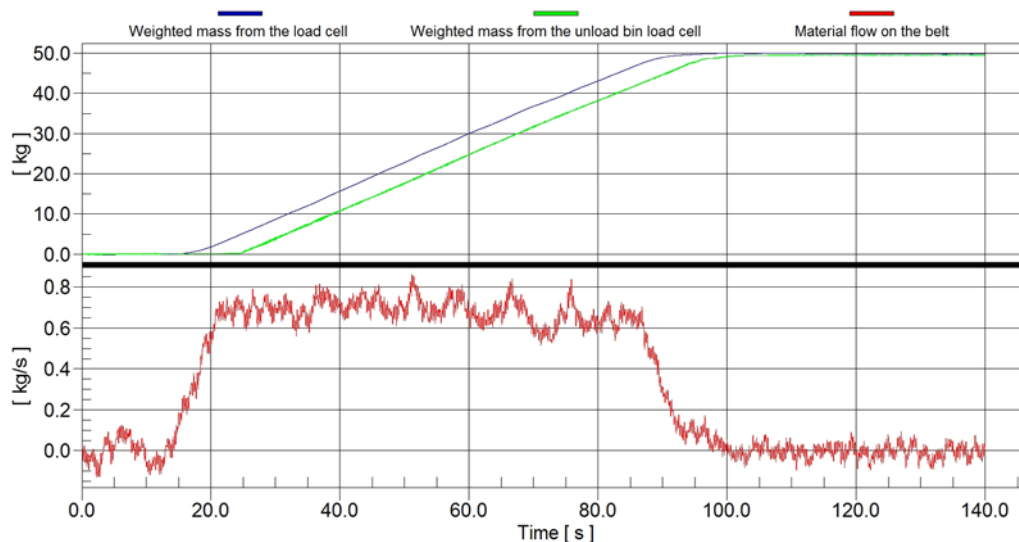


Fig. 13. Measurement results at tension II and the belt speed 0.102 m/s

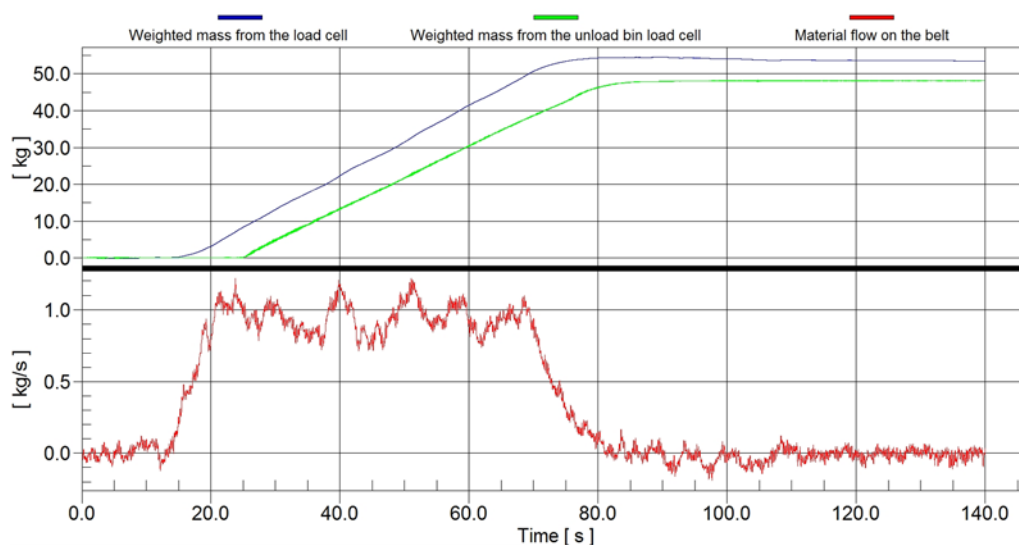


Fig. 14. Measurement results at tension III and the belt speed 0.102 m/s

- tension II – tension at which the deflection of the belt between supporting idlers could not be visually observed, tension force - 7.758 N;
- tension III – tension at which characteristic sounds occurred when the belt bends around pulleys, tension force - 12.947 N.

At each belt tension, measurements were performed at three speeds: 0.051 m/s (at 10 Hz of VFD), 0.102 m/s (at 20 Hz VFD) and 0.2405 m/s (at 50 Hz of VFD). Before each measurement, the reference scale signals were recorded due to the movement of the empty belt at three levels of tension and three levels of speed. This was necessary in order to be able to subtract later these results from the obtained signals of the scale.

First, chain calibration was performed for all 9 variants. Two chains were used - the first 1.53 m long with a total mass of 5.292 kg and the second 3.45 m long and with a total mass of 25.985 kg. Calibration was performed in the following manner – first step was to record the signal of the scale load cell from the empty belt; the second step was to record the scale load cell signal from the first and later from the second chain where the recording lasted for a full cycle and finally the last step was to subtract the signal from of empty belt from signals of chains in order to get pure signals of chains. On the Figure 11, results from one measurement with chain 2, at tension I and belt speed 0.051 m/s are shown. 5 repetitions were performed for each variant.

After that, calibration with material was performed. Since a larger number of repetitions of measurements were performed, based on the statistical processing of the obtained results, an assessment and analysis of the measurement accuracy could be evaluated. Barley was chosen for the material calibration. As during chain calibration, measurements were performed for the same 9 variants. 7 repetitions were performed for each variant.

Results from measurement at tension I and the belt speed of 0,102 m/s are given on Figure 12, at tension II and the same speed on Figure 13, and at tension III and the same speed on Figure 14.

5. Results and Discussion

At the beginning, it was concluded that the belt does not affect the signal of the scale by the effect of the elastic beam, because the planar moment of inertia of the belt with the material has an extremely small value. Based on that, it was concluded that a mathematical model according to [5] is applicable to flat belt feeders. According to this model, the error in the measurement signal is calculated according to Equation (3).

The measuring control elements and the conditions at which the measurements were performed provided the following:

- there was no slippage of the belt on pulleys because the signals of the encoder and the inductive sensor were compared;

- the measuring idler is raised in relation to the adjacent ones by 0.7 mm and this was taken into account when calculating the measurement error according to the existing mathematical model;
- the influence of belt inhomogeneity was completely eliminated;
- the material reached the speed of the belt well before the zone of the measuring idler (according to the Equation (8), the acceleration path for three speeds is 0.26 mm, 1.1 mm and 5.9 mm);
- the belt feeder is horizontal so the material does not slip backwards;
- during the experiment, the humidity of the material was controlled, which ranged from 13.6 ÷ 13.8% - it was practically constant so all potential influences of the working environment and materials were eliminated;
- the latch on the loading hopper was in the same position for all measurements, so that due to the flowability of the tested material, the same amount of material always reached the belt;
- the total mass of the material, used for material calibration, was the same in all 9 variants and in all 7 repetitions, i.e., a total of 63 measurements. It was 49.4 kg, and was controlled after each measurement.

Table 1 shows the results of material measurements. The mean values based on 7 repetitions of measurements of each variant were entered in the column "Measured mass". In order to assess the validity of the calibration and, also, the accuracy of the measurement, i.e., the scatter of the measured values, the standard deviation (σ) was calculated, as well as the coefficient of variation (CV), i.e., the relative standard deviation for all variants. The values of the expected error were entered in the last column, according to the Equation (6), where $D=0.7$ mm, $L=0.4$ m, $K=1.1$, $c=0.018$ was used. Table 2 shows the results of chain measurements (ch1 - chain 1, ch2 - chain 2).

Table 1. Results of material measurements

	v [m/s]	t	Measured mass [kg]	Measurement error [%]	σ [kg]	CV [%]	Error according to (6) [%]
1	0.051	I	48.3	2.23	0.7	1.45	1.15
2	0.102		48.55	1.72	0.85	1.75	1.71
3	0.2405		48.12	2.59	0.65	1.35	3.35
4	0.051	II	49.1	0.61	0.65	1.32	3.01
5	0.102		49.8	0.81	0.58	1.16	5.92
6	0.2405		50.1	1.42	0.61	1.22	12.27
7	0.051	III	52.42	6.11	1.8	3.43	4.21
8	0.102		55.99	13.34	2	3.57	6.67
9	0.2405		61.68	24.86	2.1	3.40	14.79

Table 2. Results of chain measurements

	v [m/s]	t	Measured mass [g]		Measurement error [%]		σ [g]		CV [%]	
			ch1	ch 2	ch1	ch 2	ch1	ch 2	ch1	ch 2
1	0.051	I	5160	25691	2.49	1.13	78	412	1.51	1.60
2	0.102		5210	25712	1.55	1.05	98	399	1.88	1.55
3	0.2405		5207	25678	1.61	1.18	84	435	1.61	1.69
4	0.051	II	5343	26192	0.96	0.80	69	422	1.29	1.61
5	0.102		5339	26188	0.89	0.78	73	383	1.37	1.46
6	0.2405		5351	26201	1.11	0.83	71	391	1.33	1.49
7	0.051	III	5586	27654	5.56	6.42	95	489	1.70	1.77
8	0.102		5643	27801	6.63	6.99	103	465	1.83	1.67
9	0.2405		5756	28106	8.77	8.16	117	532	2.03	1.89

Based on the analysis of the obtained results, it was determined that there are factors that affect the validity of the calibration and the accuracy of the measurements.

Tensioning significantly affects the error, i.e., the accuracy of measurements. It was found that at low belt tension, the speed has no effect on the measurement accuracy because the error is at a similar level at all speeds. As the speed increases, at the higher belt tension, the measurement error also increases.

With lower tension forces, the mean measured value is less than the actual mass of the material at all speeds. Increasing the tension increases the average measured value, which is a consequence of the misalignment of the measuring idler.

Chain calibration in the case of a raised measuring idler is not valid, because the measurement results indicated a significant difference in relation to the material measurements. Larger measurement errors occur in case with the material compared to measurements with the chain, which is a possible influence of the construction. In any case, it can be concluded that after chain calibration, calibration with material is required.

A small scatter of the measurement results, when calibrating with chains, indicates the accuracy of the measurement and the achievement of the best level of accuracy for a certain tension.

The values of the expected measurement errors according to the existing mathematical models correspond only to smaller forces in the belt.

The highest level of measurement accuracy, i.e., the smallest scattering of results, is achieved at an optimal tension and depends primarily on the structure and properties of the belt itself, and in this case also, after calibration with the material, it is necessary to define the zero.

6. Conclusion

In this paper, the operation of a flat belt feeder was analysed. Feeding with such a feeder is a process that is influenced by many factors, and through conducted research, the influence of tension force and belt speed has been pointed out. Measurements were performed with a known vertical misalignment of the measuring idler, in order to be able to analyse the effects of other factors and to evaluate the validity of existing mathematical models.

The results of the research showed that for a specific belt of a belt feeder, it is necessary to find the optimal tension that leads to the highest level of measurement accuracy.

The accuracy of the measurement is greatly influenced by the setting of the scale zero, because it is continuously integrated into the measured material mass. Material calibration is the most accurate method and is only valid for use in working conditions, especially if there are certain geometric irregularities and deviations from ideal values. Chain calibration can only indicate the level of measurement accuracy, but cannot be valid for the zero setting.

Existing mathematical models for estimating measurement errors with belt feeders have not fully cov-

ered all factors and can be applied to certain ranges of belt tension and speed. Also, they do not take into account all the specifics and features of the belt.

Finally, it can be concluded that during feeding with belt feeders, it is necessary to control the speed and tension of the belt and keep it

within certain limits, in order to be able to comply with the defined accuracy of measurement. Certainly, further research is necessary in order to analyse not just the influence of forces and speed, but also the characteristics of the belt of the belt feeder on the accuracy of measurements.

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