

Classification and Comparative Analysis of Belt Weigher Hoists

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Abstract

There is considered the design of kinematic configurations of belt weigher hoists from the position of mobility mechanisms. There is given an idea of groups of belt weigher errors. There are proposed the signs of classification of hoists and presented classification of these devices on the basis of which there is made the comparative analysis of their kinematic configurations. There are given recommendations on selecting rational designs of belt weigher hoists from the point of view of ensuring accuracy of weighing and realization of methods of their calibration.

Keywords: belt weigher, hoist, signs of classification, weighing error

1. Introduction

Metrological characteristics of belt weighers (BW) are defined not so much by the accuracy of the used force measuring sensors and microprocessor data-acquisition equipment, but by the features of interaction the primary measuring transducers of the bulk material pressure – hoists – with the conveyor belt itself that is an imperfect elastic body. The BW input process is the freight flow of bulk material characterized by the linear density and speed of its relocation on the conveyor belt. These parameters of the input process are the informative parameters.

In the process dynamic weighing of bulk material in addition to the main informative parameters on the hoists act non-informative parameters (resistance to movement of the conveyor belt, dynamics of lump material, belt tension, belt displacement relative to the longitudinal axis of the conveyor, etc.) which cause the emergence of weighing errors.

In addition, the BW actual accuracy class, besides the parameters of a conveyor and a conveyor belt (playing an essential role), is in a great extent affected by the choice of the hoist design itself.

The BW main characteristic is considered the dependence of the informative output parameter, namely productivity, from the informative input values provided that their oscillations are in the normalized limits. This dependence is a static conversion function which can be set in case of static calibration BW on the conveyor in the normal conditions of measurement.

In the BW operating mode parameters of the static conversion function can change not accidentally with changing the external factors (ambient air temperature, power voltage and frequency).

Besides, the conversion function parameters do not accidentally change under the influence of the above informative parameters. As their influence is inevitable, the static conversion function is corrected in the BW calibration using a weighted bulk material in the conveyor operating mode. Thus there is established the rated conversion function.

The deviation of the real conversion function from the rated conversion function when changing the informative parameters and, generally, the random non-informative parameters characterizes the BW error.

Therefore the main objective of the BW development and selection consists in achieving practical identity of the rated and real conversion functions that will permit to minimize a weighing error of the BW under the impact of the entire range of informative and non-informative parameters.

2. Belt Weigher Errors

In relation to belt weighers, as well as to other measuring devices, their errors can be divided into systematic and random ones. Systematic errors are those which are certain nonrandom functions of any factors causing the deviation of the real conversion function from the rated conversion function. Random errors are inconstant and unknown in advance errors whose nonrandom connection with any effecting factors is not established.

Systematic errors are the determined values or functions, and random errors are stochastic ones which are estimated under the laws of the probability theory and mathematical statistics.

According to (Zemel'man, 1972) it is expedient to divide the errors of measuring devices into three groups. Such a division is quite applicable to belt weighers.

Generally the errors caused only by the difference between the rated conversion function and the static conversion function under normal conditions belong to the first group. These errors are called systematic errors of the first kind. They are nonrandom functions of input values. To the first group of errors there will be referred the error which is the determined function of the input informative parameter as the linear density of the bulk material q . Conditionally it is possible to call it a systematic error of the first kind which depends on the weighing roller sag f , non-informative parameter as the belt tension σ , the weight length l and for one-roller belt weigher is defined by the expression

$$\delta = -\frac{200\sigma f}{ql^2}, \% \quad (1)$$

Generally when accounting the inaccuracy of the weighing roller installing expressed as equivalent level of displacement rather next stationary rollers, the relative error is defined by

$$\delta = -\frac{200\sigma}{cl + 2\sigma} \cdot \left(1 \pm \frac{h_0 c}{ql \cos \beta}\right), \% \quad (2)$$

where h_0 is the equivalent displacement of the weighing roller level, c is rigidity of the force measuring sensor, β is the angle of inclination of the belt conveyor.

The sign “+” is used when reducing the level of the weighing roller installing, and the sign “-” when exceeding the level of its installing.

In ideally accurate installing ($h_0 = 0$) the error

$$\delta_1 = -\frac{200\sigma}{cl + 2\sigma}, \% \quad (3)$$

remains unchangeable in the entire range of changing the bulk material linear density q under the condition $\sigma = \text{const}$ and can be excluded from the measuring result.

However with inevitable deviations of the actual dimensions of the grooved roller support elements from the nominal ones owing to technological allowances and inaccuracies of installing the condition $h_0 = 0$ is unreal. Therefore in the results of measurements there always is the second component of the error

$$\delta_2 = \pm \frac{200\sigma}{cl + 2\sigma} \cdot \frac{h_0 c}{ql \cos \beta}, \% \quad (4)$$

which depends on the current value of the linear density q and can be defined with an error characterized by the zone of uncertainty or an interval of the error values distribution. It "degenerates" in such a random value which does not answer all signs of the random process, but it also cannot be considered as a determined one (Zemel'man, 1985). Such a value at the same time possesses some (not all) properties of both the random and the determined value. In this case it is referred to the second group of errors brought by non-informative parameters.

To the second group there are referred errors which are the known determined functions of random arguments which often are functions of time. Errors of the second group are called conditionally systematic errors of the second kind which are practically shown as stochastic functions of time. It is possible to refer to the second group the errors caused by such factors inherent for belt weighers as the belt tension in the place of the hoist mounting, force of resistance to the belt movement, dynamics of the bulk material and the belt, asymmetric deformation of the belt on inclined conveyors, etc. These errors are also the known determined functions of random changes of informative and non-informative parameters and can be excluded from result of measurement when carrying out belt weigher calibration under normal operating conditions at the working point of the range of measurements.

To the third group there belong purely random errors caused by own spontaneous deviations of the real conversion function parameters. The natural connection of these deviations with any reasons is impossible to establish, as well as to give them a qualitative and quantitative evaluation.

Systematization of belt weigher errors of the first and second groups taking into account non-informative parameters contributing to their appearance is presented in Figure 1.

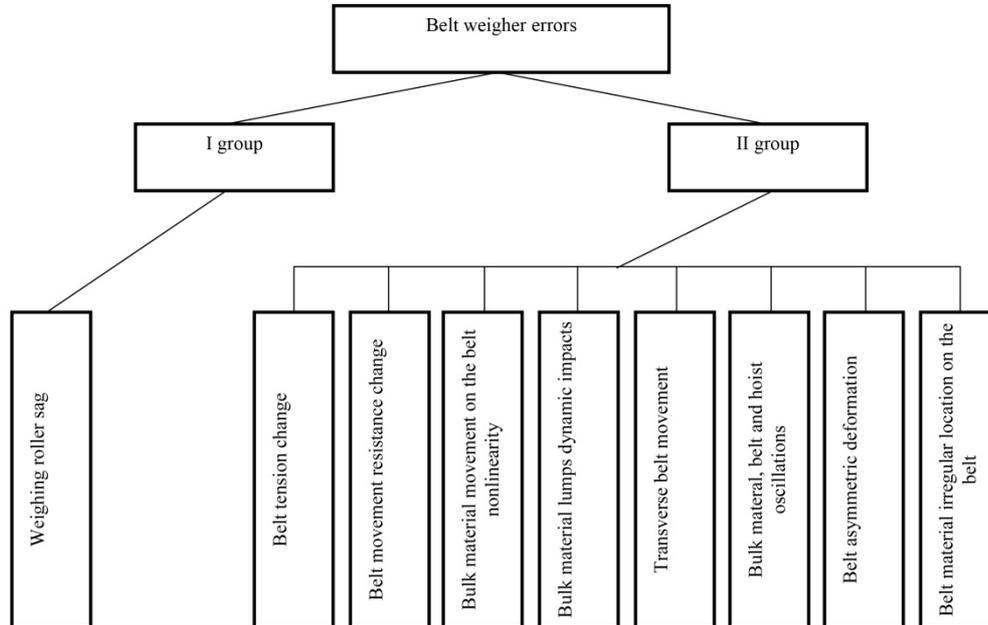


Figure 1. Systematization of belt weigher errors

Systematic errors can be divided into constant, progressive, periodic and errors changing under the complex law. In case of belt weighers the error δ_1 owing to the force measuring sensor sag according to (3) can be referred to a constant systematic error.

The second component of the error δ_2 according to (4) depending on the change of the conveyor productivity can be periodic or change under the complex law and its value can be determined only under the known law of changing the conveyor productivity that in real working conditions of operation is unreal.

That is the stochastic character of the conveyor current productivity that permits to say that the above non-informative parameters are the cause of the second group errors.

Errors of the first and second groups define the BW main error in the normal conditions. The deviation of any informative or non-informative parameters from its value at which BW in the operating mode of the conveyor were calibrated, leads to changing the main error. So the changes of errors of the second group will be considered as additional errors of the total BW error having a random character (Galín, Donis, 2014). The BW main error when calibrating in the normal conditions will be a systematic error. The criterion for significance non-informative parameters will be considered excess of relative error introduced by any parameter, 1/3 of the maximum permissible error of belt weighers.

If for the BW used in industry for bulk material accountancy the actual maximum permissible error makes $\pm 1.0\%$, the criterion of significance will be taken $\pm 0.35\%$ what is regulated by item 2.2.3 of the International recommendation (OIML R 50-1:1997).

The analysis of the belt weigher errors occurrence can enable to formulate requirements for the selection and justification of the hoist design to minimize the impact of non-informative parameters.

3. Classification of Belt Weigher Hoists

From the position of the theory of machines and mechanisms each detail in space possesses six levels of freedom relative to the selected fixed coordinate system: three linear and three angular movement relative to the coordinate

axes. In case of appearance of kinematic couples in the detail structure its relative mobility decreases depending on the number of conditions of connection. Therefore, generally, there is possible superimposing from one to six conditions of communication on any detail.

For the accurate load transfer to the weighing roller it is necessary to impose only one condition of connection, i.e. to eliminate the linear movement of the weighing roller along the vertical axis of the selected coordinate system. It can be executed in case of connection of the weighing roller with the force measuring sensor by means of a thread kinematic couple of the I class that permits to provide its maximum main mobility $W=5$ (Radchik & Pishchurnikov, 1969).

For BWs in an ideal case for the uniform bulk material located on the belt the line of action of the measured load coincides with the upper lines of the middle and side rollers of the grooved roller support. In this case on the weighing roller it is necessary, besides elimination of the linear movement along the vertical axis, to impose an additional condition of connection, i.e. to eliminate angular movement in the vertical plane of action of this force. At this the hoist design can be realized with the use of two thread kinematic couples of the I class in providing its maximum basic mobility $W=4$.

Actually, when weighing the belt with the bulk material, the line of the measured uneven load moves in two mutually perpendicular vertical planes relatively to the coordinate axes X and Y (Figure 2).

On conveyors with the grooved belt in case of its displacement and non-uniform loading across the width it is possible the appearance of unbalanced transversal forces acting in the horizontal plane; in this connection on the hoist there act load moments M_x and M_y causing the displacement of the line action of the measured load.

In connection with this circumstance it is necessary to impose three conditions of connection on the hoist which eliminate the linear movement along the axis Z and angular movement relatively X and Y axes. At this case the main mobility of the weight measuring system becomes equal $W=3$. In the design plan such a decision can be executed if the hoist is connected to three force measuring sensors by means of three thread kinematic couples of the I class.

The proposed conditions of connection will restrict completely the hoist mobility in the vertical direction.

Providing the hoist basic mobility in the horizontal plane equal $W=3$ allows to carry them to perfect hoists. At this there is achieved high accuracy of weighing of the bulk material transported by the conveyor belt in the presence of the non-informative parameters action on the hoist which are listed above, owing to its self-adjustment in case of an uneven freight flow of the bulk material.

The belt displacement relative to the longitudinal axis of the conveyor, non-uniform layout of the bulk material on the width and length belt causes occurrence of transversal forces on the conveyor belt. In the course of transportation of the bulk material there are also other additional loads which influence the hoist and change in a random way, namely longitudinal forces. Here there can be referred the resistance forces to the conveyer belt movement and the force caused by dynamics of the moving material.

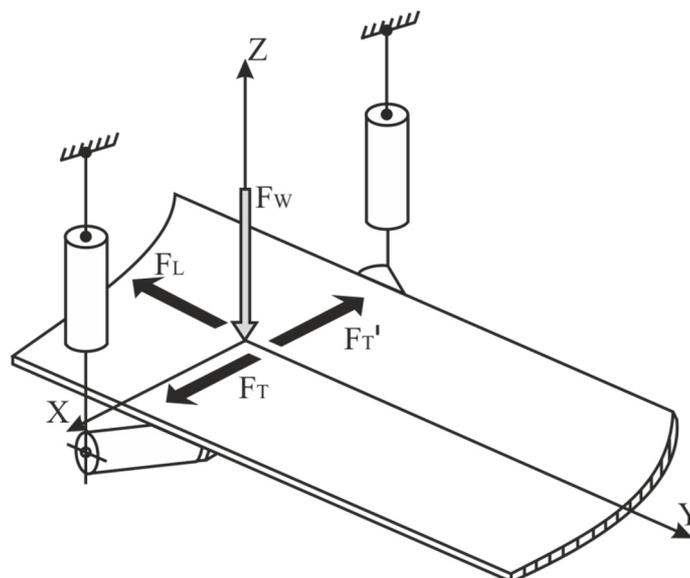


Figure 2. General configuration of belt weigher hoist

Transversal and longitudinal forces cause additional load moments relative to the fixing points of thread suspension brackets to supports, therefore their axes deviate from the original position. On inclined conveyors there begin additionally acting horizontal components of the loads above mentioned which in case of their random change cannot be taken into account in the BW calibration. In particular, the belt interacting with the hoist rollers and the entire conveyor, also imposes an additional condition of connection.

To eliminate these additional loads the hoist requires further superimposing of conditions of connection with the use of kinematic couples which won't promote the increase of its mechanical reliability.

From the above mentioned there appears a peculiar painting. For supporting the measuring accuracy of the moving material flow it is necessary to provide in the maximum extent the hoist mobility in the horizontal plane. However, instability and dispersion of the results of measurements will be a consequence of the hoist mobility. So, their reliability, recurrence and reproducibility decrease, in particular in case of determination of zero point at idle of belt.

The action of the longitudinal and transversal forces having non-informative character requires supporting the static stability of the hoist design, i.e. restriction of its mobility in the horizontal plane. The above circumstances led to the further refusal from the development of hoist designs with thread suspension brackets. And refusal from the full hoist mobility in the horizontal plane permitted to provide the stability and reproducibility results in measuring weight. However, it entailed the reduction of weigher sensitivity and, respectively, lowering the accuracy of the measurement results.

Therefore due to the need of supporting static stability of the hoist design in case of such a complex of forces operating on it, there became widely spread one-roller hoists and multiroller platform hoists (with two and more weighing rollers) with plane-parallel and angular movement which basic mobility $W=0$. In the terminology of the theory of machines and mechanisms it is accepted to call such hoists incomplete as their mobility is less than the mobility of an ideal hoist of weight systems which in the horizontal plane shall have the basic mobility $W=3$.

In the metrological aspect incomplete hoists are always worse since additional connections lead to lowering the BW sensitivity and the achievement of high accuracy of mass measurement is possible only in case of high accuracy of manufacturing and installation of the hoists, as well as stability of operating parameters of conveyor after the BW calibration.

Besides, the only accurate way of the BW calibration consisting of an incomplete hoists is calibration by the suspended material, as the use of traditional mechanical simulators of the linear density of the bulk material in case of indirect calibration does not permit to reproduce ideally the entire range of non-informative loads.

In the world practice of the belt weighers building there was developed a great number of BW, and their comparative analysis shows that there are common approaches in hoist designs. In this regard it makes sense to offer the hoists classification according to a number of selected signs of classification and to give the comparative analysis of hoists designs. This will permit to formulate recommendations on the choice of their rational structures to ensure the accuracy of weighing when operating in different conditions of production.

The hoists classification can be made by the following signs:

- 1) the way of hoist movement;
- 2) a number of weighing rollers on the belt weigh length;
- 3) a number of force measuring sensors used in the hoist design;
- 4) presence of a device for balancing the conveyor belt and weighing rollers weight;
- 5) a number of channels measuring the mass of bulk material.

The proposed classification of the BW hoists is presented in Figure 3. This classification is based on the division of hoists into two basic types: hoists with plane-parallel (translational) movement and hoists with angular movement.

In the mentioned features of the proposed classification there are not listed a number of some other additional features (for example, force measuring sensors types, etc.) which absence does not lead to an essential modification of the classification.

Kinematic configurations of some hoist designs with plane-parallel and angular movement are provided in Table 1.

Besides that there is specified the ability hoists to minimize the impact of such non-informative factors as longitudinal and transverse forces arising from the moving of the conveyor belt with bulk material.

Sign "+" means that this factor can be minimized by the choice of certain design features of the hoist kinematic configurations, the sign "-" means that this factor can not be minimized.

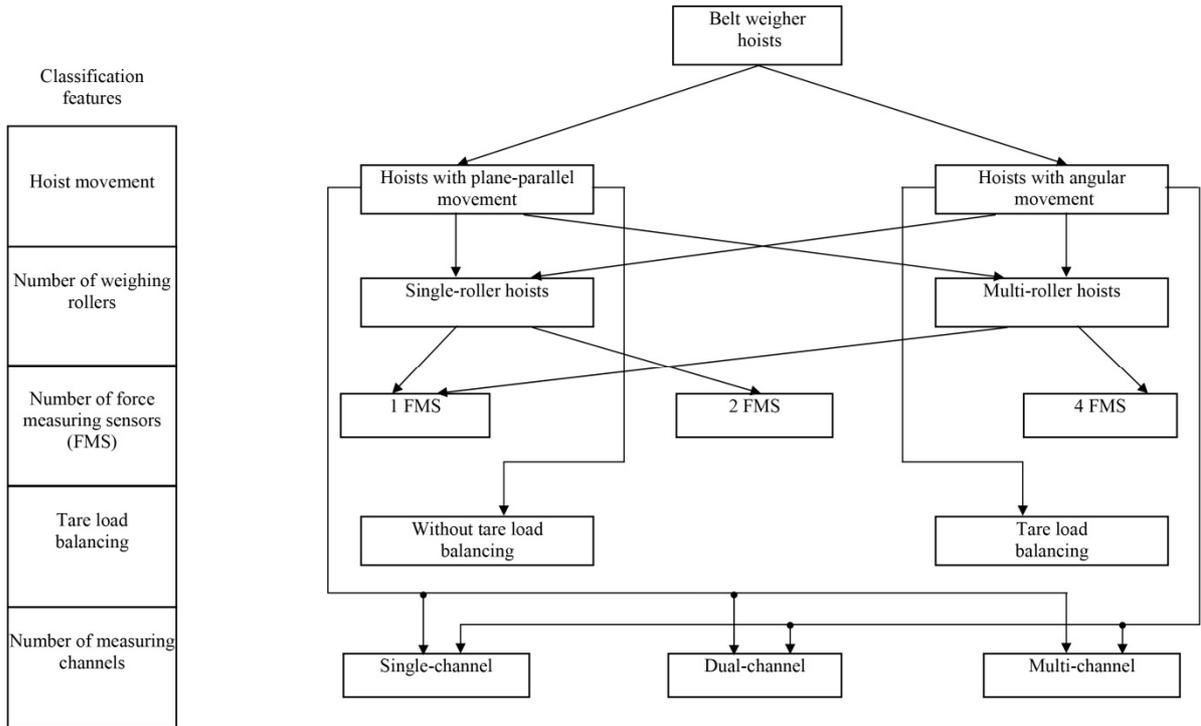


Figure 3. Classification of belt weigher hoists

As an example there will be considered kinematic configurations of hoists with plane-parallel (Figure 4a) and angular (Figure 4b) movement and will determine an expression for the force acting on the hoist depending on the value of the bulk material linear density and the design features of the hoist itself.

For hoists with plane-parallel movement the force acting on the weigh platform will be formed by the forces transmitted to the two weighing rollers from the bulk material with linear density q .

The total reaction of force measuring sensors will be determined as

$$R = P_1 + P_2 = 2ql, \tag{5}$$

where l is the distance between the conveyor rollers, $P_1 = P_2 = ql$ is pressure on the weighing rollers from the bulk material on the conveyor belt.

As the hoist weigh length (l_w) is equal to the sum of distances between the axes of the end rollers of the weigh platform and half-sum of distances between these rollers and the closest stationary rollers, there can be written down that $l_w = 2l$.

Then equation (5) can be presented as

$$R = ql_w. \tag{6}$$

For hoists with angular movement the force measuring sensor reaction R can be obtained on the basis of the equation of equilibrium moments of forces, i.e.

$$R \cdot (l_2 + l + l - l_1) = P_1 \cdot (l - l_1) + P_2 \cdot (l + l - l_1). \tag{7}$$

Equation (7) will be reduced to the following form

$$R = \frac{ql(3l - 2l_1)}{2l + l_2 - l_1}.$$

Since $l = l_w / 2$, there can be written down

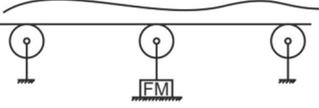
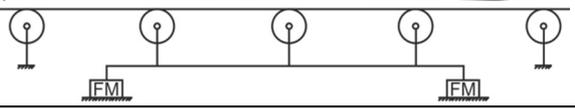
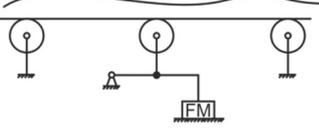
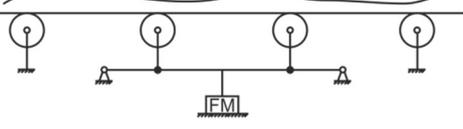
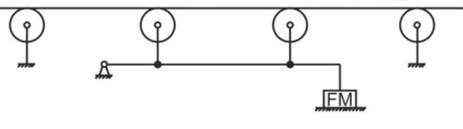
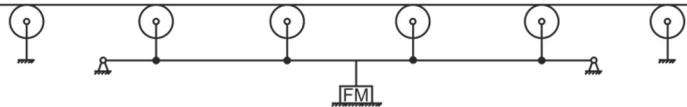
$$R = \frac{1}{2} ql_w \cdot \frac{3l - 2l_1}{2l + l_2 - l_1}.$$

If we take $l_1 = l_2 = l / 2$, then

$$R = \frac{1}{2} q l_w \cdot \tag{8}$$

On the basis of expressions (6) and (8) it is possible to mark out the main distinction between two considered hoists types with plane-parallel and angular movement.

Table 1. Kinematic configurations of belt weighers hoists

No	Number of sensors	Number of weighing roller	Kinematic configurations	Non-informative parameters	
				Longitudinal force	Transversal force
Hoists with plane-parallel movement					
1	1 or 2	1		+	+
2	4	2		+	+
3	4	3		+	+
4	4	4		+	+
Hoists with angular movement					
5	1	1		-	-
6	1	2		+	-
7	1	3		-	-
8	1	4		+	-

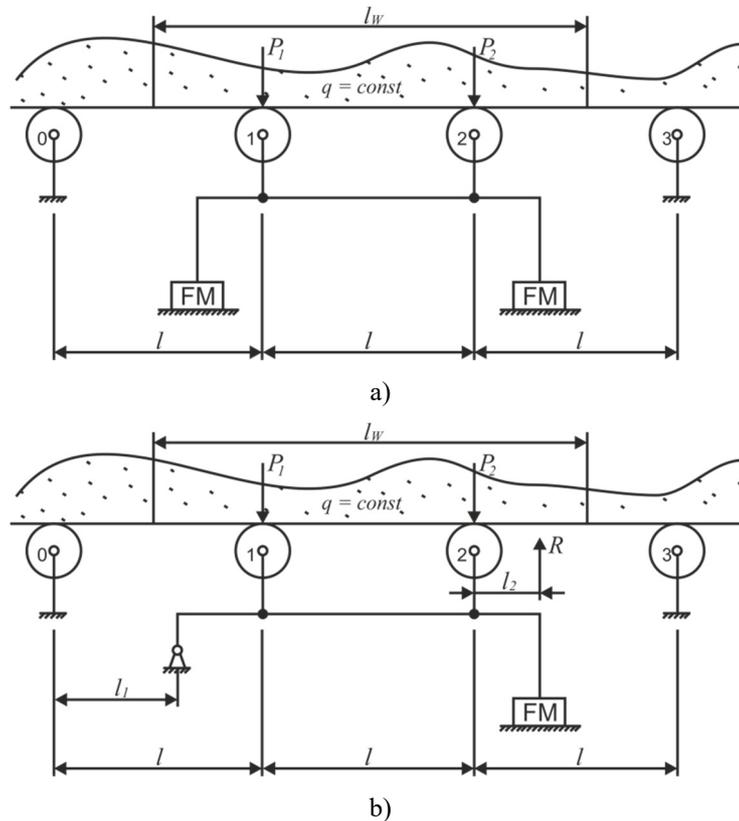


Figure 4. Hoist kinematic configurations

a – with plane-parallel movement; b – with angular movement

The force acting on the hoist with plane-parallel movement is equal to the product of the average value linear density on the theoretical weigh length, and for the hoist with angular movement the force acting on the hoist is equal to the half-product of the average value linear density on the theoretical weigh length under the condition of observing only certain relationships ($l_1 = l_2 = l/2$) between the design parameters (Karpin, 1971). If this relationship is not observed, there are possible variants when the condition (8) is not met, i.e. $R > ql_w/2$ or $R < ql_w/2$.

4. Comparative Analysis of Kinematic Configurations for Belt Weigher Hoists

When using the parallelogram force measuring sensors all kinematic configurations with plane-parallel movement possess the property of invariance to the action of longitudinal loads (for example, forces of resistance to the conveyor belt motion).

As for kinematic configurations with angular movement, the invariance to the impact of the longitudinal forces have only configurations No. 6 and No. 8 presented in Table 1. Compensation of longitudinal forces in these configurations is carried out owing to the fact that the moment of longitudinal forces applied to the first weighing roller of the weigh platform loads additionally the force measuring sensor while the moment of this forces applied to the second weighing roller of the weigh platform unloads the sensor and in its output signal there is absent non-informative component caused by longitudinal forces.

By the number of weighing rollers hoists can be divided into single-roller and multi-roller (with two or more weighing roller), and they can be of both types – with plane-parallel and angular movement.

With increasing number of weigh rollers the weigh length of the belt increases. This reduces systematic error of the first kind in accordance to (3) and the error in accordance to (4) which is caused by imprecise installation of belt weigher.

The number of force measuring sensors can be equal to 1 or 2 in designs of single-roller hoists. In single-roller hoist with angular movement there is used 1 sensor, and in single-roller hoist with plane-parallel movement there is used one or two sensors. An example of such a hoist can be kinematic configuration No. 1 presented in Table 1 for which there are possible two options:

- weighing roller is supported by two console parallelogram sensors;
- weighing roller is supported by one sensor but in the hoist design there is additionally used an external parallelogram mechanism.

Platform hoists with angular movement (multi-roller hoists) can be presented in the form of two separate weight platforms leaning on one force measuring sensor (configurations No. 6 and No. 8). The existence of two hinge units and one force measuring sensor provides static stability to the design as a whole. However, the location of force measuring sensor in the centre of hoist design makes hoist non-invariant to the action of transverse forces that reduces the weigher accuracy if the conveyor belt displaces relative to the conveyor longitudinal axis or if there is uneven loading of the material on the belt width.

In the designs of platform hoists with plane-parallel movement there are, as a rule, used four force measuring sensors. All hoists of this type will be invariant to transversal loads because of the location of the force measuring sensors on both sides of the conveyor. The disadvantage of the multi-roller platform hoists leaning on more than three force measuring sensors is their static uncertainty which can result in the unevenness of sensors loading. However, it does not practically affect the results of measurement, but forms conditions for a possible overload of separate sensors reducing reliability of the weigh system as a whole.

To increase the sensitivity of mass measurement in hoists with angular movement there is used device balancing tare weight of the belt and rollers (so-called "mechanical" balancing the tare weight as a counterweight).

In the hoists with plane-parallel movement such balancing device, as a rule, are not used, and used so-called "electric" balancing the tare weight by the initial zero-setting of belt weights.

Under continuous production the requirements to improve the accuracy of measurements of freight flow of bulk materials rise sharply.

One of methods of ensuring high accuracy and, respectively, stabilization of the real conversion function of the BW is the method of compound parameters based on the principle of "dual-channels" like methods of developing invariant systems in automatic equipment. The BW additional channel represents the second working channel through which non-informative parameters which are an integral part of the input bulk material flow impact the real conversation function to the side reverse to the action of the same non-informative parameters through the first channel aside.

Besides, the increase of accuracy of the bulk material weighing can be reached with increasing the weigh length of the belt that demands increasing the number of weighing rollers in the BW design by the use of several one-roller or multi-roller hoists.

By the number of hoists in the structure of weighers they are subdivided into single-channel BW with the use of only one hoist, dual-channel BW using two mechanically and electrically not connected with each other hoists and multi-channel BW with the number of separate hoists that is more than two.

Conveyor weighers can be integrated into various transport ways complicated technological process. In these circumstances, the question of BW calibration is of particular relevance.

In integrating BW both types of hoist permit to provide the demanded weighing accuracy in case of their direct calibration with the use of the weighed in advance bulk material sample. In the absence of such an opportunity one of indirect methods of calibration used often. This method uses reference weight which in the belt idling run is applied directly to the hoist by-passing the conveyor belt.

The simulated by the reference weight mass material is calculated in accordance with the following expression

$$Q_{SIM} = q_{SIM} V t_{SIM}$$

where $q_{SIM} = m_w / l_w$ is simulated linear density of the material, m_w is mass of reference weight, V is the conveyor belt speed, t_{SIM} is the time of the BW calibration carrying out.

For the hoist with angular movement in the calculation of the simulating linear density it is necessary to take into account the place of the reference weight setting in the hoist spatial design in view of its geometrical parameters and the conveyor elevation angle. This will require the definition of a so-called calibration coefficient k_{CAL} of the weight setting point. This coefficient will be the ratio of the two moments of the forces about the hinge support - the moment of the weight of the bulk material applied to the weighing rollers and the moment of the weight of the reference weight.

In case of equal weight of the bulk material and reference weight the calibration coefficient will be the ratio of the action shoulders of these forces about the hinge support. Therefore in general form the dependence for the simulated

linear density can be presented as $q_{SIM} = (k_{CAL} \cdot m_W) / l_W$ where $m_{EF} = k_{CAL} \cdot m_W$ is so-called "effective" mass of the reference weight.

In relation to the inclined conveyor there will be considered the kinematic diagram of a two-roller hoist with angular movement on which there are designated its main geometrical dimensions (Figure 5).

For this diagram the calibration coefficient of the setting point of the reference weigh is calculated according to the equation of moments of forces and can be provided by the following

$$k_{CAL} = \frac{l_1 + l_2' - a \cdot \operatorname{tg} \beta}{2l_1 + l_2' + l_2''}$$

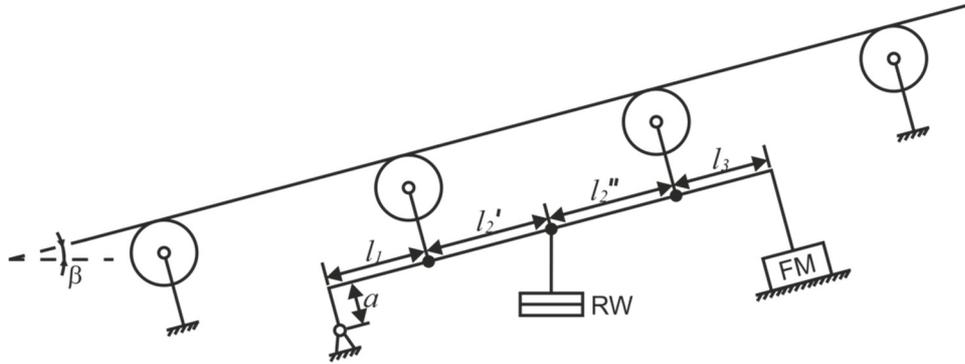


Figure 5. Kinematic configuration of two-roller hoist with angular movement

At this any change of the setting point of the reference weigh to the hoist will lead to changing the calibration coefficient and, accordingly, the "effective" mass of the reference weight.

If the setting point of the reference weigh and its hinge support are in one plane relative to the surface of the conveyor ($a=0$), the calibration coefficient k_{CAL} won't depend on the inclination angle of the conveyor any more and it can be written down

$$k_{CAL} = \frac{l_1 + l_2'}{2l_1 + l_2' + l_2''}$$

For hoists with plane-parallel movement the "effective" mass of the reference weight will be equal to its real value regardless of geometrical parameters of the weigh platform and the conveyor elevation angle, i.e. the calibration coefficient is accepted equal to $k_{CAL} = 1.0$.

Therefore, from the point of view of using this method of calibration with the use of reference weight the preference should be given to kinematic configurations with the use of hoists with plane-parallel movement as the real accuracy of determining the calibration coefficient on industrial conveyors can make (0.4÷0.5) % that leads to the emergence of an additional methodical error of calibration.

The overview of all the currently existing calibration methods of continuous conveyor-type weighers and comparative evaluation of their accuracy is presented in (Donis et al., 2003). The calibration method with the use of a reference weight which is successively loaded in turn to each of two mechanically and electrically independent hoists in the course of transporting the bulk material has the best indicators of accuracy.

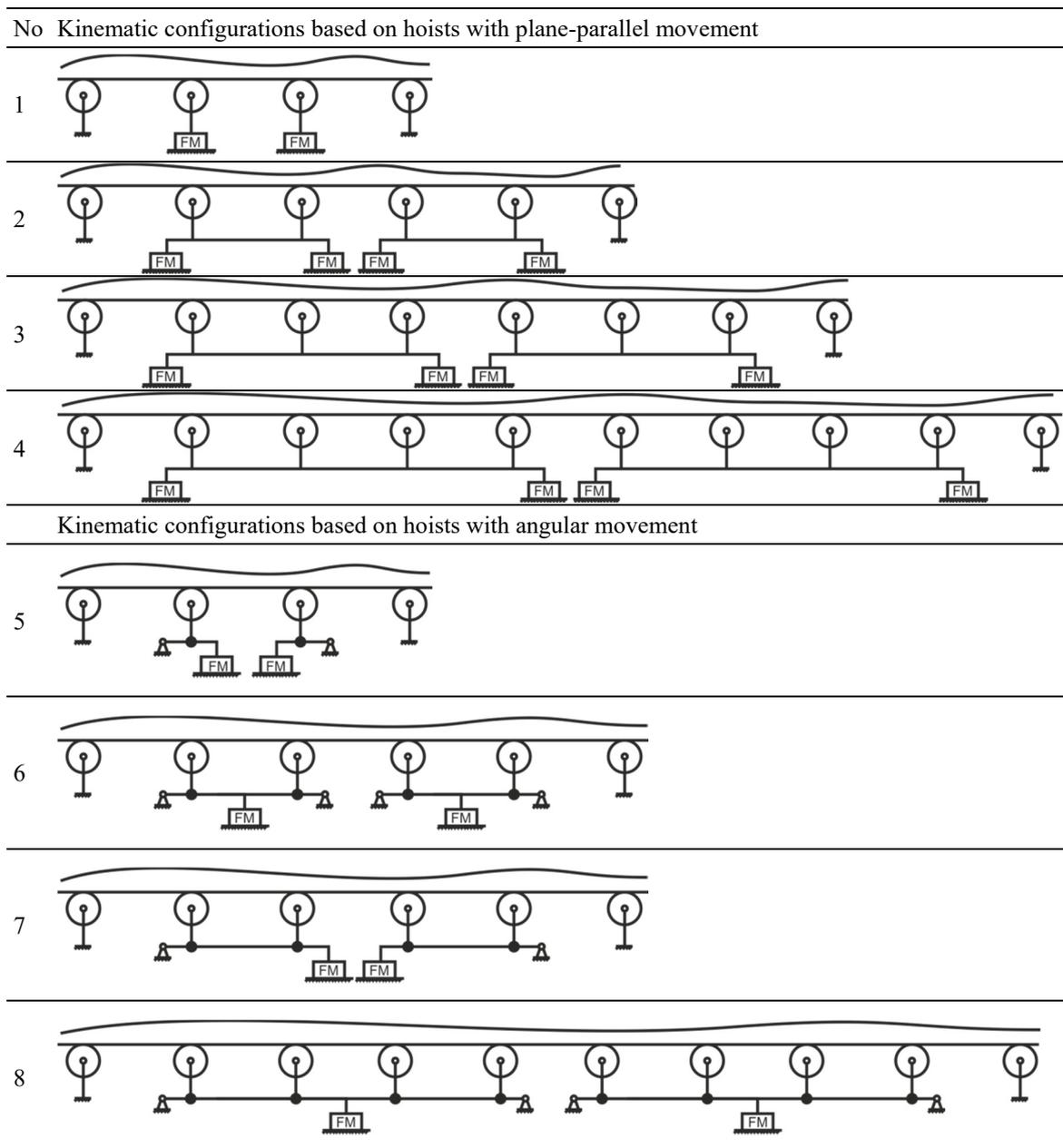
Thus in the basis of developing dual - and multichannel BW there are to be laid two principles:

1) implementation of the kinematic configuration that is invariant to the effects of most mayor non-informative parameters inherent in the process of weighing the bulk material on the conveyor belt;

This invariance should be provided on the entire range of changing the conveyor productivity that permits to provide stabilization of the real conversation function of the BW;

2) realization of the indirect method of calibration BW using reference weighs without stopping the technological process (Galín & Donis, 2014) that permits to provide the regulated weighing accuracy in the absence of opportunity to realize the direct calibration method with the use of the weighed bulk material.

Table 2. Kinematic configurations of dual-channel belt weighers

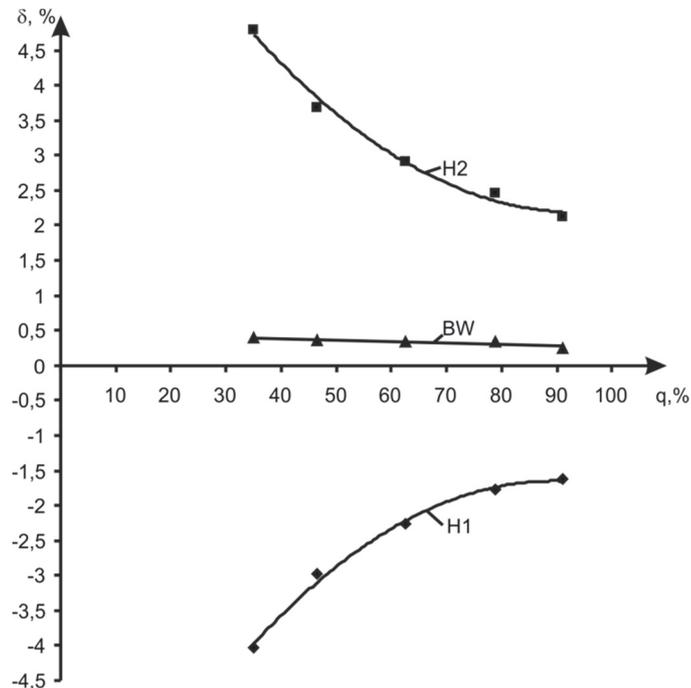


In the kinematic configurations presented in Table 1 there is only one channel of measurement of the bulk material mass, therefore they can be referred to single-channel hoists. Using these kinematic configurations of hoists with plane-parallel and angular movement, there can be proposed the versions of kinematic configurations of dual-channel BW presented in Table 2.

All kinematic configurations of dual-channel BWs will possess invariance to the effect of the majority of non-informative parameters as in their basis there is put the above-mentioned method of compound parameters. It is clearly demonstrated in Figure 6 where there is an example of metrological characteristics of two separate hoists with angular movement and dual-channel BWs as a whole (No.5, Table 2). Similar metrological characteristics demonstrated in Figure 6 inherent to other hoists with angular movement (No.7, Table 2).

Moreover this characteristics of separate hoists are nonlinear and differ from each other, and the resultant characteristic of a dual-channel BW already possesses invariance to the non-informative parameters impact in the entire range of changing the conveyor productivity.

From the position of achieving the high accuracy of weighing the identical metrological characteristics of measurement channels are one of the main conditions of realizing the indirect method of BW calibration using reference weighs without stopping the technological process at instability of the belt conveyor productivity and unevenness of the freight flow of the bulk material. Therefore in its realization for dual-channel BW with angular movement hoists there will be preferable kinematic configurations No. 6 and No. 8 where the metrological characteristics of both measurement channels will be identical.



H1 – first hoist; H2 – second hoist; BW – dual-channel belt weigher

Figure 6. Metrological characteristics of separate hoists and dual-channel belt weigher

In realization of the indirect method of calibration dual-channel BW there are preferable all kinematic configurations of hoists with plane-parallel movement (No. 1 to 4 of Table 2), owing to the identity of their metrological characteristics, at this each hoist can already provide stabilization of the real conversation function.

All of the above is equally true in developing the construction of multi-channel BW on the basis of hoists with plane-parallel and angular movement, in which kinematics configurations of individual hoists has the ability to stabilize the real conversation functions even with an odd number of measurement channels.

5. Conclusions

In the paper there is proposed classification of hoists kinematic configurations and carried out the comparative analysis for the purpose of justification of rational designs proceeding from the requirements to ensuring accuracy of weighing of the bulk material on the conveyor belt and the possibility of realization of the indirect calibration method of the BW in various service conditions of production.

BW hoists as the main unit of weight systems are incomplete mechanisms as practically in all of them the basic mobility in the horizontal plane is equal to zero. The belt weighers themselves are not autonomous measuring units and have inevitable mechanical communications with the belt and the design elements of the conveyor which limit hoists mobility and reduce BW sensitivity and accuracy. The impact of these communications, as well as present in the process of transporting bulk material non-informative parameters may be accounted only in the BW calibration by the weighed bulk material. In realization of indirect method of calibration with the use of mechanical simulators of the material linear density it is impossible to reproduce these non-informative parameters completely that does not permit to use them in production owing to the low accuracy of reproduction of the real freight flow of bulk material.

Therefore the BW designs shall include hoists which use permits to solve two problems: to minimize the non-informative parameters impact on the BW rated conversation function and to realize the indirect method of calibration by reference weights without stopping the technological process by means of developing dual - and multichannel belt weighers.

References

- Donis, V. K., Rachkovskii, A. E., & Gudovskaya, N. Y. (2003). Methods of Verifying Continuous Automatic Belt Weighers. *Measurement Techniques*, 46(9), 851–856.
- Galim, I. A., & Donis, V. K. (2014). Calibration of Continuous Conveyor-type Weighers Using Reference Weights without Stoppage of Production Process. *Measurement Techniques*, 57(8), 884–890. <http://dx.doi.org/10.1007/s11018-014-0554-5>
- Karpin, Y. B. (1971). *Automation Facilities for Mass Measuring and Dosing*. Moscow, M: Mashinostroenie.
- OIML, R. (1997). Continuous Totalizing Automatic Weighing Instruments (Belt Weighers). Part 1: Metrological and Technical Requirements, Tests. OIML R 50-1:1997.
- Radchik, A. S., & Pishchurnikov, I. A. (1969). *Selecting Rational Hoist Designs of Electronic Tensometric Weighing Systems*. Kiev, UkrNIINTI.
- Zemel'man, M. A. (1972). *Automatic Correction of Measurement Devices Errors*. Moscow, M: Standards Publishing House.
- Zemel'man, M. A. (1985). Classifying Measurement Errors. *Measurement Techniques*, 28(6), 471–475.

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