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Theoretical aspects of dynamic weighings

The paper discusses the theoretical aspects of the dynamic weighing by the conveyor scales. In the framework of the statistical equilibrium thermodynamics we obtain a formula that relates the parameters of the measuring system, the characteristics of the cargo and movement of the conveyor. Conditions are obtained for optimization of dynamic weighing. Considered the problem of weighing the particulate material. It is shown that the error in measuring the weight of the material proportional to the square of its porosity. The problems of thermodynamic constraints on the process of dynamic weighing are considered. It is shown that the energy cost information can not be arbitrarily small, even for arbitrarily large time (or bandwidth). The principal possibility of excluding the majority of the factors affecting the accuracy of the information-measuring systems for weighing on conveyors is shown.

Key words: thermodynamics, dynamic weighing, measuring system, scales, the conveyor, porosity, entropy, accuracy of measurement

Introduction

Currently in development, research and application of systems of measuring the weight of the material and its dosing has been a lot of design, engineering and industrial organizations [1, 2]. However, the necessary theory and techniques of engineering calculations are not well developed, and the fragmentation of information makes it difficult to choose the best solutions.

Static weighing of materials has reached a considerable accuracy and hardware implementation, while the dynamic weighing is still far from perfect. The reason for the latter is the large number of factors that affect in varying degrees, the measurement value of the dynamic weighing. Dynamic weighing is most often used when moving material on the conveyors. At present time scales of various modifications, such as overhead, LTM, etc. These scales are designed for continuous weighing of bulk materials transported by stationary conveyor belts. These meters have a number of significant weight disadvantages of a mechanical lever-weight systems. They are sensitive to shock and overload, pollution prisms, pillows, racks, gears and other components that are used to measure movement of the lever and the transmission systems to the transmitter. This also applies to the balance -spring measuring unit. If the weight of such systems being used under the weight portion of the weighing belt pulley, then turn it affects the accuracy of dosing.

Should be considered more sophisticated weight gauges that have weighing platform or roller bearing is fixedly mounted, and the weight is perceived tough weight sensor. Integral strain gauge weighing conveyor with continuous electronic strain-gauge produce at present in many countries of the world.

In this paper, we examine some of the fundamental aspects of dynamic weighing.

Thermodynamic aspects of dynamic weighing

The theory of measurements, as well as any physical theory, consists of two parts supplementing each other: principles of measurements of physical sizes; the laws connecting results with a condition of object and laws of change of a condition of object in the course of measurement [3–6].

Any measurement assumes interaction of investigated system with other physical system named the measuring device. Result of measurement, namely, result of interaction of the device with object of research is the information on properties of object.

Everyone (artificial or natural) system of co-operating objects can be considered as information system. Any part of set of co-operating objects (in particular, and one of objects) can be studied for the purpose of extraction of the information on other part of this set (in particular, about other separate object) as interaction provides conformity of conditions, i.e. reflexion, the information maintenance.

Any measurement — is irreversible, i.e. loss of a part of the information takes place. A measure of a missing part of the information is entropy.

Let's consider the conveyor with cargo in weight m on unit of its length, moving with a speed *v*, and with the strain gauge as the measuring device. The strain gauge we will consider as a subsystem of noninteracting particles or a subsystem of the elementary raised conditions (ERC), connected to the thermostat (conveyor) at temperature T.If the subsystem with the thermostat exchanges only energy the ensemble of particles corresponding to it will be initial. The quantum transitions caused by interaction ERC with the thermostat, will be dissipative (with probability *P*) unlike interaction with an external field (with probability *F*). Dissipative processes lead to that a secondary field (the system response) always less primary, causing occurrence ERC (i.e. a signal).

For function of the response of the device in the course of its interaction with object we receive the formula [7] which, in is considered a case, looks like:

$$\eta = \frac{k^2 T}{2\Delta S} \cdot \frac{\tau}{\tau_p} \cdot \frac{E}{G^0} \cdot N, \tag{1}$$

where ΔS — entropy change in dissipative process (in the course of measurement); τ — relaxation time (time of operation of the device); τ_p — time of interaction of the conveyor with the device; E — full energy of the thermostat (the conveyor with cargo); G^0 — Gibb's energy of the thermostat; N — number ERC; T — temperature; k — Bolzman's constant. Size $k^2N/\tau_p = \text{const}$.

Change of entropy of object in inverse proportion to quantity ΔI information on it [8], i.e.:

$$\Delta S = \frac{k \ln 2}{\Delta I}, \tag{2}$$

where $k\ln 2$ — a power equivalent of the information.

Then for response function we will receive expression:

$$\eta = C \cdot \frac{\tau T E}{G^0} \cdot \Delta I, \tag{3}$$

where $C = \text{const}$. Limiting value $\eta = 1$ and for this case it is had:

$$\Delta I = C_1 \cdot \frac{G^0}{\tau T (mv^2 / 2 + mgh)}, \tag{4}$$

where $C_1 = 1/C$, and E it is equal to the sum of kinetic and potential energy of the conveyor.

The quantity of the information ΔI is proportional to size of a signal from the strain gauge. Thus, indications of the measuring device depend on properties of cargo through G^0, its temperatures and from parametres of movement of a conveyor tape in its speed v.

The Gibb's energy G^0 defines heterogeneity of environment, i.e. cargo, and in the elementary case is given by expression [9]:

$$\mathrm{G}^0 = X_1 G_1^0 + X_2 G_2^0 + \ldots = \sum_{i=1}^{n} X_i G_i^0, \tag{5}$$

where X_i — quantity i — that cargo components.

In case of change of structure of cargo on the conveyor, for example at the ore transportation, the arriving information will change proportionally ΔG^0. At the big speed of movement of the conveyor the information size will decrease according to (4) and can lead to the big size of an error of measurement. In the same result results also big time of operation of the gauge and measuring system as a whole.

Parity performance will be a condition of optimum weighing on conveyor scales:

$$\Delta G^0 / \tau \upsilon m T \to \max. \tag{6}$$

As shown us in work [10], size G^0 is proportional to channel capacity of information-measuring system or a memory size of used processor *W*. Expression will be definitive a condition of optimisation of process of dynamic weighing on conveyor scales:

$$W / \tau \upsilon m T \to \max. \tag{7}$$

Porosity and consolidation of particles of cargo

Porosity of a material of cargo on the conveyor leads to an error in weight definition. We will result some characteristics of porous materials necessary for us at the further theoretical analysis of dynamic weighing. The detailed statement of the mentioned questions can be found in works [11–13]. In the same place the extensive bibliography is given.

Porosity *P* of a layer or briquette is equal shares from the general space, expressed in percentage which is not occupied by a granular material. Volume (or seeming) the density is equal to weight of particles in unit of volume of a layer. The seeming volume V_a is equal to the volume of a layer occupied in individual true volume of particles. The consolidation factor is equal parts (share) of full volume of the layer, $V_в$ occupied with a granular material V_p, i.e. is equal to the relation $V_p / V_в$. The porosity factor (or relative porosity) is equal $1 - V_p / V_в$.

Theoretically, in a layer consisting of one-dimensional spherical particles, the average size of a time will be equal to the size of the empty space formed at a single-layered chess arrangement of three spheres. Porous radius:

$$r = 0{,}154R\,, \tag{8}$$

where r — porous radius; R — particle radius.

Theoretical consolidation (packing) of spherical particles can be established proceeding from the same geometrical reasons which are used for definition of packing of ions in a crystal lattice. Data for five kinds of packing of one-dimensional spherical particles are resulted in table. It is necessary to mention, that irrespective of a packing kind, total porosity does not depend on diameter of particles. From table it is visible, that at spherical one-dimensional particles porosity and coordination number are closely interconnected.

Table

Regular packing of one-dimensional spherical particles

Packing kind	Volume of porous	Coordination number
Cubic	47,64	6
Single chess	39,55	8
Double chess	30,16	10
Pyramidal	25,95	12
Tetraedrical	25,95	12

As follows from the table, this interrelation really exists only at the ordered packing. There is a possibility of achievement of some intermediate value of porosity between any two nearest kinds of packing by a correct arrangement of particles without change of coordination number. For example, when the coordination number is equal six (as in case of the ordered cubic packing), can vary porosity of a layer from 47,6 to 39,5 %. Thus, correlation between coordination number and porosity appears not so rigid as it is usually considered to be.

Packing (consolidation) of one-dimensional spherical particles does not allow to receive absolutely nonporous a layer, the minimum porosity in such system, caused by packing, there can be not more low approximately 26 %. Cargo on the conveyor can have distribution on the sizes of particles and a time in enough wide area. However in technological processes aspire to make a cargo stream more homogeneous, applying crushing, then a sieve and other adaptations. Special value in the sizes has distribution of particles at dispensing of granular materials [14].

Here we will consider model of consolidation of particles of cargo, partially using the approach stated by us in work [15].

Let's consider the sample with number of particles m. Let distance between particles equally and equally R. We will describe round each particle 0 sphere in radius R. Let the density of number of particles is equal in this sphere n_0 then (r) that the nearest particle is on distance r from a particle 0, it is easy to receive probability W_0 from the classical statistical physics and it is equal:

$$W_0(r) = 4\pi n_0 r^3 \exp[-4\pi n_0 r^3 / 3]. \tag{9}$$

The probability of finding N_0 of particles r is equal in a zone of a particle in 0 radius, obviously,

$$W_{N_0}(r) = \prod_{k=1}^{N_0} W_k(r) = (4\pi n_0)^{N_0} r^{3N_0} \exp[-4\pi N_0 n_0 r^3 / 3]. \tag{10}$$

Probability (10) we will define on the other hand as the relation of number of particles N_0 in a zone of a particle 0 to the general number of particles in the allocated sphere — $Q_0 = 4/3\ \pi n_0 R^3$:

$$p_0 = \frac{N_0}{Q_0} = (4\pi n_0)^{N_0} r^{3N_0} \exp[-4\pi n_0 r^3 / 3]. \tag{11}$$

For system from m particles it is had:

$$p_0=(4\pi n_0)^{N_0}r^{3N_0}\exp[-4\pi N_0 n_0 r^3/3]=\frac{N_0}{Q_0},$$
$$p_1=(4\pi n_1)^{N_1}r^{3N_1}\exp[-4\pi N_1 n_1 r^3/3]=\frac{N_1}{Q_1},\qquad(12)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$p_m=(4\pi n_m)^{N_m}r^{3N_m}\exp[-4\pi N_m n_m r^3/3]=\frac{N_m}{Q_m}.$$

For all sample with number of particles 0, 1, 2, …, m it is had:

$$P=\prod_{i=0}^{m}p_i=\prod_{i=0}^{m}(4\pi n_i)^{N_i}r^{3N_i}\exp[-4\pi N_i n_i r^3/3]=\frac{\prod_{i=0}^{m}N_i}{\prod_{i=0}^{m}Q_i}.\qquad(13)$$

System the equations (12) and (13) represents system of the transcendental equations, to solve which it is possible only the approached or numerical methods.

In this connection, it is possible to make a numerical estimation, being based on a real situation and the equation of 1 system (12):

$$\ln N_0-\ln Q_0=N_0\ln(4\pi n_0)+2N_0\ln r-\frac{4\pi}{3}N_0 n_0 r^3.$$

The corresponding estimation gives, that the first member of the left part of the equation and first two members of the right part — are very small. As a result we will receive:

$$N_0=\frac{3\ln Q_0}{4\pi n_0 r^3}.\qquad(14)$$

Considering, that $4\pi r^3/3=V$ and $\ln n_0>\ln R$, from (13) is had:

$$V_0=\frac{\ln n_0}{n_0 N_0}.\qquad(15)$$

Taking as function of the response volume of the sample, it is similar (1), we will receive:

$$V_0=c\frac{kT}{G^0}\cdot N_0.\qquad(16)$$

Comparing (15) and (16), we will receive:

$$N_0=\left(\frac{1}{c}\cdot\frac{\ln n_0}{n_0}\cdot\frac{G^0}{kT}\right)^{1/2}.\qquad(17)$$

The formula (17) answers equilibrium value of number of particles in the sample. If to consider molar substance shares the factor of consolidation of substance of cargo will be defined as relation N_0 to number of particles in one pier, i.e. to Avogadro's number — K_p — N_0/N_A.

The more there will be a deviation of size K_p from unit, the there will be a measurement error more. Considering formulas (6), (7) and (17), for an error of measurement of the weight connected with porosity of a material of cargo we will have following expression:

$$\Delta_p\approx\beta(1-K_p)^2=\beta P^2.\qquad(18)$$

where β — some constant; P — porosity of a material.

The equation (18) shows square-law dependence of an error of measurement of weight on porosity of a material. It is stronger dependence, than it follows from usual theories.

Thermodynamic restrictions of accuracy of dynamic weighing

At each stage of elementary information interaction growth of entropy of the thermostat ΔS lays within [8]:

$$1/\Delta^2\geq\Delta S\geq\Delta S_{\min}=2/\Delta.\qquad(19)$$

The left border corresponds to extremely irreversible realisation of transient, and right — to its optimum delay. The following is necessary to rebuke. Really, as it follows from (7), transient delay (i.e. at increase τ), a measurement error decreases. However in practice such way is unacceptable and, on the contrary, modern and future information-measuring systems should possess the big speed for transfer of the big file of the information.

On the other hand, effect of negentropy (effect of ordering in system, $\Delta K = -\Delta S$), according to [8]:

$$\Delta K \approx \ln\left(1/\Delta\right) \approx \ln\sqrt{U/T} \approx \Delta I, \tag{20}$$

where ΔI — the quantity of the information received in the course of measurement.

Thus, efficiency of entropy of information-measuring process

$$\eta \le \eta_{\max} = \frac{1}{2}\frac{\Delta K}{\Delta S_{\min}} = \frac{\Delta}{4}\ln\frac{1}{\Delta} << 1,\ \ \Delta << 1. \tag{21}$$

Let's notice, that the effect of negentropy in information-measuring system is by all means connected with managerial process. In the course of measurement the effect of negentropy appears only when the result of measurement is presented in the form of scalar physical size. Only such measurement, which result it is presented in the form of scalar physical size, can be used as a managerial process stage.

Processes of transfer, storage and information processing are not connected directly with effect of negentropy, and only with carrying over of the information from one place in another, duplication and its transformation.

Therefore at these stages it is possible to achieve considerable economy of energy if to refuse from scalar and to pass to item representation of numbers (only at last stage of management it is necessary to return again to scalar representation of the operating parametre).

Let's underline, that all known ways of reduction of the power price of accuracy of representation of numbers are by all means connected with time increase (see the formula (7)). Time increase, however, reduces power expenses only to certain limits. Though these limits are various for different information processes, but are always final. The power price of the information cannot be as much as small even at as much as big resources of time (a strip of frequencies).

At measurement transition from dependence $\Delta S \sim 1/\Delta^2$ to $\Delta S \sim 1/\Delta$ is connected with optimum (in $1/\Delta$ time) transient delay.

At unequivocal transformation of scalar size in vector each component of last demands essentially smaller accuracy of representation — in a limit it can appear sufficient to distinguish only its two conditions: presence or absence of a signal. Though with increase in quantity of components (dimension of vector space) requirements to reliability 1/raise w (i.e. probabilities w of transition of a signal in any of components in other interval of digitization), the power price of accuracy of representation of all number decreases.

At the expense of refusal of scalar representation and transition to vector it is possible to receive dependences [8]: $\Delta S \sim \left[\ln\left(1/\Delta\right)\right]^2$ at a digit way of coding when time $\Delta\tau$ or a strip of frequencies increases in $\ln\left(1/\Delta\right)$ time; $\Delta S \sim \ln\left(1/\Delta\right)$ — at one-item coding, when $\Delta\tau \sim 1/\Delta$.

Asymptotic the best (in sense of product $\Delta S \Delta\tau$) is superfluous coding on Shannon, using digit representation with additional (verifying) categories: here the increase in dimension of vector space allows to find out and correct errors of some frequency rate, that lowers requirements to probability p of distortion (and to the relation a signal/noise) in one category. It is thus reached $\Delta S \sim \ln\left(1/\Delta\right)$ with simultaneous growth of time only in $\ln\left(1/\Delta\right)$ time.

The conclusion

The majority of domestic and foreign conveyor scales, at all class of accuracy of a data-acquisition equipment do not provide the declared accuracy of weighing. It is caused, basically, impossibility of the account of some factors, such as, for example, geometry and speed of the conveyor, humidity and dispersion of a material of cargo, quality of a tape, variable force of a friction of rollers in support and their palpation, and variety of others.

In present article by us basic possibility of the account of the majority of the factors influencing accuracy of information-measuring system for weighing on conveyors is shown.

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Үдемелі өлшеудің теориялық жақтары

Мақалада конвейерлік таразыда динамикалық өлшеудің термодинамикалық жақтары қарастырылған. Авторлар ойлап тапқан салмақ өлшеу кешенінің құрылымын сипатталған. Тепе-теңдіксіз статистикалық термодинамика шеңберінде өлшенетін дабыл шамасы мен өлшенетін жүктің күйі, конвейердің қозғалу параметрлері және өлшеу жүйесінің тез әрекет ету қабілеті арасында байланысы анықталған. Конвейердің сусымалы материалдарды салмақтау ақпараттық-өлшеу жүйесінің құрамына енетін әмбебап хабар таратушысының жұмыс алгоритмі мен блок-сұлбасы келтірілген. Конвейерлік таразының құрамына енетін аналогтық-цифрлық түрлендіргіштің тұжырымдамасы жасалған.

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Теоретические аспекты динамического взвешивания

В работе рассмотрены теоретические аспекты процесса динамического взвешивания на конвейерных весах. В рамках статистической неравновесной термодинамики получена формула, связывающая параметры измерительной системы, характеристики груза и движения конвейера. Определены условия оптимизации процесса динамического взвешивания. Рассмотрена задача о взвешивании дисперсного материала. Показано, что погрешность измерения веса материала пропорциональна квадрату его пористости. Рассмотрены вопросы термодинамических ограничений на процесс динамического взвешивания. Показано, что энергетическая цена информации не может быть сколь угодно малой даже при сколь угодно больших ресурсах времени (полосы частот). Показана принципиальная возможность учета большинства факторов, влияющих на точность информационно-измерительной системы для взвешивании на конвейерах.

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