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WEIGHING AND DOSING SYSTEMS FOR MINING AND METALLURGY

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ВАГОВИМІРЮВАЛЬНІ Й ДОЗУЮЧІ КОМПЛЕКСИ ДЛЯ ГІРНИЧОЇ ПРОМИСЛОВОСТІ ТА МЕТАЛУРГІЇ

Purpose. Development of models, algorithms, and conveyor scales of new generation by modern design and element base, ensuring accuracy class (1–0.5), using modern methods of information processing and analysis, as well as development of weighing systems for conveyors having a short length and operating under high dynamic loads and shocks.

Methodology. Methods of thermodynamics and analogies for design, analysis parameters and functioning of measuring systems are used. New software of microprocessor controls and top-level ability to instantly analyze the state of the object and to control actuators of dosing devices timely and accurately has been developed.

Findings. The model and algorithm of dynamic weighing by conveyor scales have been proposed connecting the measuring device with parameters of material to be weighed and the environment. A new generation of conveyor scales by modern design and element base are created.

Originality. First, models and algorithms of measuring systems using the method of analogy and nonequilibrium thermodynamics have been developed. On the basis of these models the cost-effectiveness and feasibility of their design, heredity, life cycle, vitality and resources are evaluated.

Practical value. To improve the efficiency of transportation of ore, coal and other bulk material conveyor scales of a new generation were created using modern design and element base. New models of information-measuring systems, dynamic weighing and conveyor scales are proposed. The first generation of automated electro tensoresistive conveyor scales complex is used at enterprises of Kazakhstan: Iron and Steel Works JSC "Mittal Steel Temirtau", JSC "Kazchrome" Donskoy, Aktobe Ferroalloy Plant, Aksu Ferroalloy Plant, Mining Group Kazmarganetc, Sokolov-Sarbay Mining and Processing Production Association (SSGPO), Eurasian Energy Corporation (EEC), etc.

Keywords: *model, algorithm, software, thermodynamics, the method of analogy, conveyor, dynamic weighing, microprocessor module*

Introduction. Continuity of technological processes in mining and metallurgy creates a very favorable environment for integrated automation. The main prerequisites for fully automated sites, workshops are to increase the level of mechanization in the areas, the use of remote control mechanisms, and a high level of equipping units with control instrumentation.

Automation of management control is one way to improve the performance of units and improve product quality. In its turn, the automation affects the process of technology, the development of a more complete mechanization, and improved equipment.

In practice of the global engineering, producing information and measuring systems (IMS) involves constant tightening of requirements for the quality of the final product, increase in speed, accuracy and other factors that ultimately determine the economy of relevant industries.

Currently, a lot of design, engineering and industrial organizations deal with development, research and implementation of systems for measuring the weight of the material and its dosing. However, the necessary theory and methods of engineering calculations are not well developed, and the fragmentation of information makes it difficult to choose optimum decisions.

Thus, the development of theoretical models of dynamic weighing, conveyor scales, development of models, algorithms, and conveyor scales of a new generation of modern design and element base is an urgent problem for the mining and metallurgical industry.

Analysis of the recent research and publications. In recent years, mining companies and steel mills are increasingly using conveyor transport for transportation of bulk raw materials and fuel [1, 2].

Stationary weighing of materials has achieved significant accuracy and hardware implementation, whereas the dynamic weighing on conveyors is still far from being perfect. The reason for the latter is a large number of factors affecting the results of measurements of dynamic weighing to a greater or lesser extent.

Conveyor scales are designed and produced by virtually all industrialized countries. One of the world leaders in the development of conveyor scales is considered to be "Control systems technology" company (Australia). Large amount of work in the field of continuous conveyor weighing of bulk materials has been done by "Thermo Scientific" company. The list of such companies can be continued.

In recent years the thermodynamics methods for the analysis of complex systems in various fields of science and technology, economics, etc., have attracted the interest of researchers [3–5], because thermodynamics is the most common of physical theories.

Unlike works [4, 5], in [6] we used methods of nonequilibrium thermodynamics to analyze information-measuring systems (IMS).

Objectives. The purpose of this work is to review the developed models, algorithms, industrial prototypes weighing and dosing systems for the mining industry and metallurgy of ferrous and non-ferrous metals.

Presentation of the main research. Thermodynamics, the method of analogy and the main characteristics of IMS.

Block diagram of any IMS can be represented as shown in Fig. 1.

Sensors (S) perceive various parameters of the object of measurement; unifying converters (UC) unify and transmit sensor signals through communication channels into a single point of data collection. Software device (SD) perceives sensor information and transmits it to the receiver of information. According to this block diagram almost all MISs are constructed, including the modern information transmission system with satellites and automatic interplanetary stations.

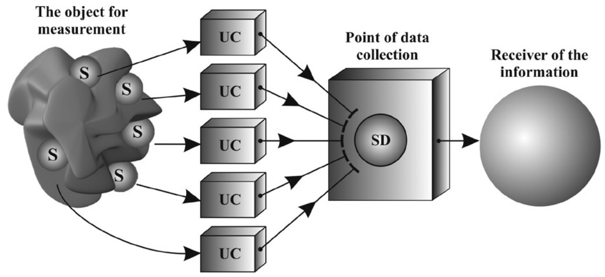

Fig. 1. Block diagram of information and measuring system:

S – sensors; UC – unifying converters; SD – software device

There are simple and universal laws of functioning and development of the physical world that are applicable to virtually all objects. Identifying these simple laws, lying at the base of the entire world order, will allow creating a method for actual implementation of the integration of science. Currently, this method is a method of analogies [6], the pioneer of which should be regarded George Maxwell, who contrasted the classical theory of electromagnetism hydrodynamics of incompressible fluids developed by him and stressed the importance of such an approach in science. Table 1 shows an example of the method of analogies.

Let us consider some examples of the use of Table. The most important parameter of IMS (as well as for any system) is its efficiency η. In thermodynamics, efficiency corresponds to the efficiency of the heat engine

$$\text{efficiency} = 1 - T_h/T_r, \quad (1)$$

Table 1

Analogy between thermodynamic, IMS and microeconomic systems [6]

Thermodynamics	IMS	Microeconomics
Free energy, Work, A	The memory capacity, W	Base resource, M
Quantity of substance, m	The number of sensors (channels), n	Stock of resources, N
Entropy, S	The quantity of information, I	Related capital, F
Temperature, $T(t)$	The accuracy of IMS, Δ	Coast, $c(t)$
Entropy of production, σ	Production of information, σ	Dissipation of capital, σ
Efficiency, eff	Efficiency of IMS, η	Profitability of the system, P
The internal energy, U	The energy intensity of IMS, E	Full capital $U = M + F$

where T_h and T_r are temperatures of the heater and refrigerator, respectively.

For the IMS, equation (1) would look like

$$\eta = 1 - \Delta_{out}/\Delta_{in}, \tag{2}$$

where, according to Table 1 Δ_{out} and Δ_{in} are input and output power of IMS, respectively.

The first is determined by the sensitivity of the sensor, and the second is determined by the sensitivity of the sensor parameters and unifying converters (Fig. 1). Equation (2) shows that efficiency of IMS largely depends on the structure and parameters of the US and SD (Fig. 1).

If we take the efficiency of IMS η as the response function F from [6], we obtain

$$\eta = \frac{kT}{C} \cdot \frac{A}{G^0} \cdot m, \tag{3}$$

where A is work (energy); T is the temperature; G^0 is Gibbs potential; m is the number of substances; k is Boltzmann constant; C is constant.

Using Table 1, we obtain

$$\eta = C_1 \frac{nW\Delta}{W - I\Delta}. \tag{4}$$

Here C_1 = const. Limit value $\eta = 1$, and from (4)

$$W = \frac{I \cdot \Delta}{1 - C_1 n\Delta}. \tag{5}$$

Equation (5) defines a rule for choosing the processor in the design of IMS. From this it follows that the memory of the processor is determined primarily by the product of the amount of information coming from the object, and the accuracy of MIS. The latter, as a rule, is inversely proportional to the signal/noise ratio and tends to the optimal value while reducing the level of noise. It should be noted that the right choice of the processor determines largely the cost of the developed IMS.

Economic indicators of designing and manufacturing MIS play as important a role as their technical and information specifications, providing a competitive IMS both in the domestic and foreign markets.

According to the (3) and Table 1, we will have the following expression for the cost-effectiveness of the design and manufacture of IMS

$$\eta = C_1 \frac{N \cdot M \cdot c(t)}{M - Fc(t)}. \tag{6}$$

Equation (6) shows that the design efficiency of IMS is mainly determined by the basic resource M and its stock N, and its price $c(t)$. With a maximum efficiency of $\eta = 1$ the value of the price of designing and manufacturing IMS will be determined by the relation

$$c(t) = \beta \frac{M}{F + C_1 NM}. \tag{7}$$

Here β is the coefficient of dimension. Related capital F is defined as all of the money invested by investors in the production of the products they are going to sell.

Innate ability of IMS. In [6] the following equation is obtained for the effectiveness of IMS

$$E = \varepsilon \ln W, \tag{8}$$

where ε is a parameter model; W describes the resources of IMS, which is proportional to the amount of IIS memory, the sensitivity of the sensors and a number of other parameters. At the initial education system $W = \varepsilon$, so

$$E_\varepsilon = \varepsilon \ln \varepsilon. \tag{9}$$

The resulting expression is the innate ability of IMS. Referring to the expression (8), let us make a few remarks. If the innate ability of IMS ($\sim\varepsilon$) is small, the increase in W resources due to IMS modernization slightly alters its effectiveness. This is due to the logarithmic dependence of E on W. For example, increasing the resources of IMS by 100 times leads to changes in E approximately by 5 times. Such IMS must be either substantially reconstructed or liquidated. The resulting equation allows determining the innate ability of IMS experimentally. When the ratio of the output/input is taken as the efficiency of IMS, it is possible to determine the $E1$, $E2$,... according to the set $W1$, $W2$,... and thus, to determine the innate ability of IMS. Thus, it is possible to analyze the IMS in terms of their technical performance and economic prospects.

Moore's Law. IMS efficiency is defined as the ratio of its development time t to the period of its existence – T, then, from (8) we obtain the time dependence of W

$$W = W_0 \exp\left(\frac{t}{\varepsilon T}\right), \tag{10}$$

where $W_0 = \varepsilon \ln \varepsilon$.

Equation (10) is a mathematical expression of the law of Gordon Moore, who was later one of the founders of the corporation Intel, who drew attention to an interesting pattern in the development of computers. He noticed that the amount of computer memory doubles approximately every two years. This pattern became a kind of rule of thumb in the computer industry, and soon it turned out that not only memory, but each performance indicator of a computer – the size of chips, processor speed, etc. – follow this rule.

In 2007, Moore stated that the law, obviously, would soon cease to operate because of the atomic nature of the matter and the speed limit of light. The limitations of Moore's Law naturally follow from relation (10). At $t = T$ exponential dependence becomes W = const.

Life cycle and vitality of IMS. The concept of life cycle is one of the basic concepts of design methodology for IMS [8]. The life cycle of IMS is a continuous process, starting with the decision on the development of IMS and ending with the full withdrawal of its operation. At $t = T$ (10), the system ceases to evolve. Time T is its lifecycle IMS, the limit value is equal to

$$W_T = \varepsilon \ln \varepsilon \exp(1/\varepsilon), \tag{11}$$

i.e. is completely determined by the innate ability of IMS.

Now we make the following remark. Each structural element of the IMS, shown in Fig. 1, has the innate ability and life cycle. In this case, the entire life cycle of IMS will be determined by the smallest value of T structural element of IMS. Experimentally, the life cycle of IMS is possible to be determined regarding the time of failure of one or another of its structural elements, using a large arsenal of available methods for determining the reliability of electronic systems.

Thermodynamic aspects of dynamic weighing of heterogeneous environment. Every measurement is irreversible, i.e. there is a loss of information. Entropy is a measure of the missing piece of information. Let us consider the conveyor with a load of mass m per length unit, moving with the velocity υ, and with the load cell as a measuring device. For the response function of the device during its interaction with the object in [6], we obtain a formula

$$\eta = \frac{k^2 T}{2\Delta S} \cdot \frac{\tau}{\tau_d} \cdot \frac{E}{G^0} \cdot N, \tag{12}$$

where ΔS is a change in entropy in dissipative processes (process measurement); τ is relaxation time (response time of the device); τ_p is time of interaction with the conveyor device; E is the total energy of the thermostat (conveyor with a load); G^0 is Gibbs energy of the thermostat; N is the number of links; T is the temperature; k is Boltzmann constant. The value $k^2 N/\tau_d = const$.

The change in entropy of the object is inversely proportional to the number of ΔI information about it, i.e.

$$\Delta S = \frac{k \ln 2}{\Delta I}, \tag{13}$$

where $k \ln 2$ is the energy equivalent of information.

Then we obtain the expression for the response function

$$\eta = C \cdot \frac{\tau T E}{G^0} \cdot \Delta I, \tag{14}$$

where $C = const$.

Limit value $h = 1$ and in this case we have

$$\Delta I = C_1 \cdot \frac{G^0}{\tau T (m\upsilon^2/2 + mgh)}, \tag{15}$$

where $C1 = 1/C$, and E is the sum of kinetic and potential energy of the conveyor.

The amount of information ΔI is proportional to the signal from the load cell. Thus, the meter readings are dependent on properties of the cargo through G^0, its temperature and the parameters of movement of the conveyor belt across its speed υ. Gibbs energy G^0 defines a heterogeneous environment, i.e. cargo. In case of change of the load on the line, for example when transporting the ore, the information received will vary in proportion ΔG^0. The rate of movement of the conveyor being high, the quantity of information decreases in accordance with formula (15) and can lead to a large magnitude of a measurement error.

The same result can be obtained due to a large response time of the sensor and the measuring system as a whole. Optimality weighing conditions on conveyor scales will involve performing the following relations

$$\Delta G^0/\tau\upsilon m T \to \max. \tag{16}$$

The value is proportional to the channel capacity G^0 of IMS or the amount of memory used by the processor W. The final terms of process optimization of dynamic weighing on conveyor scales will be expression

$$W/\tau\upsilon m T \to \max. \tag{17}$$

The two-channel electric tensoresistance weight complex WET – 7678. This complex was designed by one of the authors of [9], together with a team of “Kazchermetavtomatika” ltd. WET-7678 complex is a working tool to measure technical and commercial systems, including the mass of bulk materials transported by belt conveyors. Metrological characteristics of the weights correspond to the requirements of GOST 30124-94 at their operation on horizontal and inclined conveyors in a wide range of linear density of the transported material. Graduations and calibration weights can be done both with a weighted material according to GOST 8.005-82 and an indirect method using a static load.

WET-7678 scales are designed to work in the flax-precision conveyor having the following characteristics:

- strap width, mm – 300, 400, 500, 650, 800, 1000, 1200, 1400. 1600, 2000;
- conveyor belt speed, m/s up to 3;
- productivity t/h to 4000;
- angle of inclination of the conveyor belt, dg 20;
- the largest range of linear density of material, kg/m from 9 to 500.

WET-7678 scales provide:

a) the integration of performance over time with the registration of the progressive total in discrete form;

b) the zero setting balance when the conveyor is idle;

c) the issuance of the standard signal (4–20 mA) proportional to the instantaneous performance, for use in automatic control systems and visual inspection performance of conveyor;

d) the issuance of a signal in the form of “dry” relay contacts to the control conveyor lines:

- while reducing the performance of the conveyor below a certain value or complete cessation of receipt on the conveyor;
- at or above the conveyor maximum performance of values for it.

The lowest limit of weighing constitutes 0.1 of the bulk material, weighed on the scales for 1 hour at the highest linear density (GOST 30124-94).

The smallest linear density of material to be weighed in the balance makes 20 % of the maximum linear density (GOST 30124-94).

WET-7678 electronic strain gauge conveyor balance has accuracy class 2.0, corresponding to GOST 30124-94 in the range (20–100) % of the maximum linear density.

Scheme of scales WT-7678 is built on the principle of "dual-channel", implemented using a quasi-invariant device for measuring the performance of the conveyor. Two half-sets of the weighbridge (two weighing platforms) are two transducers, whose transmitters on the efforts receive informative phase signal corresponding to the measured useful linear load (linear density) and uninformative differential signal corresponding to perturbations. The summation of the output signals provides full compensation or minimizes the impact of disturbances. "Dual" principle of performance measurement at the same time allows for an indirect way of calibration and verification of balances in the form of static load calibrated goods, applied directly to the device receiving the goods.

Dual output device receiving the cargo weights consists of two identical one-roller load receiving devices RD1 and RD2 imposed on a counter circuit and embedded into the pipeline instead of two adjacent idlers staff.

The diagram of the device is shown in Fig. 2.

Opposed location of load receptors eliminates weighing errors due to changes in the level of the forces of resistance of the belt and load in relation to elastic joints that occur on horizontal and inclined conveyors when changing their productivity and minimizes errors due to the dynamics of the material.

The advantages and design features of the mechanical part of the WET-7678 conveyor scales should also be noted compared with known commercially available products:

- the lack of thrust bearings, roller bearings and prisms;

- easy and accurate installation by installing two load-bearing devices which are not connected mechanically on the frame of the conveyor;

- combined (mechanical and electrical) compensation "tare";

- compensation for errors caused by the resistance to the belt moving along weight rollers, gathering conveyor belt relative to the longitudinal axis of the conveyor, asymmetric deformation of the tape on the inclined conveyor idlers.

Conveyor complex is resistant to dynamic influences and impacts. Block diagram of the weights for conveyors with a short base by applying the developed complex force measuring CS-7718 is shown in Fig. 3.

In the pipeline with a short base, setting a weight roller is done instead of one standard roller. The weight roller carriage is designed to transmit force from the cargo transported on the conveyor belt to the magneto sensors. The weight roller carriage is a prefabricated structure consisting of two towers, where self-aligning double row ball bearing is mounted and a cylindrical roller with pins is fixed.

On one side of the shaft of the weight roller, a displacement sensor for determining the speed of movement of cargo is fixed. At the bottom of the supports there are slots in which there are two force sensors set.

The designed conveyor scales do not require complete replacement of technological equipment; they are able to work in harsh environments, are resistant to dynamic overloads and shock effects, and it is possible to use them on conveyor belts with restrictions regarding the installation location of the load device.

The principle of operation of the instrument is based on the summation method, which adds the mass of consecutive loads, each of which corresponds to the weight of the section weighing.

The mass is measured over a certain period of time based on the velocity of the conveyor belt, defined by a motion sensor. A commercially available non-contact end switch BTP-101, which is secured to the shaft base with four petals, is used as a displacement sensor. Activation of the travel sensor occurs during the passage of the petals along the end face of the cross switch BTP-101.

According to information from the sensors and motion sensor, the measuring and computing unit cal-

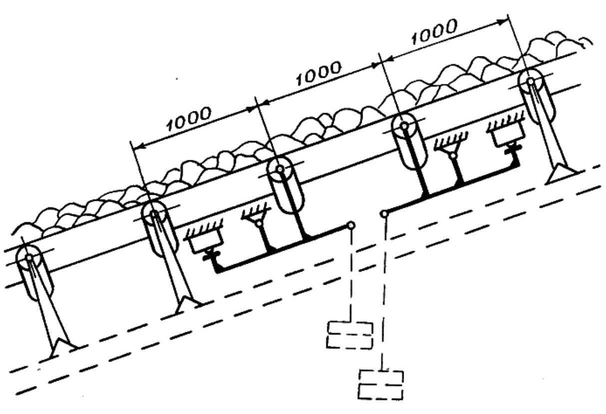

Fig. 2. Scheme of setting the two electric resistive-strain complex for weight control of bulk materials WET-7678

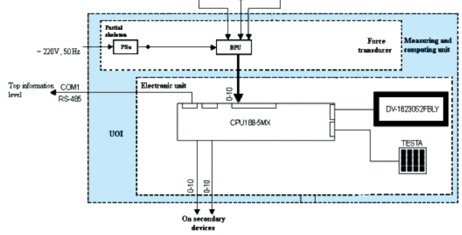

Fig. 3. Block diagram of the weights for conveyors with a short base:

VRO – weight roller carriage; DP – motion sensor; DMA – sensor; BPU – conversion unit and gain culates the weight of transported cargo weighing on the site, integrating mass calculated performance of conveyor dose determination.

Software and hardware of weight systems. Within the complex, the universal transmitter is given two roles: the first and foremost is to send an informative signal, as well as all the technological and logical and tuning parameters of the Analog-to-digital converter to the microprocessor unit display and control, the second involves the connection with a wireless remote control, used to configure and monitor and adjustment of conveyor scales. The apparatus consists of the transmission of the transmitter of the communication module with a processor, structurally formed on the isolated printed circuit board based on a microcontroller. The module performs integrity monitoring software to receive and impart information. The module is associated with the physical environment adjacent modules of transmitting information over the RS-485 protocols and on a radio channel at a distance of several meters. The transmitter also includes a Wi-Fi antenna.

The firmware for the CPU module is implemented in the programming language C/C++ programming environment, Visual C++ and interpreted by the compiler IarWB.

Unit with a universal analog to digital converter is the heart of IMS weighing bulk materials. It carries out the primary training of the analog signal proportional to the weight of the material on the scales and digitizes its subsequent handling and storage.

The analog-to-digital converter is designed as an isolated double-sided printed circuit board with various integrated modules based on modern microprocessor STM32F103RBT6. A universal analog to digital converter is also built on the principle of modularity. The power supply is structured on a separate circuit board and provides the entire range of supply voltage of the analog-to-digital converter system.

Conclusions. The main results of this paper can be summarized as follows:

- a model of innate ability of IMS is proposed. An equation that allows determining the innate ability of IMS experimentally is obtained;

- an equation which is the mathematical expression of Moore's Law is obtained. However, unlike the usual interpretation of Moore's Law, this equation contains the innate ability, which is a significant fact. The fact is that the exponential dependence of the type of Moore's Law is typical for many processes in nature and society, far from microelectronics, but the innate ability of the system is always present;

- the model and the formulas for determining the survivability and life cycle of IMS are suggested. It is shown that the persistence of IMS also significantly (*by W*) depends on an innate ability or technological heredity of IMS;

- a thermodynamic model of the dynamic weighing conveyor scales is proposed, taking into account the impact of the external environment and the internal parameters of the measuring system;

- in view of the constructed models, conveyor scales of a new generation are designed using a modern design and element base, ensuring accuracy class (1–0.5), using modern methods of information processing and analysis;

- new software of microprocessor controls and top-level ability is developed to instantly analyze the state of the object and to control actuators metering devices timely and accurately;

- a new weighing system is designed for conveyors with a short length and working in conditions of high dynamic loads and shocks, their software is developed as well.

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Мета. Розробка моделей, алгоритмів, а також нового покоління конвеєрних ваг на сучасній конструкторській і елементній базі, що забезпечують клас точності 1–0,5, з використанням сучасних методів обробки та аналізу інформації, а також розробка ваговимірювальних систем для конвеєрів, що мають коротку довжину та працюючих в умовах великих динамічних навантажень і ударних впливів.

Методика. Використовуються методи термодинаміки та аналогій для проектування, аналізу параметрів і функціонування вимірювальних систем. Розроблене нове програмне забезпечення мікропроцесорних модулів управління й верхнього рівня, здатного миттєво аналізувати стан об'єкта та вчасно й точно управляти виконавчими механізмами дозувальних пристроїв.

Результати. Запропоновані моделі та алгоритм динамічного зважування на конвеєрних вагах, що зв'язують параметри вимірювального пристрою з параметрами зважуваного матеріалу та навколишнього середовища. Створене нове покоління конвеєрних ваг на сучасній конструкторської та елементній базі

Наукова новизна. Уперше розроблені моделі та алгоритми функціонування вимірювальних систем з використанням методу аналогій, нерівноважної термодинаміки. На основі цих моделей проведена оцінка економічної ефективності та доцільності їх проектування, спадковості, життєвого циклу, живучості та ресурсів.

Практична значимість. Для підвищення ефективності транспортування руди, вугілля та інших сипучих матеріалів створене нове покоління конвеєрних ваг на сучасній конструкторській та елементній базі. Запропоновані нові моделі інформаційно-вимірювальних систем і динамічного зважування на конвеєрних вагах. Перше покоління автоматизованого електротензорезистивного конвеєрного вагового комплексу використовується на підприємствах Казахстану: металургійний комбінат АТ „Mittal Steel Теміртау", АТ „ТНК Казхром" Донський ГЗК, Актюбинський завод феросплавів, Аксуський завод феросплавів, Рудоуправління Казмарганець, Соколовсько-Сарбайське гірничо-збагачувальне виробниче об'єднання (ССГВО), Євроазійська Енергетична Корпорація (ЄЕК).

Ключові слова: *модель, алгоритм, програмне забезпечення, термодинаміка, метод аналогій, конвеєр, динамічне зважування, мікропроцесорний модуль*

Цель. Разработка моделей, алгоритмов, а также конвейерных весов нового поколения на современной конструкторской и элементной базе, обеспечивающих класс точности (1–0,5), с использованием современных методов обработки и анализа информации, а также разработка весоизмерительных систем для конвейеров, имеющих короткую длину и работающих в условиях больших динамических нагрузок и ударных воздействий.

Методика. Используются методы термодинамики и аналогий для проектирования, анализа параметров и функционирования измерительных систем. Разработано новое программное обеспечение микропроцессорных модулей управления и верхнего уровня, способное мгновенно анализировать состояние объекта и своевременно и точно управлять исполнительными механизмами дозирующих устройств.

Результаты. Предложены модели и алгоритм динамического взвешивания на конвейерных весах, связывающие параметры измерительного устройства с параметрами взвешиваемого материала и окружающей среды. Созданы конвейерные весы нового поколения на современной конструкторской и элементной базе.

Научная новизна. Впервые разработаны модели и алгоритмы функционирования измерительных систем с использованием методов аналогий и неравновесной термодинамики. На основе этих моделей проведена оценка экономической эффективности и целесообразности их проектирования, наследственности, жизненного цикла, живучести и ресурсов.

Практическая значимость. Для повышения эффективности транспортировки руды, угля и

других сыпучих материалов создано новое поколение конвейерных весов на современной конструкторской и элементной базе. Предложены новые модели информационно-измерительных систем и динамического взвешивания на конвейерных весах. Первое поколение автоматизированного электротензорезистивного конвейерного весового комплекса используется на следующих предприятиях Казахстана: металлургический комбинат АО „Mittal Steel Темиртау", АО „ТНК Казхром" Донской ГОК, Актюбинский завод ферросплавов, Аксуский завод ферросплавов, Рудоуправление Казмарганец, Соколовско-Сарбайское горно-обогатительное производственное объединение (ССГПО), Евроазиатская Энергетическая Корпорация (ЕЭК).

Ключевые слова: *модель, алгоритм, программное обеспечение, термодинамика, метод аналогий, конвейер, динамическое взвешивание, микропроцессорный модуль*

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