Testing the system detection unit for measuring solid minerals bulk density

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Abstract. The paper provides a brief description of the system for measuring flux per volume of solid minerals via example of mineral coal. The paper discloses the operational principle of the detection unit. The paper provides full description of testing methodology, as well as practical implementation of the detection unit testing. This paper describes the removal of two data arrays via the channel of scattered anddirect radiation for the detection units of two generations. This paper describes Matlab software to determine the statistical characteristics of the studied objects. The mean value of pulses per cycles, and pulse counting inaccuracy relatively the mean value were determined for the calculation of the stability account of the detection units.

1. Introduction

Gamma radiation flux attenuates while passing through the controlled environment, for example, through the coal flux on the belt conveyer. The degree of this attenuation depends on the controlled environment parameters, for example, bulk density of the transported material, its chemical composition, and presence of various types of the medium non-uniformities [1].

As it is known, the radioactive decay process is described by the Poisson's law, namely: a random value ξ, equal to the quantity of gammas, reaching, within definite time, the predetermined space portion (detection unit sensitive element), has the following distribution density [2]:

$$p\{\xi=k\}=I^k/k!\cdot e^{\lambda}, \quad (1)$$

where ξ-is a parameter of the Poisson distribution, equal to average flux rate of gammas, i.e. gammas quantity statistical expectation, as registered per the fixed time interval. Quantitative attenuation of radiant flux is determined by intensity variation of the flux I.

The flux intensity variation of a narrow beam of the direct gamma radiation, that passed though the layer of a substance with bulk density γ , thickness d and constant in time features is described by the Beer–Lambert exponential law [3]:

$$I_d = I_0\cdot\exp(-\mu_0\cdot d) = I_0\cdot\exp(-\mu\cdot\gamma\cdot d), \quad (2)$$

where I_0, I_d are the flux rate of the direct radiation, in absence and in presence of the controlled environment, correspondingly; μ_0, $\mu$are linear and mass attenuation coefficients of the direct radiation by the environment.

When interacting with the substance together with the direct radiation, the scattered radiation, which spreads in all directions, emerges [4]. When describing the interaction between the scattered radiation and environment, the scattered field, with parameters determined by the measuring system configuration, may be in question.

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The intensity of the scattered radiation flux, passing through the controlled substance with a bulk density γ , under certain conditions may also be described by exponential dependence as follows:

$$I_s = I_0 \cdot \exp(-\mu_0 \cdot d) = I_0 \cdot \exp(-\mu \cdot \gamma \cdot d \cdot \kappa), \quad (3)$$

where I_s is the intensity of the scattered radiation flux;μ_0,μ- are linear and mass attenuation coefficients of the scattered radiation by the environment;κis a correction to the linear attenuation coefficient for the scattered radiation.

The sum of the direct and the scattered gamma rays is registered during interaction between gamma rays with energy within the range of 400-800 keV and the rock mass. Thus, after adding the two intensities, one gets total intensity of gammas at the outlet of the primary transducer of radioisotope measuring system (RMS):

$$I = I_d \cdot + I_s = I_0 \cdot \exp(-\mu \cdot \gamma \cdot d \cdot (1+\kappa)), \quad (4)$$

The theoretical dependence of bulk density on the total intensity of gammas, according to equation 4, is defined as follows:

$$\gamma = \ln(I_0 \cdot - I)/(\mu \cdot d \cdot (1+\kappa)), \quad (5)$$

The amount of material, as well as its quality, can be defined by the material's bulk density. These parameters are important during extraction, transportation and processing of any mineral product.

The operation of RMS, which consists of the gamma radiation unit, detection unit (DU), controlled material and the unit of the measuring data recording, conversion and transfer, is based on the said principle. With the system in operation, the narrow beam of gammas, attenuated by the controlled environment, runs into the detection unit (DU), wherein it converts into the sequence of electrical impulses. Those signals run into the microcomputer, built into the detection unit, where they are converted into a digital form to be further processed in accordance with algorithms, providing determination of the numerical values of the controlled flux parameters [5].

The detection unit is presented as scintillation gamma radiation counter based on scintillation crystal Na J(Tl) with dimensions 30x40 mm, a photoelectronic multiplier PEM-122, pulse former and secondary high-voltage power supply [6]. The pulse former is a threshold device, implementing amplitude discrimination of input pulses in accordance with the energy of primary gammas and formation of the detection unit's output pulses by their amplitudes and time durations [7]. The pulse counting rate at the outlet of the detection unit is an information parameter of the measuring system.

One or another advantage or disadvantage of the radioisotope metering system can be correctly estimated and analyzed, by testing the conversion channel of measuring data in the system, from the detection unit to it's conversion, recording, displaying and transfer. Herein, the additive component of systematic inaccuracy or inaccuracy "0" is the basic inaccuracy, subject to be tested with RMS.

This paper discloses the results of comparison testing of two measuring systems, one of which is developed by LLC "Complex-resource", and the other one, is developed by employees of the National Mineral Resources University.

2. Method description

This research work does not describe the operation of gamma radiation unit due to stability of gamma radiation source and low drift of radiation, having no impact on systematic and random inaccuracy of measurement.

This work employs two detection units: Detection Unit No.1 (DU No.1), being developed and applied for fiscal metering of oil flows and Detection Unit No. 2 (DU No.2), being developed and applied for heterogeneous streams of rock mass. The aim of the research work is to determine and compare the counting stability (pulse counting inaccuracy determination relatively the mean value) of Detection Unit No. 1 and Detection Unit No.2, for it is this particular indicator that defines the degree of inaccuracy for the controlled environment parameters. The developed system is based upon methodology for calibration characteristics automated correction and random inaccuracies minimization via increasing measurement frequency, as well as radiation energy registration, the energy presented as a sum of correlation functions of random oscillation processes within the bulk density of the controlled environment.

1) Let us put the detection units on the line and, via using Fvor_18, let us get two data arrays via the channel of scattered radiation S and direct radiation D (on line, the unit operates 96 hours), with data arrays taken in the morning (at 9.00 am), afternoon (at 13.00 pm), evening (at 17.00 pm), and with the measurement done within 30 minutes.

2) Let us process the data arrays, according to S and D channels, via MatLab software:

3) Let us search for statistical expectation per each cycle.

4) Let us search for average squared displacement per the whole interval of operation (30 minutes).

5) With the Excel program, let us find the average number of pulses during the entire time of the research, search for relative inaccuracy per each cycle, construct graphs for mean values per cycles and graphs for deviation of average number of pulses per cycles from average number of pulses per the whole interval of the research.

6) Using the data arrays, as received in Fvor_18, let us construct histograms for DU No.1 and DU No.2, which characterize probability density function (OriginLab software was used).

7) Based on the research findings, the authors come to the conclusion regarding the stability of the detection units accounting process.

The authors used Matlab software to create an app to discover parameters, which would characterize the detection unit accounting procedure stability.

Program in MatLab for arrays processing:

```
load bdl_h.txt
x=bdl_h;
N =100000;
n=floor(length(x)/N)*N
x = x(l:n);
xx = reshape(x, N, [ ]);
mm = mean(xx)
S = std(x)
```

It is with those software products that the authors process all the data arrays obtained with Fvor18, to get, as a result, pulse mean values per each cycle, mean square deviation for the entire operation interval (30 minutes).

All the results obtained for DU No.1 and DU No.2, via MatLab were recorded in Excel table, wherein the following was calculated: the mean value of pulses per whole interval of operation, relative inaccuracies. Also the graphs were created for mean values of pulses per cycles and graphs for deviation of average number of pulses per cycles from the average number of pulses per the whole interval of the research. Herein, the mean value of pulses is as follows [8]:

$$X=X_1+X_2+...+X_{48}/48 \quad (6)$$

The relative inaccuracy is as follows [9]:

$$RI=|(X-X_j)/X|*100\% \quad (7)$$

Referring to DU No.1, as seen from the graph in fig.1, the mean value of pulses throughout the entire interval of operation is 9.2179, with the minimum value of 9.2022, and the maximum value of 9.2347.

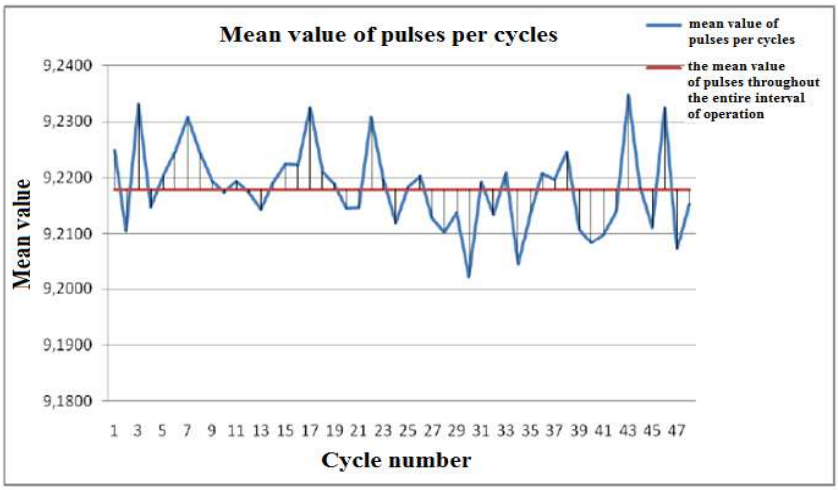


Figure 1. Mean value of pulses per cycles, DU1.

As seen from the graph in fig.2, the maximum value of deviation is 0.18%, in general, with the most points located below 0.1%.

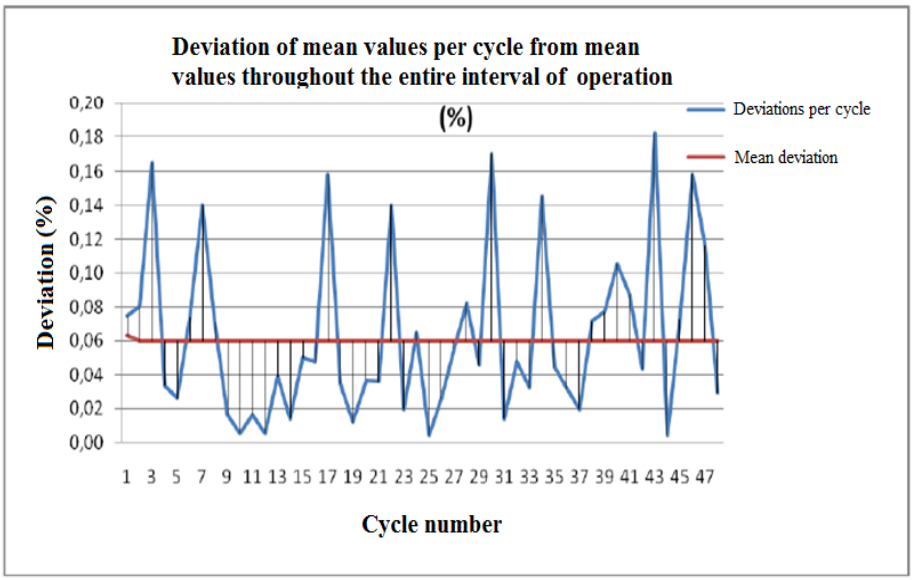


Figure 2. Deviation of mean values per cycle from mean values throughout the entire interval of operation, DU1.

Referring to DU2, as seen from the graph in fig.4, the mean value of pulses throughout the entire interval of operation is 14.8585, the minimum value is 14.8398, and the maximum value is 14.8790.

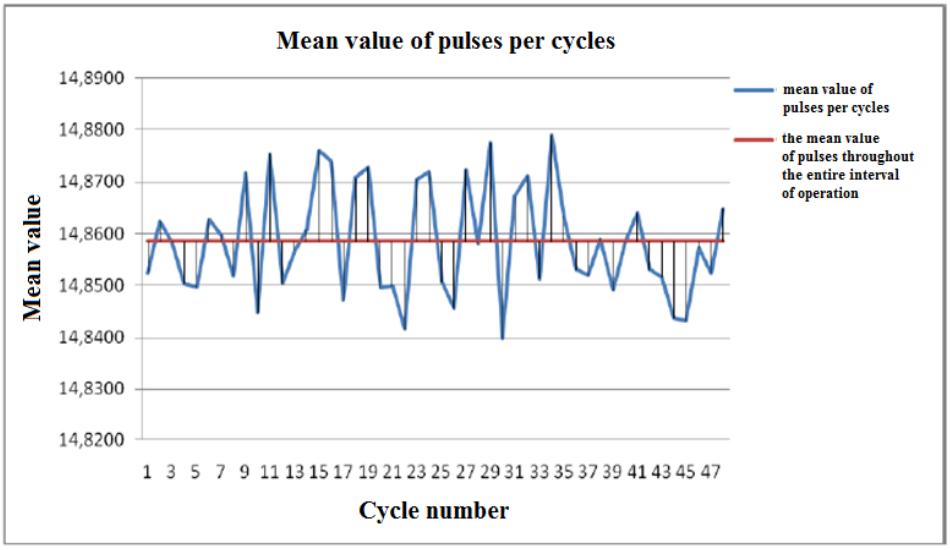


Figure 3. Mean value of pulses per cycles, DU2.

As seen from the graph in fig.4, the maximum value of deviation is 0.14%, the most points are located below 0.1%.

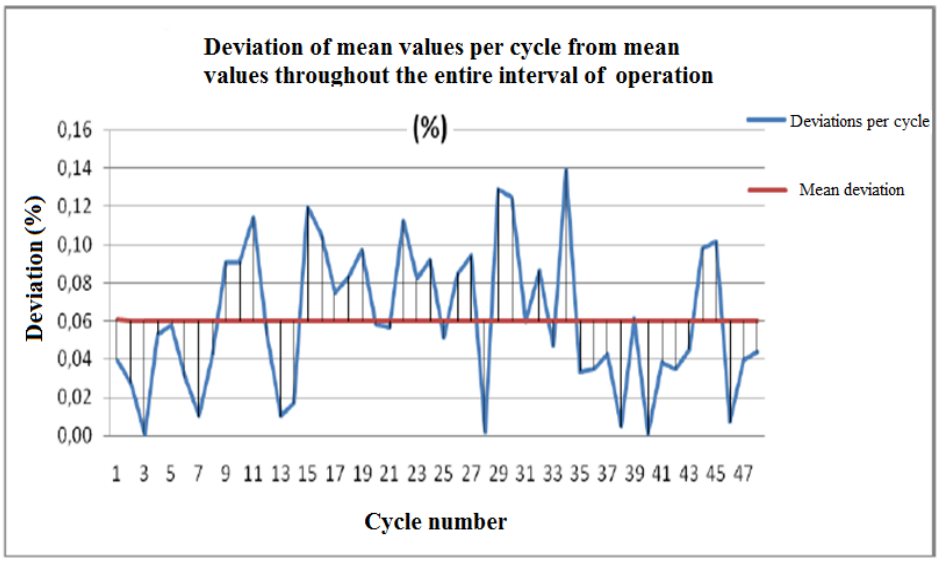


Figure 4. Deviation of mean values of pulses per cycle from mean value throughout the entire interval of operation, DU2.

Based on the obtained data arrays, by D and S channels (Fvor_18), the histograms, as shown in fig.5, fig.6 were constructed, with the OriginLab software, and the approximation of histograms, according to the Gauss method, was carried out.

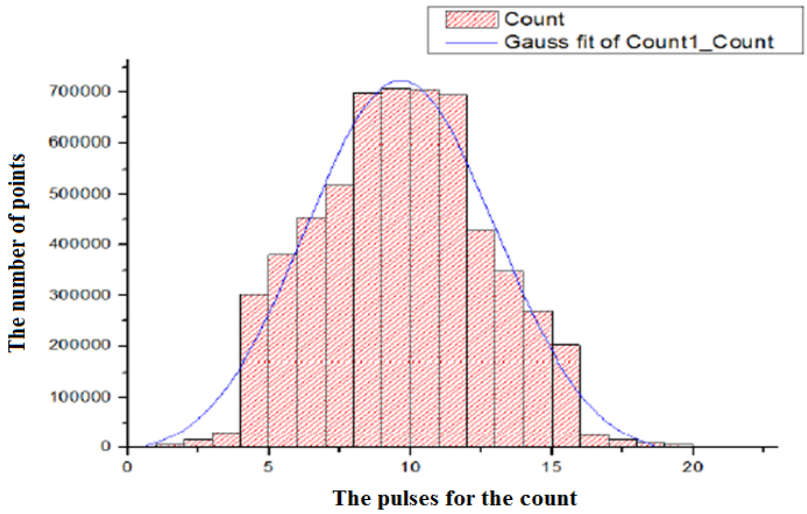


Figure 5.. The values of pulses histogram and the function of normal distribution for DU1.

Statistical expectation is equal to 9.22, with the mean square deviation equal to 3.02.
For DU2:

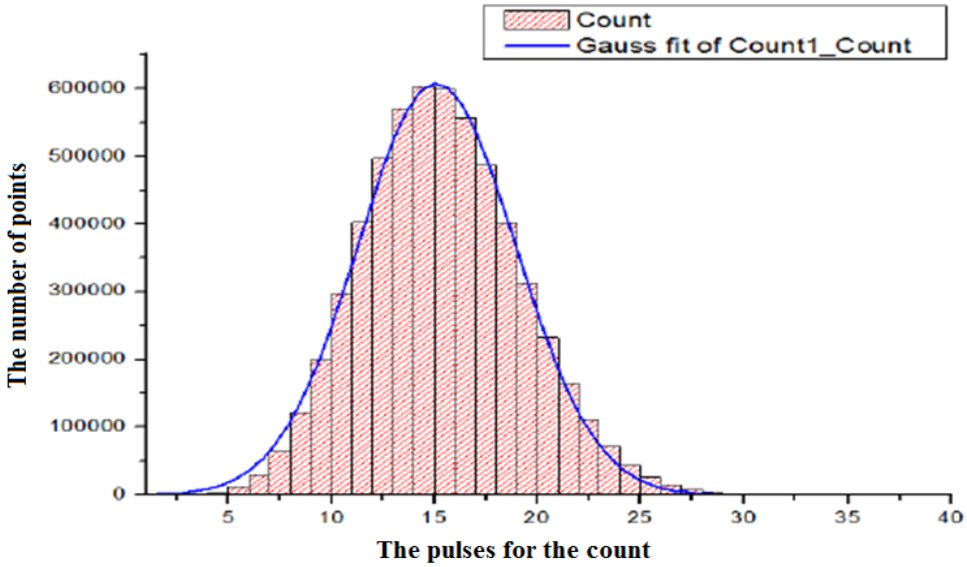


Figure 6. The values of pulses histogram, and the function of normal distribution for DU2.

The Statistical expectation is equal to 14.86, and the mean square deviation is equal to 3.84.

3. Results of research

Based on the histogram constructed, one may conclude that report distribution, relatively the mean value for DU2, would be a much more near-normal distribution. Thus, it may be concluded there is a systematic inaccuracy, for DU1. In fig.6 it is clearly seen, that the curve of normal law of distribution is much more compact, than in fig. 5, the approximating functions are narrower, and it may be confirmed by determining coefficients of variation [10]:

For DU1:

$$\Theta=(\sigma/M)_{14}=3.02/9.22=0.33 \quad (8)$$

For DU2:

$$\Theta=(\sigma/M)_{24}=3.84/14.86=0.26 \quad (9)$$

Based upon the results obtained, it is seen that coefficients of variation for DU2 are less than for

DU1, thus it may be concluded that the spread of pulses for DU2 is less than the one that DU1 has.
It is also worth noting that one task to be achieved is the stability of pulses accounting procedure (Deviations of pulse values from the mean value not exceeding 0.1%). As a matter of fact, the uncertainty of measurement depends on this parameter. On the graphs, resulting from the research study, it is apparent that the spread relatively the mean value for DU1 is bigger, than the same for DU2. As for DU1, according to the channel H, 20% of points are located above 0.1%, while DU2 has only 10%. According to the channel S, for DU1, 70% of points are located above the value of 0.1%, while all the points, for DU2, are located below the value of 0.1%.

4. Conclusion

All the results of the research study can be explained by the following:

1) In DU1, the entire stabilization of total absorption peak is implemented only in software.

2) Components, included into DU2, are more stable than those, included into DU1.

This brings us to the conclusion that the apparatus DU2, metrologically, has superior characteristics; therefore it is the onethat should be recommended to be used as a basic device for measuring bulk flux parameters under development, more specifically, for rock mass on the belt conveyer.

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