ZESZYTY NAUKOWE WYŻSZEJ SZKOŁY ZARZĄDZANIA OCHRONĄ PRACY W KATOWICACH
Nr 1(10)/2014, s. 24-31 *ISSN-1895-3794*
eISSN-2300-0376

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Optical reflectometric sensor of lime stone concentration in dust residing in coal mines excavations

Optyczny reflektometryczny czujnik zawartości kamienia wapiennego w pyle zgromadzonym w wyrobiskach kopalń węgla kamiennego

Abstract

For safety reason it is required to check periodically concentration of non-flammable components in dust deposited in coal mines entries . The traditional procedure requires the dust samples to be collected in locations determined by safety regulations and transport them to the surface where the concentration of non-flammable components can be evaluated in the laboratory. It would greatly simplified the required procedure if the dust samples could be tested directly on site . Attempts to construct the suitable equipment, based on measurements of relative intensity of light reflected from dust sample, although almost completed, finally has been abandoned because the manufacturer of reflectometric sensors ceased its production.

The following paper presents results of research project which goals was to develop probe, based on commonly available components, which could substitute, the initial sensor choice and further to make possible to complete finally the measuring device. It seems that the initial goal of the project has been successfully achieved.

Keywords: *coal mines, coal dust, stone dust, reflectometric sensor*

Streszczenie

Ze względów bezpieczeństwa wymagane jest okresowe sprawdzanie stężenia niepalnych składników w pyle znajdującym się w wyrobiskach kopalń. Tradycyjna procedura badawcza wymaga pobrania próbek pyłu w miejscach określonych przez przepisy bezpieczeństwa i przetransportowania ich na powierzchnię, gdzie stężenie niepalnych składników może być oceniane w laboratorium. Znacznym uproszczeniem wymaganej procedury byłoby badanie próbek pyłu bezpośrednio na miejscu w wyrobisku. Prowadzone były próby skonstruowania odpowiedniego sprzętu badającego względne natężenia światła odbitego od próbki pyłu. Jednak pomimo prawie zakończonych badań pomysł ten został porzucony z uwagi na fakt, iż producent czujników reflektometrycznych zaprzestał ich produkcji.

W pracy przedstawiono wyniki badań, których celem było opracowanie sondy, w oparciu o powszechnie dostępne elementy. Mogą one zastąpić pierwotnie wybrany przetwornik reflektometryczny i umożliwić zakończenie budowy urządzenia pomiarowego. Wydaje się, że początkowy cel projektu został skutecznie osiągnięty.

Słowa kluczowe: *kopalnie węgla kamiennego, pył węglowy, pył kamienny, przetwornik reflektometryczny*

1. Introduction

Unavoidable side product during coal excavation is coal dust that spreads randomly everywhere. It is potentially hazardous situation, as in the case of local methane explosion in the mine the blow rises a cloud of coal dust that, when mixed with the air, explodes spreading the disaster all over the place.

Such a chain explosion does not happen when the proportion of flammable components (coal) in the dust is less than a certain percentage. It is agreed that if the contents of non-flammable components of the dust exceeds 80% the side is safe. For the non methane mines the percentage is lowered to 70% [1]. It is therefore required by mine safety rules to control periodically concentration of non-flammable components in the dust residing in excavations.

If the level of non-flammable components is not within the safety margin it is a common temporary protective measure to spray water over the dust, or finally spraying mine entries with lime stone dust, or add it in some other way to the deposited dust in order to limit proportion of non-flammable components to the safe level.

The traditional way to evaluate concentration of non-flammable components of the dust is to collect several samples of dust and analyze them in the laboratory on the surface, which is quite long and tedious process.

First attempts to simplify the evaluation procedure of non-flammable components in the dust were based on the fact that pure coal dust is black and non-flammable components of it, mainly lime stone dust, are white. The mixture of coal and lime stone is gray and the percentage of gray is related to the proportion of coal and non-flammable components of the dust.

The prototype working on the base of such principle [2] was designed and built by Pittsburgh Research Laboratory associated with US Bureau of Mines around year

1988, but later the project has been abandoned for not known reasons. Instead two models of the device have been passed to GIG around year 2001, where on the base of its documentation new constructions have been developed [3]. For the detection of reflecting light intensity reflectometric sensor P7816 made by Hamamatsu has been employed. Although the construction of the meter has been completed and the final tests started, the further development was postponed because the manufacturer of reflectometric sensor abandoned its production.

As the idea of the simple measuring device enable quick evaluation of concentration of non-flammable components in the dust deposited in mine entries seems still very attractive the small new project carried jointly by WSZOP and GIG has been proposed. The aim of the project was to develop new construction of the reflectometric sensor probe based on popular opto-electrical components that can substitute the Hamamatsu sensor, which is no longer available.

2. Sensor principle

The reflectometric sensor must be a combined structure of source of light and photo- sensitive element i.e. photo-diode or photo-resistor. As the source of light a LED diode seems the most natural choice. The main structural problem is the mutual placement of both elements.

The elements should be placed in some fixed distance from the dust sample to be measured. The surface of dust should be uniformly illuminated, and the reflected light should be collected by the photosensitive component. This creates some designing problem as the LED cannot be placed exactly on top of the photo- sensitive element unless some optic-fibers are used. The possible placements of the both type of elements are presented in figure 1.

To verify metrological properties of various arrangements it was necessary to build rigid mechanical constructions of all of them and measure their responses to various samples of different gray intensity. As the photo-sensitive elements photo-diodes from different manufacturers have been employed as well as photo-resistors.

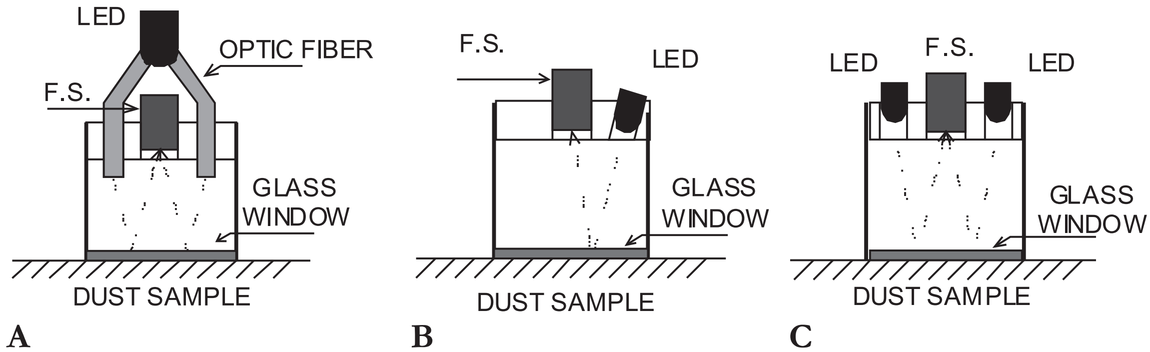

Fig. 1. The possible mutual placements of light sources (LED) and photo-sensitive element (F.S.) under consideration; A – arrangement with optic-fibers, B – arrangement with single light source, C – arrangement with multiple light sources

Rys. 1. Możliwe wzajemne położenie źródeł światła (LED) i elementu światłoczułego (FS); A – z wykorzystaniem światłowodów, b – układ z jednym źródłem światła, C – układ z wieloma źródłami światła

3. Basic tests

For the basic test to be performed it was decided to substitute the real dust samples, collected from the coal mine, by much simpler to use paper standard of various gray grades produced on laser printer by suitable graphic software. The real mine dust samples are rather troublesome to use in laboratory. Dust easily flies everywhere making the stand dirty, and tested sensor arrangements requires permanent cleaning. As there was significant number of test to be completed the much more practical standard, presented in figure 2, has been used.

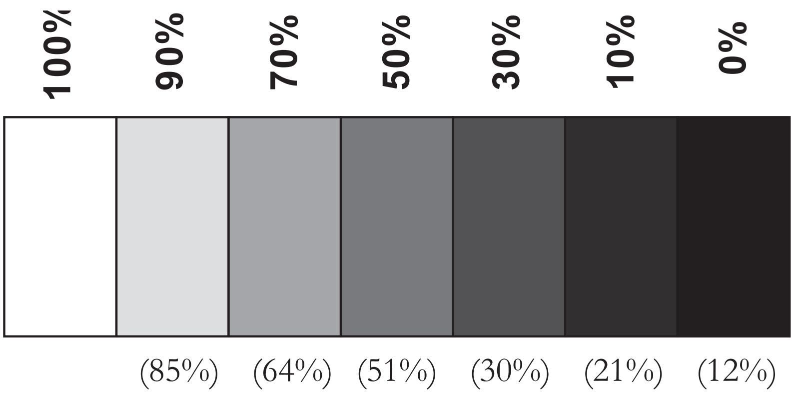

Fig. 2. Standard of various gray grades employed for basic tests
Rys. 2. Wzorzec stopnia wybielenia stosowany do badań

As the shades of gray of the standard depends strongly both on the graphic software and the printer itself, the shades of gray have been preliminary tested using luxmeter of L-51 type. The arrangement employed for testing the standard is presented in figure 3. The luxmeter readings are presented in table 1.

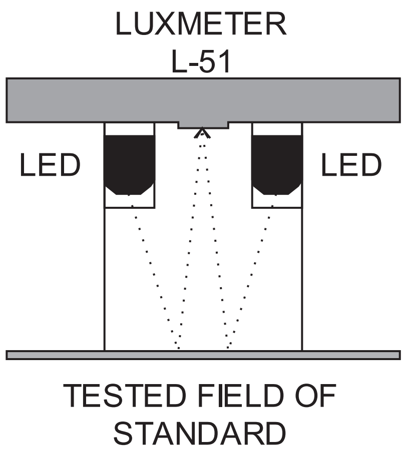

Fig. 3. Arrangement with luxmeter for testing the standard
Rys. 3. Szkic adaptera do badań weryfikujących wzorzec

Tab. 1. Luxmeter readings during basics tests
Tab. 1. Wskazania fluksometru podczas badań wstępnych

Standard nominal percentage of white [%]	100	90	70	50	30	10	0
Reflected light intensity [lx]	515	347	168	99	58	49	40

There is no single commonly accepted algorithm to evaluate the grade of gray on the base of relative intensity of reflected light as there are different models describing sensitivity of human vision to changes of light intensity. For the low grade of gray i.e. high whiteness quite common is to use the cube roots of figure describing relative intensity of reflected light, related to intensity of light reflected by sample assumed to be the standard of 100% whiteness [4]. For the low percentage of whiteness (< 30%) the power coefficient is usually modified to 0.43 instead of 1/3 [5]. Using such an algorithm the estimations of percentage of whiteness obtained for the tested standard are presented in table 2.

Tab. 2. Estimated percentage of whiteness for standard (fig. 2) based on measured reflected light intensity
Tab. 2. Szacunkowy odsetek białości dla wzorca (rys. 2) na podstawie zmierzonego natężenia światła odbitego

Nominal whiteness of standard [%]	100	90	70	50	30	10	0
Estimated whiteness of standard [%]	100	85	64	51	30	21	12

The estimated standard whiteness percentages values have been used to evaluate responses of various arrangements of LED and photo sensitive elements.

4. Basic tests results

Various combination of mutual placement of light sources and photo sensitive elements have been tested and there was practically no difference in their performance i.e. their responses to the grade of gray is very similar. The family of their characteristics is presented in figure 4.

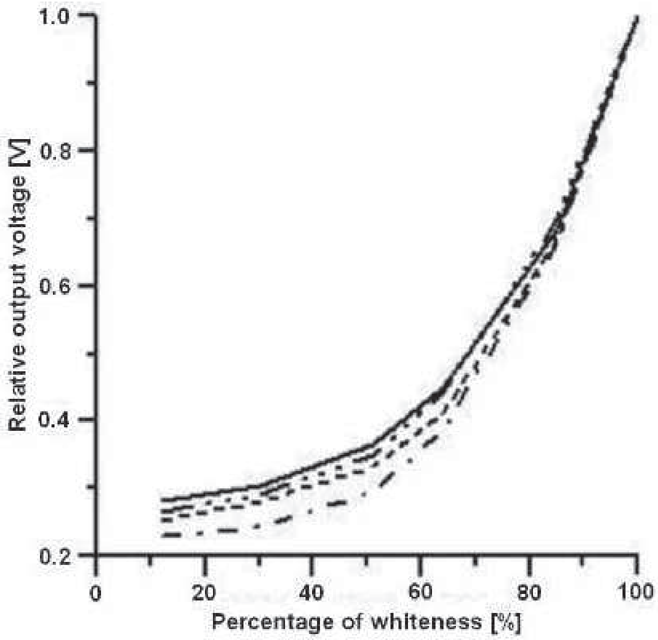

Fig. 4. Examples of voltage characteristics of various probe arrangements, according to fig. 1; where:
_______ 1C - with photo-diode, __ … __ 1C - with different photo-diode,
_ _ _ _ _ 1 B - with photo-resistor, __ . __ . 1A - with photo-diode
Rys. 4. Przykłady charakterystyk napięciowych dla różnych konfiguracji sondy zgodnie z rys. 1; gdzie:
_______ 1C - z fotodiodą, __ … __ 1C - z inną fotodiodą,
_ _ _ _ _ 1 B - z fotorezystorem, __ . __ . 1A - z fotodiodą

It was decided therefore that for further test the arrangement 1C, presented in figure 1, will be used as its mechanical construction is comparatively the simplest one. The LED and photo-diode arrangement was placed in a metal tube together with electronic preamplifier in classical configuration presented in figure 5.

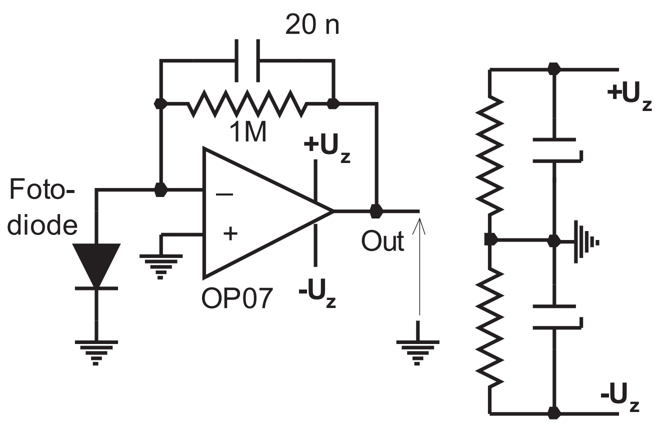

Fig.5. Circuit diagram of photo-diode preamplifier
Rys. 5. Schemat przedwzmacniacza fotodiody

The final sensitivity test has been performed using real dust samples of known percentage contents of lime stone dust. The test results are presented in figure 6.

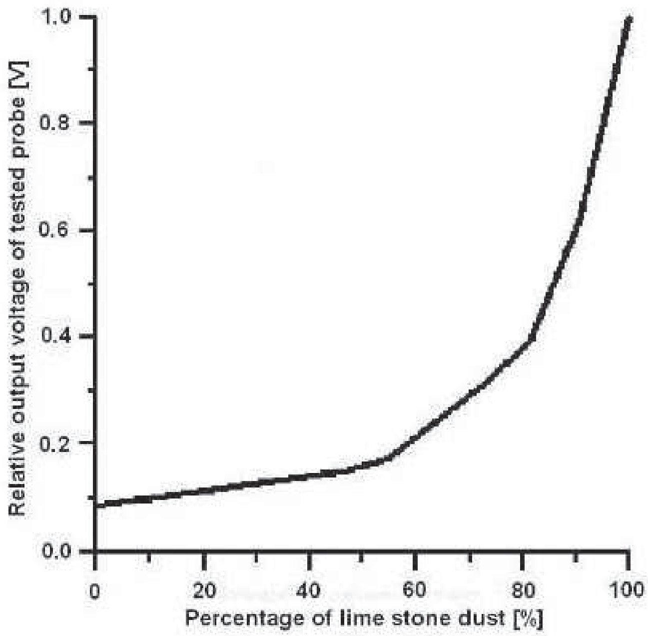

Fig.6. Complete probe final test result
Rys. 6. Końcowy wynik testu sondy kompletnej

5. Tests of probe sensitivity to enviromental factors

As the probe might be used in environments of various temperatures it is important to find out how its response is affected by the rise of temperature. The complete probe was closed in small, styro-foam insulated, chamber heated internally by small resistive heater. Permanent contact of probe front with standard of certain percentage of whiteness was secured.

After few hours the temperature inside the chamber was measured by mercury thermometer and the probe output voltage recorded. Then the heater was activated and after 3 hours the temperature and output voltage recorded again. The temperature rise of 10° C from 24° C to 34° C caused the output voltage drop of 8 mV from 1.406 V to 1.398 V what is equivalent to temperature coefficient of 0.05%/1° C. It can justify the conclusion that the temperature influence on probe performance is insignificant.

To find out how the relative humidity of real mine dust affects the probe reading the real dust sample of 63% of lime stone was used. The probe reading was taken before and after some water has been added to the sample. It was found out that in the case of lime stone dust treatments with hydrophobic agent – stearic acid it was no practical change of probe reading observed.

6. Conclusions

On the base of the tests results it can be concluded that the presented construction of probe might be used to substitute previously developed construction, and the meter of lime stone concentration in dust residing in coal mine entries can be finally completed. As it was mentioned previously such a meter would make it possible to take measurements directly in the mine without the need to take and transport the samples of dust to the surface.

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