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Rapid Coal Analysis with the Online X-ray Elemental Analyzer OXEA®

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ABSTRACT

To control the mineral processing, e.g. coal preparation, an online coal analyzer system should be installed on a bypass belt. Compared to main-belt installations an improved accuracy is obtained at a bypass stream, because the material stream can be crushed down to a constant particle size distribution and shaped to a constant cross section profile. To minimize sample preparation, the material stream running across a bypass should be small, but the thin material layers require a re-design of the existing coal analyzers. The bypass was optimized for the OXEA® Online X-ray Elemental Analyzer regarding a constant material layer with a smooth surface. Consequently only minor changes were necessary concerning the OXEA®. However, the state-of-the-art microwave transmission moisture meters are designed for thicker material layers. Therefore a novel microwave transmission moisture meter was developed. As in the past, it is based on the measurement of the microwave attenuation and phase-shift, but the new device also makes it possible to measure thin material layers all the way down to 3 cm thickness with a much higher accuracy.

Key Words: Online Measurement, Moisture, Ash Content, Calorific Value, Elemental Analysis, Sulfur, XRF, Microwave Transmission

INTRODUCTION

In a previous paper (Klein, 2013) a concept for an online analysis system for minerals has been described. Now this concept has been realized within a European Research Project called DRAGON, which was finalized in September 2015. The task of this project is to re-use the excavated material from the tunnel. The material is analyzed directly in the tunnel and sorted according to its quality and potential use. For this purpose the bypass system was designed to be installed directly on a Tunnel Boring Machine (TBM). The DRAGON analyzer system has to measure the physical and chemical properties of the excavated material. The bypass including the Online X-ray Elemental Analyzer OXEA® and the PMD 2500 moisture meter is part of the DRAGON analyzer system. All tests were made with the prototype, as shown in Figure 1, installed at the Herrenknecht works in Schwanau (Germany). The width of the bypass-belt is 40 cm, the speed is about 20 cm/s. The material layer is about 25 mm thick. The bypass-belt has been optimized for the OXEA®. Therefore only small modifications of the OXEA® were required. But in order to achieve the requested accuracy on thin material layers (25 mm), a complete redevelopment of the moisture meter's microwave unit became necessary.

ONLINE X-RAY ELEMENTAL ANALYZER OXEA®

The improvements regarding the accuracy and the detection limit of the OXEA® are described in (Klein, 2013). For the installation at the bypass of the DRAGON Prototype, the OXEA® was modified. The bypass belt has side walls to guide the material. The OXEA® sensor box (OSB) is located between these sidewalls. For a very simple and convenient maintenance, a pneumatic lift has now been integrated in the fixing frame as a compact unit, as shown in Figure 1. To optimize the material flow, the material is scraped to a constant layer thickness and smoothed with a roller. With these arrangements the bypass is designed to be ideal for the OXEA®. To control the sorting process, the type recognition feature of the OXEA® was used. This method is based on the comparison of spectra. A quantitative analysis and a calibration of the OXEA® is not necessary for this purpose. The automatic sorting of different excavated tunnel material worked perfectly.

Figure 1: Bypass with OXEA® elemental analyzer and the PMD 2500 moisture meter

ONLINE MOISTURE MEASUREMENT

In the same step within the DRAGON project, the novel microwave transmission moisture meter PMD 2500 was developed, which is specially designed to measure thin material layers on bypass belts with very high accuracy of about 0.1 %.

The technique is based on the measurement of the attenuation and phase shift of a microwave beam transmitted though the material layer. State of the art is to install the instrument on a main belt, where the material layers are typically 100 to 200 mm thick. However, below 3 cm layer thickness the measuring effect is rather small and the accuracy is reduced. The greater material layer thickness at main belts is ideal for microwave transmission measurements in the frequency range of 2 - 4 GHz. In order to increase the measuring effect for thin layers, using higher frequencies is beneficial: Both, attenuation and phase shift become higher. But also the influence of particle size becomes bigger with increasing frequency (Klein, 1981). Measurements of Australian coal widely confirm these results. (Cutmore et al., 1989 and 1991). Therefore we decided to develop a new microwave moisture meter. We used a wider frequency range, which also includes the old frequency range, to improve the stability of the moisture meter (Klein, 2013). The newest data of the prototype is given in Table 1.

Table 1: Advantages of the PMD 2500 compared to PMD 2450

	PMD 2500	**PMD 2450**	**Improved**
Frequency range	1.2 – 4.5 GHz	2.4 – 3.0 GHz	Factor 5
Long-term accuracy	Phase shift: 0.5 °/GHz Attenuation: 0.1 dB	2 °/GHz 0.3 dB	Factor 4 Factor 3
Noise	-120 dBm	-90 dBm	Factor 1000

For the design of the PMD 2500 it is taken into account, that the accuracy is reduced by multiple reflections at the surfaces of the material, if the attenuation of the transmitted material layer is low (Klein, 1981). Additionally the antennas generate multiple reflections, because they are not ideally matched over the whole bandwidth. To compensate this effect, the interferences caused by the multiple reflections must be averaged out by measuring over a wide frequency range. This is very important, especially for thin material layers, which are typical for bypass-belt applications.

The use of the wideband technology makes it necessary to transmit very low microwave power levels, in order to meet the new ETSI UWB regulations for Europe (ETSI, 2010) or the corresponding FCC (FCC, 2010) and RSS (RSS, 2014) regulations for USA and Canada. The allowed transmitted power level is about –60 dBm for a transmitting antenna with 15 dB gain. The insertion loss of an antenna pair with a typical distance for mounting at a conveyor belt is about 15 dB, i.e. the received power level for an empty measuring path is then –75 dBm. To calculate the dynamic range we must determine the noise. The noise floor was determined by increasing the attenuation with a calibrated step attenuator (HP8496 A/110 dB). In this test the transmitted power was set to – 40 dBm. Figure 2 shows, that the noise floor of the PMD 2500 is at 80 dB below the transmitted power, i.e. the noise floor of the PMD 2500 is at –120 dBm.

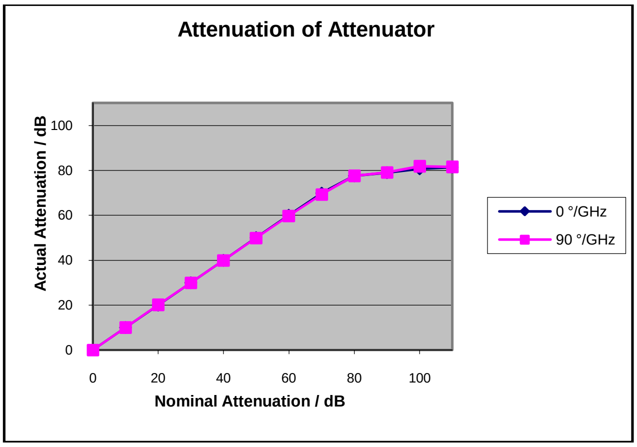

Figure 2: The attenuation reading of the PMD 2500 versus the setting of a calibrated step attenuator

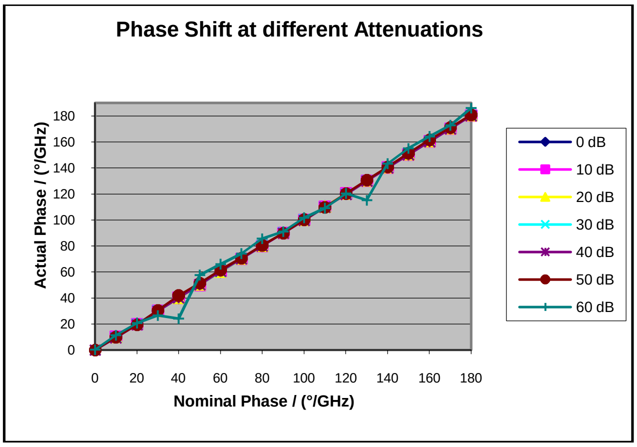

Figure 3: Phase shift reading of the PMD 2500 versus the setting of the phase shifter with different setting of the step attenuator

For the second measurement additionally a calibrated microwave phase-shifter (Narda 3752) was inserted in the measuring path, to check the accuracy of the phase measurement. Figure 3 shows the phase measurements versus the settings of the phase shifter from 0 to 180 °/GHz with different attenuations from 0 to 60 dB.

At 60 dB attenuation, i.e. at –100 dBm and a S/N ratio of 20 dB, we see the first significant deviations, as expected. With an allowed max. receiving level of –75 dB in an open system with the pair of antennas according the new ETSI UWB or FCC regulation, the insertion loss of the measured material is limited to <25 dB, i.e. the new PMD 2500 fulfills all requirements, even for thick or rather moist material layers.

The noise floor of the previous microwave transmission moisture meter is typically –90 dBm only. This means, that the noise floor is only 15 dB below the allowed receiving power level of the empty measuring path. These instruments consequently have a noticeably reduced accuracy, because the S/N ratio is too low.

The ETSI UWB and the FCC regulations are very restrictive, because the wideband technique uses bands, which are reserved for the original users of these frequencies. Therefore the allowed power level for UWB applications must be low enough, so that the original users are not disturbed. Vice versa, the PMD 2500 must be robust enough against electromagnetic fields generated by the original users. This is widely realized by several provisions.

Especially for thin material layers the long-term stability of the novel moisture meter is eminently important, because for all transmission measurements the measuring effect is proportional to the thickness of the measured layer. The typical measuring effect for coal is 1 °/GHz per % moisture and cm material layer. A long-term drift is created by a drift in the electronics and by temperature effects of the microwave cables. With a new method (patent pending) the drift of the electronics and the temperature effect of the cables are compensated. With these features the long-term accuracy given in Table 1 is achieved. For a coal layer of 3 cm thickness, this results in an error of 0.16 % moisture.

As mentioned above, the disturbance from interferences caused by multiple reflections at the material surfaces is reduced by the wide frequency range technique. Tests were carried out by filling a vertical positioned S-Band waveguide with crushed sandstone with a moisture content of 4.48 %. The S-band waveguide, which is used as sample-holder, has a length of 22 cm. The cross section of the S-band waveguide has the dimensions 24 x 72 mm. The material was filled in 50 g steps.

The first test was made with the novel PMD 2500 with 10 frequencies between 2.41 and 2.94 GHz, as used for the PMD 2450. Figure 4 shows the plot phase shift versus the mass of the filled in material. The linearity is excellent with a correlation coefficient of 99.99 %. The phase shift is known to be much more robust regarding multiple reflections compared to attenuation measurements (Klein, 1981).

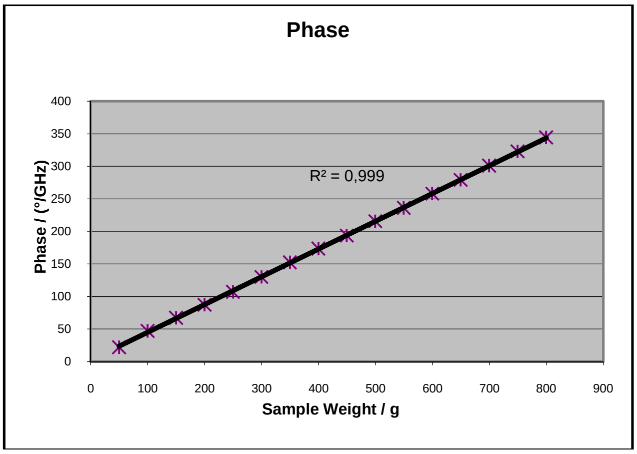

Figure 4: Phase shift of the sandstone measured in a waveguide as function of sample weight

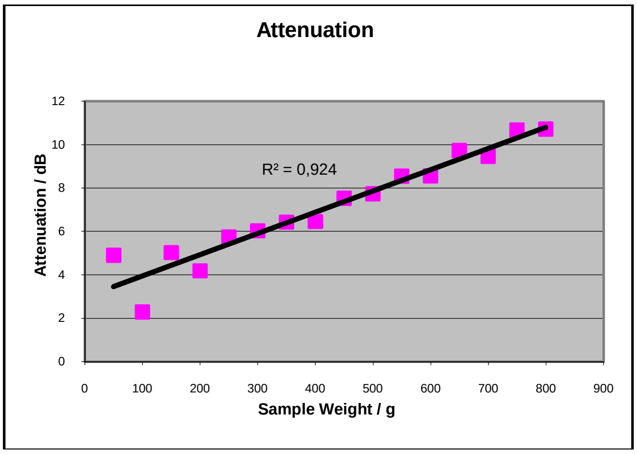

Figure 5: Attenuation of the sandstone as function of sample weight measured in the frequency range from 2.41 – 2.94 GHz

Figure 5 shows the corresponding plot of the attenuation. Here we see remarkable deviations at thin layers, which are caused by the multiple reflections.

The second measurement was done with 41 frequencies in the range from 2.4 to 4.4 GHz according to ETSI. The improvement in the low load range is obvious: The correlation coefficient is increased from 0.9246 to 0.9948, as shown in Figure 6.

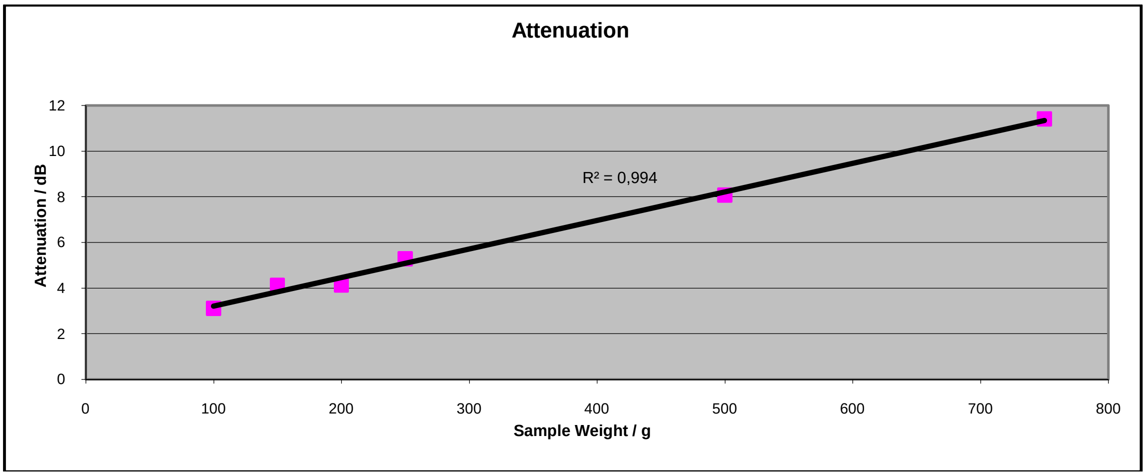

Figure 6: Attenuation of the sandstone measured in a waveguide as function of sample weight measured in the frequency range from 2.41 – 4.4 GHz

ONLINE MEASUREMENTS

Parallel to the development of the PMD 2500 a bypass analyzer system was installed at the NRG Conemaugh Powerstation in PA, USA. Here an existing XRF analyzer and a capacitive moisture meter were removed by the plant, because these devices did not meet the performance and did not generate reliable results, neither for BTU and sulfur nor for moisture. It was very difficult to convince the customer to replace the insufficient instrument with another instrument, which is based on the same technology. After first tests in the laboratory scale we could install the OXEA® analyzer together with the PMD 2450 as a long-term test with 5 milestones. The required accuracy (RMSD) is 0.2 % sulfur and 180 BTU to control the process. Here we installed an OXEA® 3000 analyzer, which was modified with the improvements, developed within the DRAGON project (Klein, 2013). As moisture meter the old PMD 2450 was used. Within this project we also developed a new pneumatic lifting system, which has dramatically improved the design of the prototype developed within the Dragon project. The installation was in summer 2013. The first test was scheduled for September 2013. 33 samples were taken with a secondary automatic sampling system, which is installed at the bypass belt after the analyzers. Each sample was taken with 20 cuts over a period of 30 minutes. The readings of the analyzers were collected and saved using the sampling software package of the OXEA® and the PMD 2450 software. The data was evaluated by an independent consultant. The results are summarized in Table 2.

Table 2: Results of the first Conemaugh Performance test

	RMSD	**arranged limit**	**comment**
BTU	165.958	180	passed
Sulfur %	0.108	0.2	passed
Ash %	0.585	not specified	
Moisture %	0.781	not specified	

The first performance test was passed successfully. In the meantime all 5 performance tests have been successfully passed.

In 2015 the beta series of the PMD 2500 was completed. The Frequency range is from 2.4 to 3.5 GHz according to the FCC regulations. In May 2015 the PMD 2450 was replaced with the novel PMD 2500. Within these tests it was found, that in the hopper of the bypass-belt the material gets classified: On one side of the belt coarse material with lower moisture accumulates and on the other side the fines with higher moisture. This means, that the microwave beam is partly running through the less moist material and partly through more moist coal. This is a typical two path propagation, by which the accuracy of the moisture meter is significantly reduced. Different changes were done to solve this problem. Further improvements will be done soon. A preliminary calibration of the PMD 2500 was done with 8 samples only, which gave an RMSD of 0.3 %. This shows, that we are on the right way. A performance test with a sufficient number of samples will be done, as soon as the mechanical issue is sorted out.

Furthermore, the Conemaugh installation allows the comparison of OXEA® with a PGNAA analyzer. Some miles away from Conemaugh is the Keystone Power station, which uses the same coal. Keystone also has a bypass system for the blended coal. Here a PGNAA analyzer is installed. From both installations the results of the analyzers are saved and updated daily as a one week tracking plot (s. Figure 7 and Figure 8). The analyzer readings for BTU, Sulfur and moisture are shown in green for boiler unit 1 and in yellow for boiler unit 2. For comparison the sulfur is also measured in the flue gas. BTU, moisture and ash are determined over the heat balance (blue: unit one, magenta: unit 2) The red line is a digital signal, which indicates, if the online analyzer is measuring (high) or not (low). In times when the analyzers are not measuring, the analyzer readings are substituted with default readings by the Accutrack® software (Santucci, M. et al., 2008), (Garaventa et al., 2014). The delay between the different measuring points is compensated by a bunker model. The calculation of moisture content with the heat balance is naturally poor, because the heat balance cannot distinguish, if a reduction of the BTU is caused by a higher ash or moisture content in the fuel. However, the results for BTU and sulfur are reliable.

A comparison of the results from the online analyzers shown in Figure 7 and Figure 8 gives good evidence about the superior accuracy and availability of the Conemaugh installation with OXEA® compared to the Keystone installation with the PGNAA analyzer.

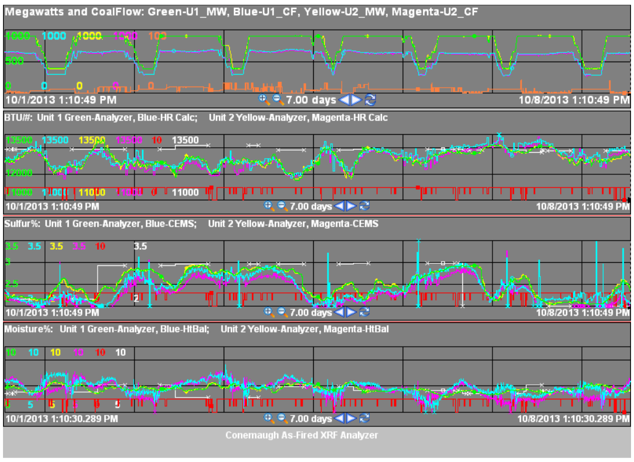

Figure 7: Trend Plot of BTU, Sulfur and Moisture results from the OXEA® Analyzer

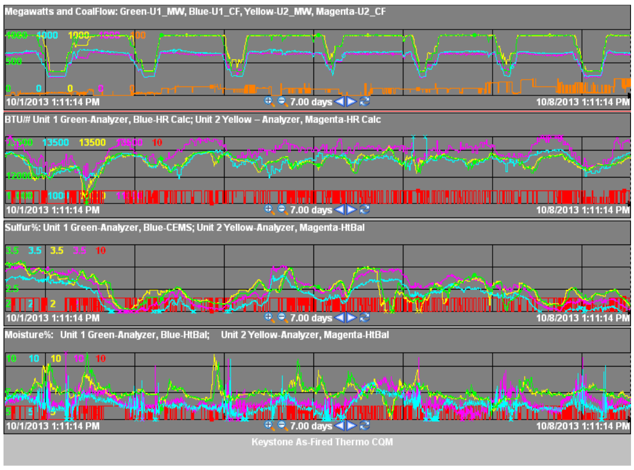

Figure 8: Trend Plot of BTU, Sulfur and Moisture results from a PGNAA Analyzer

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