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Electromagnetic radiation method for rock and gas outburst forecast

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Abstract

An increase of rock and gas outburst hazard changes different geophysical parameters of rocks near mine workings. We consider a new modern method of rock and gas outburst forecast that relies on registration of electromagnetic radiation caused by rock fracture. Features of electromagnetic radiation were investigated at different mine situations, and relationship between a buildup of rock and gas outburst hazard and an appearance of anomalous electromagnetic radiation of rocks was revealed. © 1997 Elsevier Science B.V.

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1. Introduction

At present the standard geomechanical method of rock–gas outburst hazard forecast in coal mine consists of measurement of volume of drilled coal rubble and of gas liberation rate (Petukhov and Lin'kov, 1983). This method is widely used although sometimes boreholing can initiate rock–gas outburst. This problem could be solved by development short-term geophysical methods. Natural acoustic emission is an extensively accepted method for fracture investigations. As shown by (Mogi, 1985; Li and Norlund, 1993; Lockner, 1993; Mansurov, 1994) Acoustic emission monitoring is unique for 'long-term' prognosis of fracture process. Numerous mines of the former USSR are equipped by micro seismic stations. These stations allow to keep track changes of rock–gas outburst hazard in the whole mine field or its large parts. However, when rapid and detailed prognosis of mine working regions (for example, in face of drift) is needed a roughness of mine working walls becomes a marked problem for rapid data acquisition due to inferior contact between acoustic emission sensor and mine working wall. For reliable contact additional time expenses are needed that is a serious disadvantage in mine condition. Besides, during short-term rock–gas outburst forecasting by acoustic emission method an operator carries out registration di-

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rectly near a mine working face that can be dangerous. At the present time no other geophysical method exists that could satisfy requirements of minimal duration and maximal forecast safety. One of the modern methods of rock–gas outburst hazard short-term forecast recently in development is the method of electromagnetic activity registration. Since electromagnetic radiation appears much faster than acoustic emission (King, 1983; Yamada et al., 1989; Yoshino and Tomizawa, 1989) and its measuring is much easier and safer (electromagnetic radiation antenna does not require any contact with mine working wall), there can be an obvious advantage in using the electromagnetic radiation prediction method. The electromagnetic radiation phenomenon emanating from fractures has been investigated for about two decades (Urusovskaja, 1969), but its physical origin is not completely understood (King, 1983; Mogi, 1985; Rabinovitch et al., 1995, 1996). Applied interest in electromagnetic radiation is connected with the problems of earthquake forecast (King, 1983; Gershenzon et al., 1989; Fujinawa et al., 1992; Yoshino et al., 1993), stress estimation (Goncharov et al., 1980; Warwick et al., 1982; Cress et al., 1987; Yamada et al., 1989; Xu et al., 1991; Rabinovitch et al., 1995, 1996) and rockburst prediction (Khatiashvili, 1984; Frid et al., 1992).

It could be very promising to investigate possibility of an electromagnetic radiation to be used also for the rock–gas outburst forecast.

2. Research method

Electromagnetic pulse excited by rock fracture shows up as a 'bell-shaped' oscillation characterized by an amplitude, by a frequency and an individual rise and fall time (Rabinovitch et al., 1995, 1996). As a rule, electromagnetic radiation is measured in mines within the narrow band, out of the 30–150 kHz range. The middle part of this range (100 kHz) is the most convenient one at a coal underground mine (Frid et al., 1992). This range is conditioned both by the industrial electromagnetic noise level in underground mine and electromagnetic pulses' amplitude. The electromagnetic pulses' field amplitudes are excited by coal failure near the face of mine working range between 5–50 μV/m (Frid et al., 1992), that is at least one order of amplitude larger than mine industrial noise level. Industrial noise level at the earth surface is usually not lower than 5 mV/m. Hence, an industrial electromagnetic noise in coal mines springs from underground mining machines, but not from the earth surface.

Daily work cycle of a mine consists of four six hour shifts: three extraction (mining) ones and one repair shift. Probability to pick up an electromagnetic transient process pulse due to starting–stopping of a mining electrical machine during extraction shifts is big enough, while the electrical noise level during a repair shift is as noted above. Thus, we carried out our measurement during repair shift. Electromagnetic radiation was measured by a resonance electromagnetic antenna with a resonance frequency of 100 kHz. The antenna was located at 1 m from mine working face and connected with a counter. We measured a number of intersections (per unit time) by the amplitude of oscillated electromagnetic pulses of a given counter sensitivity level. We call this parameter after electromagnetic radiation activity. At all studied points 30 electromagnetic radiation activity readings were taken with a duration of each one of 10 s. For simplicity, we named units of Electromagnetic activity 'impulse per 10 s' and symbolized as 'imp/10 s'. One cycle of electromagnetic measurements at one drift face is 5 min. This method allowed us to determine a stable mean that characterized electromagnetic radiation activity at a given point. As shown by the Frid et al. (1992) registration of electromagnetic radiation near a face of coal drift enables us to obtain electromagnetic signals excited by coal failure up to a depth 10 m from the drift face. Daily drift moving in North Kuzbass conditions was usually about of 6 m. Thus, measurement of electromagnetic radiation during repair shift can characterize at least daily activity at a coal drift face.

After registrations of natural electromagnetic radiation activity, the degree of rock–gas outburst hazard at that point of mine working is detected by the standard method of measurement of the volume of drilled coal rubble and gas liberation rate. Forecast boreholes are usually being drilled by intervals (the length of each interval is 1 m). After the drilling of each interval the volume of drilled coal rubble and quantity of gas liberation rate are measured. If both of these parameters exceeded definite limited values, drilling was finished, and the given part of mine working was supposed rock–gas outburst hazardous. Experience of mining works in North Kuzbass shows that formation of rock–gas outburst hazard zones is reliably fixed by the quantity of drilled coal rubble more than 5–6 l/m (liter per meter) and gas liberation rate value more than 5 l/min (liter per minute) at fourth–sixth intervals of forecast borehole (from fourth to sixth meter from a mine working face).

3. Mine investigations

Increase of rock–gas outburst hazard is usually associated with existence of pillars, geological faults, sharp changes of inclination angle or thickness of coal seams (Petukhov and Lin'kov, 1983). We conducted our investigations in coal mines of the North Kuzbass in these conditions.

The first example of the electromagnetic radiation registration is shown on Fig. 1. In this case drift was conducted in the zone of an intensively variable thickness of coal seam and a sharp changeable inclination angle. Fig. 1 shows that a decrease of seam thickness from 2.6 m (18 April) to 1.1 m (from 17 May up to

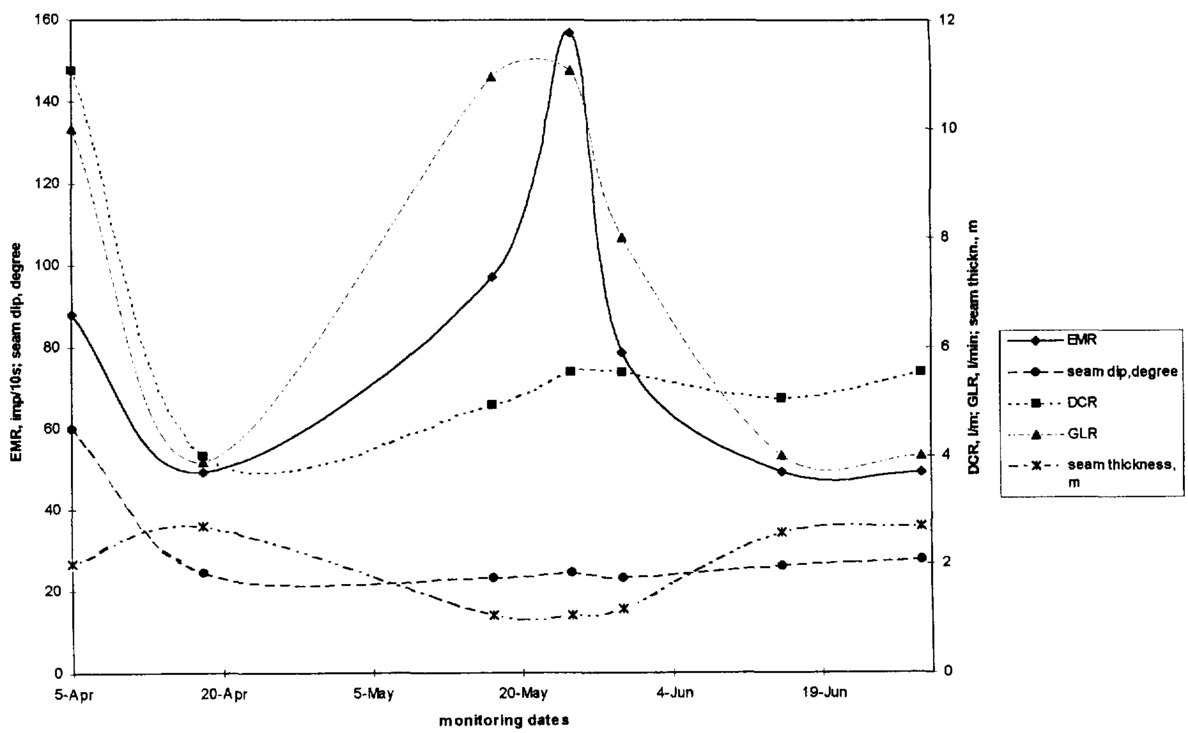

Fig. 1. Electromagnetic radiation monitoring in mine working. Note following abbreviations on this figure: EMR = electromagnetic radiation activity; DCR = drilled coal rubble value; GLR = gas liberation rate value.

30 May) is attended by rock–gas outburst hazard increase (an increase of drilled coal rubble value of up to 6 l/m and gas liberation rate quantity of up to 7–12 l/min), which was followed by an increase of a natural electromagnetic radiation activity level. Restoration of coal seam thickness up to its original value (15 June–29 June) decreases drilled coal rubble and gas liberation rate parameters to their regular levels and also electromagnetic radiation activity. An increase of electromagnetic radiation activity was also obtained during drift conduction through the inclination angle raise (up to 60°) of coal seam (5 April, Fig. 1).

An example of electromagnetic radiation registration at the zone of geological fault influence is shown on Fig. 2. At the distance of 8 m from the geological fault anomalous electromagnetic radiation activity was registered (20 October, Fig. 2). Control boreholing showed that the value of drilled coal rubble was of up to 6 l/m and gas liberation rate was of up to 16 l/m (Fig. 2). Further conduction of this drift was outside the fault influence and electromagnetic radiation activity was at usual level (from 5 November up to 28 October).

The electromagnetic radiation monitoring was also conducted in mine working where influence of pillars was found along 150 m of a drift. Profiling of the mine working showed electromagnetic radiation activity at stressed region under pillar (values of drilled coal rubble and gas liberation rate were also irregular-more than 7 l/m and 8 l/min respectively.

4. Electromagnetic radiation forecast criterion development

We conducted more than 50 investigations in rock–gas outburst dangerous and nondangerous mine situations. Fig. 3 depicts a scatter of elec-

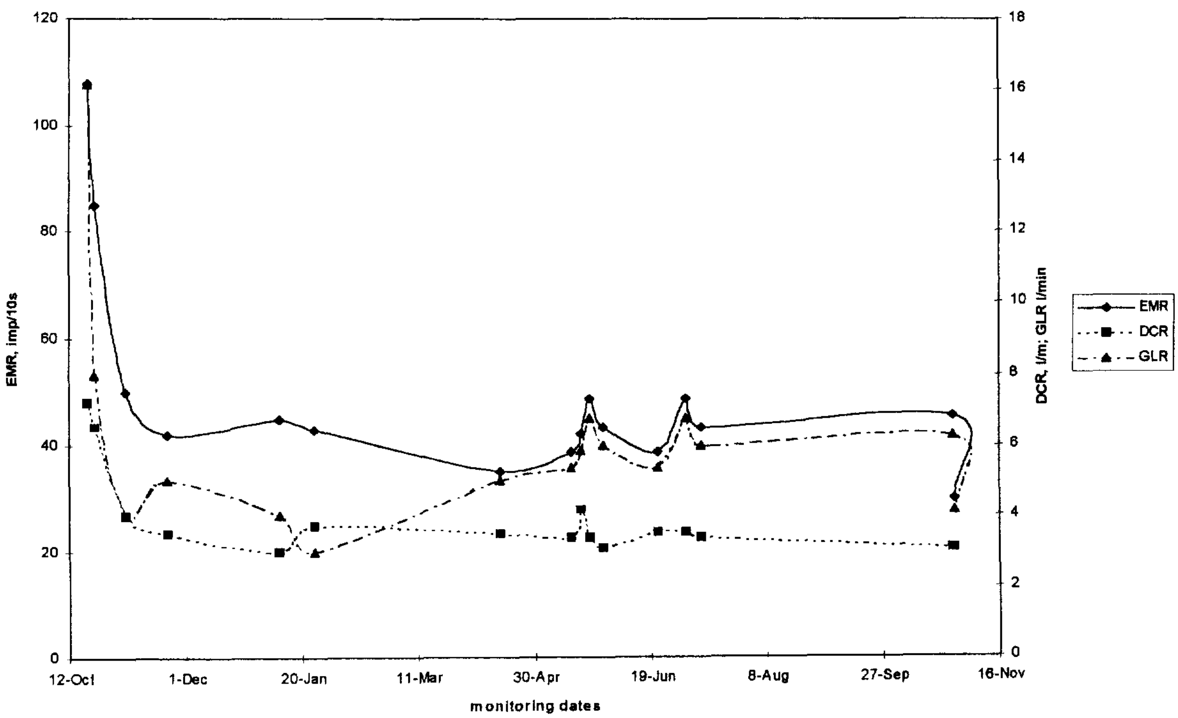

Fig. 2. EMR monitoring in drift (for abbreviations see Fig. 1).

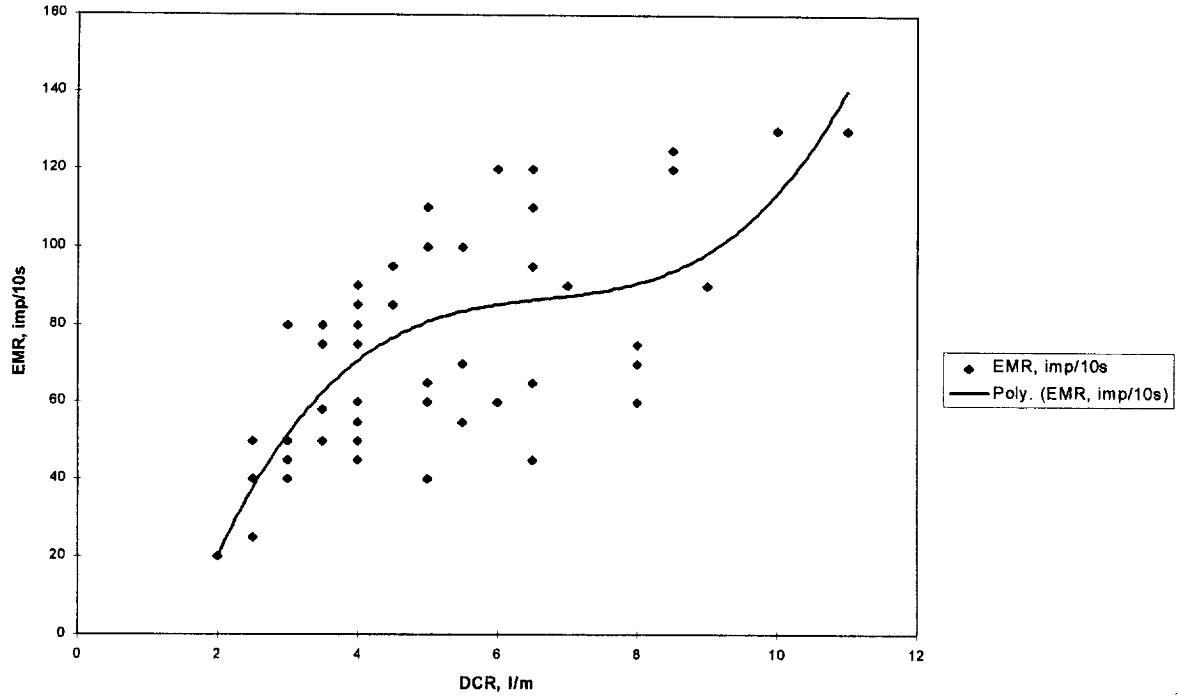

Fig. 3. EMR activity vs. drilled coal rubble (for abbreviations see Fig. 1).

tromagnetic radiation activity data versus drilled coal rubble values, while Fig. 4 shows the first one versus gas liberation rate values. Note, that experimental electromagnetic radiation data is marked by hatched points on either figures. An examination of these two stretches discloses a

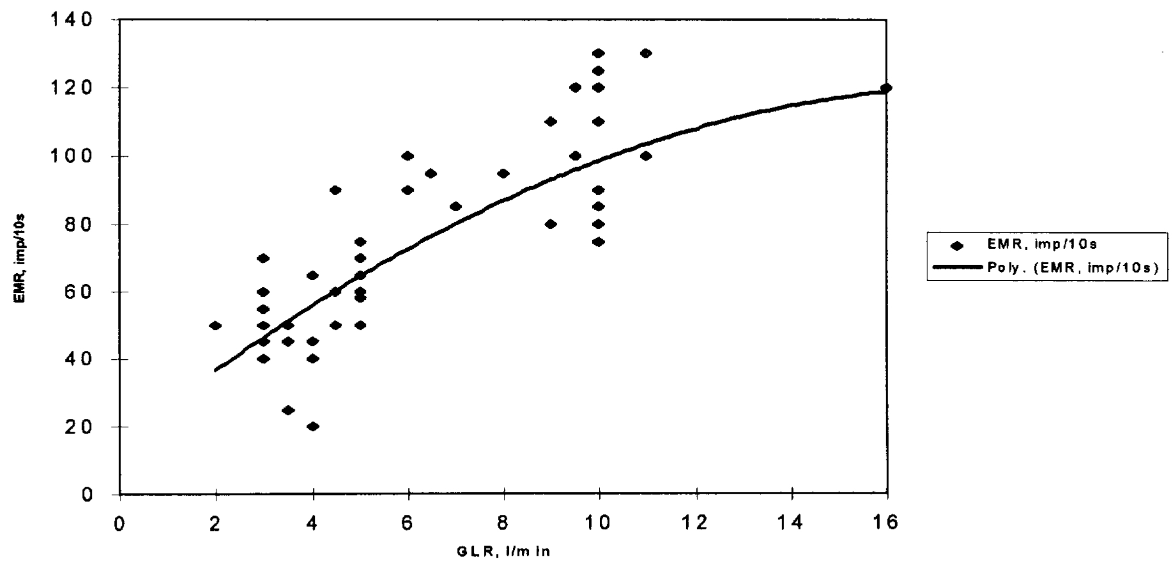

Fig. 4. EMR activity vs. gas liberation rate (for abbreviations see Fig. 1).

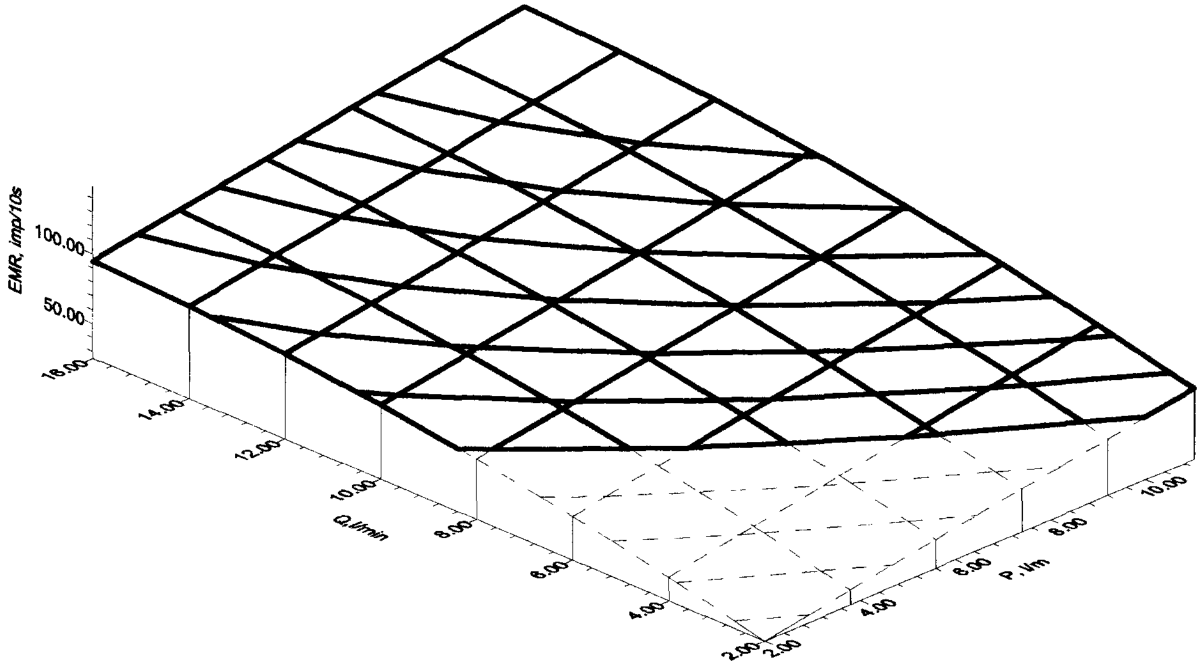

Fig. 5. EMR activity surface vs. drilled coal rubble (P) and gas liberation rate (Q).

significant data dispersion in the both cases. Squared regression coefficients in both cases are not more 0.7. However, it would be correct to note that trendlines on both of these figures intimate clear tendencies of Electromagnetic radiation activity increasing by a raise of both

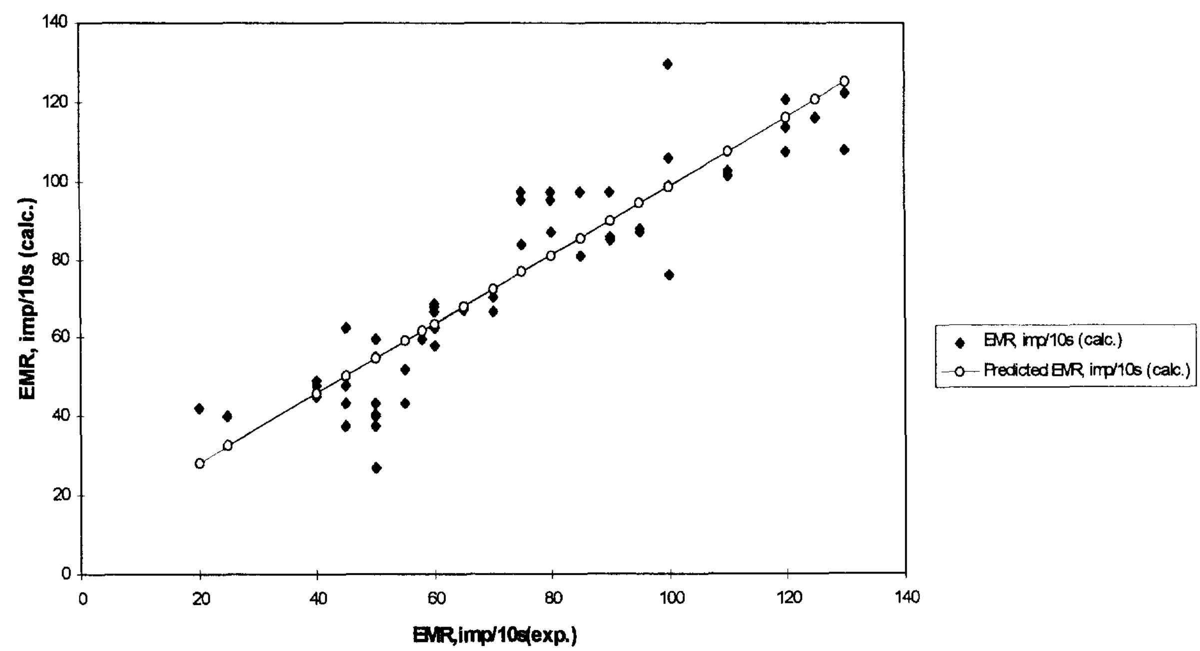

Fig. 6. Regression between EMR activity experimental and calculated data (for abbreviations see Fig. 1).

Table 1
Statistical analysis experimental and calculated data

Statistical parameters	DCR (l/m)	GLR (l/min)	EMR (EXP) (imp/10 s)	EMR (calc.) (imp/10 s)
Mean	4.91	6.43	72.72	74.77
Median	4.00	5.00	70.00	69.66
Minimum	2.00	2.00	20.00	26.95
Maximum	11	16.00	130.00	129.71
Count	58.00	58.00	58.00	58.00

drilled coal rubble and gas liberation rate. We hypothesized that these low correlation coefficients show that value of electromagnetic activity depends not only on one from these parameters individually, for example, on drilled coal rubble value or on gas liberation rate quantity but on both of them together. To examine this hypothesis we stretched all experimental data (58 experimental points) in the form of electromagnetic activity surface versus drilled coal rubble volume and gas liberation rate quantities (Fig. 5). The equation of this surface calculated by the least-squares method is the following:

$$N(P, Q) = -16.1651 + 13.2875Q - 0.361033Q^2 + 6.44858P - 0.227596PQ, \quad (1)$$

where N is electromagnetic radiation activity, while P and Q are drilled coal rubble and gas liberation rate quantities respectively. Comparison of experimental and calculated (Eq. (1)) electromagnetic radiation data reveals a very good correlation (Fig. 6) The correlation coefficient is 0.908. Thus, Eq. (1) reflects existence of relationship between electromagnetic radiation activity of coal seam on one side and drilled coal rubble and gas liberation rate quantities on the other side. As we noted above, these two latter parameters characterize rock–gas outburst hazard development. Hence, electromagnetic radiation activity increase reflects its formation also.

We used this equation for the electromagnetic radiation criterion forecast working out. As it was noted above, formation rock–gas outburst hazard zones is fixed by quantity of drilled coal rubble more than 5–6 l/m and gas liberation rate more than 5 l/min. Electromagnetic radiation criterion calculated by the Eq. (1) on the basis of this values is 67–73 imp/10 s, that is close enough to the mean and median values of electromagnetic radiation experimental (and also calculated) data (Table 1).

The analysis of a rock–gas outburst hazard estimations by both methods (by the drilled coal rubble–gas liberation rate method and by the proposed electromagnetic radiation activity criterion) shows that correlation coefficient between them is of 0.966. That indicates a very high forecast probability by the electromagnetic radiation method. Thus, if electromagnetic radiation activity is more than 70 impulses per 10 s, a given zone of mine working would be detected to be rock and gas outburst dangerous. This dangerous range of electromagnetic radiation is shown by the bold lines on Fig. 5, while nondangerous by the dotted lines.

5. Discussion

Eq. (1) allows to explain the relationship between a buildup of stress and gas liberation in a mine working face (hence, rock and gas outburst hazard raise) and an increase of electromagnetic radiation activity. As seen, electromagnetic radiation activity level is affected by both stress level and gas liberation rate. An extension of stress level near mine working causes an intensive fracturing process at the zone of extremely stressed coal. This fracturing process is the source of electromagnetic radiation activity increase. Therefore, fracturing of coal seam at the zone of higher stress excites an intensive process of gas liberation and in turn it forms additional internal pressure. This gas internal pressure is something akin to tension stress in coal mass that enhances fracturing vigor. In this manner it also magnifies electromagnetic radiation activity. Thus, both stress and gas liberation rising results in an increase of electromagnetic radiation activity and, hence, it provides the basis to rock and gas outburst forecast by electromagnetic radiation activity method.

6. Main conclusions

(1) Variations of electromagnetic radiation activity in mine working reflect changes of rock and gas outburst hazard. Measurement of electromagnetic radiation activity is much faster and safer than acoustic emission. Thus, electromagnetic radiation method could be reasonably perspective for 'short term' rock and gas outburst prognosis.

(2) A comparison of electromagnetic radiation data with standard geomechanical method (for coal seams it is the measurement of the volume of drilled coal rubble and gas liberation rate) serves as guide for working out an electromagnetic radiation criterion for rock and gas outburst forecast.

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