

INNOVATIVE APPLICATION OF T-RAY IMAGING UNIT FOR CRACK DETECTION AND MINE SAFETY – AN APPRAISAL FOR EXPERIMENTAL TRIAL

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ABSTRACT

Although extensive instrumentation for strata monitoring has been carried out to know the support-strata response at various mines, still some more innovative techniques are required for identification of deformation of rock, ground movements, cracks etc in mines for taking proper precautions and improving safety measures. Although efforts are being made in many coal mining areas to establish strata management cell as per recommendations of the 10th National Conference of Safety in Mines held at New Delhi 26-27th Nov, 2007, further modifications are required for its proper organization with suitable instrumentation. This paper presents overview of problems of mining in India and the need of innovative applications of trans-disciplinary research for geotechnical investigations for improved safety. Instrumentation required for better understanding of strata behaviour around underground opening is presented. Recent studies also describes the integration of TDR directly with Arduino boards and XBee modules for real-time transmission of slope monitoring data as a part of Ministry of Mines, Government of India (GOI) sponsored project. In view of the significant level of accidents due to roof/side falls, slope failures in Indian mines, emphasis is made on the recent trends in geotechnical instrumentation including innovative application of T-ray unit for crack detection for better understanding of strata behaviour in underground and opencast mines. Experimental trials in the laboratory and mining field are required to implement solid-state T-Ray source and detector array in the wideband (75 GHz to 0.75 THz) tunable frequency range network along with Network analyzer and thermal spectrum analysis algorithm based on the imaging data for warning of mining accidents. The novelty of the project is that for the first time solid-state T-Ray source and detector array based imaging tool will be used for crack identification in Mines (coal / metallic sample) by studying /mapping variation of dielectric properties and thermograph images at a time.

INTRODUCTION

In India, about 3000 Mt of coal reserves is locked up in pillars of existing coal mines, and similarly considerable ore reserve is awaiting suitable technology for extraction with safety and economical mining. Liquidation of these pillars is now becoming essential from various points of view such as to avoid crushing, heating, locking of bottom seam as well as to maintain these pillars. Considering the quantity of coal which is blocked, the extraction has to be faster, productive and safe. Although various Mechanized technology as one of the solutions to liquidate these standing pillars at suitable locales is being implemented, instrumentation to understand the status of workings need further innovative applications of Electronics and computer science for improving the safety. The progress of the technology in many branches of engineering is quite rapid in recent years. However, in case of underground coal mining, the progress is not as expected. It remained a lot with traditional systems, and only a few attempts were made to adopt/absorb recent trends. Although it could be attributed partly to availability and adoptability of the modern mining machinery, but also mainly due to limitations of available strata control technology, be in underground (suitable designs of workings and support systems) or opencast mines (suitable design of pit slopes, and stabilization of high walls/spoil dumps etc).

In olden days, due to lack of proper instruments, qualitative observations with limited possibility of quantification lead to some empirical relations/thumb rules. However, now-days, with improved technology of mining/instrumentation, numerical models - computer applications for analysis of data; investigators gained enhanced satisfaction through observational approaches. Acceptability of such studies by the field personnel may be improved by proper interpretation of the data so generated by experts in the strata monitoring. There is a need to be more innovative in application of the existing instrumentation with proper planning by experienced strata control engineers which may lead to possibility of modification in existing practices for better safety and economy of mining venture.

UNDERGROUND MINING – SAFETY ISSUES

Nearly 61% of the total reserve of coal is estimated within 300m depth cover, distributed in all coalfields from Godavari Valley to Upper Assam. The prime quality coking coal of Jharia is available mainly in upper coal horizons while the superior quality non-coking coal of Raniganj is available in lower coal horizons. The quality coal of central India to Maharashtra is also available mainly in seams within this depth range. As a result all the mines worked such seams extensively, primarily developing on pillars and depillaring with sand stowing. With the unfavorable economics of sand stowing and non availability of virgin patches for further development, most of the mines have been working- splitting or slicing the pillars, winning roof or floor coals manually or with SDL, conveyor combination. Typical situations of underground coal mines with pillars and roof susceptible for cracks and need of suitable monitoring instrumentation to understand the stability is shown in Fig 1.



Fig 1: Status of pillars in typical underground coalmines prone for cracks and failure

India has large resources of coal deposits for underground mining and lot of coal was blocked in existing underground mines. Safe extraction of these can be made possible by effective strata management. Accidents due to movement of strata in underground coal mines (Table 1) had been a major concern for the mining industry and it is largest contributing factor of underground coal mine accidents. Continuous efforts were being made by all concerned to reduce the hazard of strata movement. The analysis of the accidents due to strata movement for last 12 years (1997-2008) revealed that the roof fall and side fall accidents accounted for 59% of all below ground fatal accidents in coal mines. All types of strata were involved in roof and side fall accidents (shale, coal, sand stone, shaley coal, shaley sand stone etc. Accidents due to fall of roof occurred in almost same proportion in bord & pillar development as well as depillaring districts.

Table 1: Cause wise Fatal Accidents in Coal Mines, due to ground Movement.

| Year | Fall of roof | Fall of sides | Total | Total below-ground accidents | Percentage of accidents due to strata movement |
|--------------|---------------------|----------------------|--------------|-------------------------------------|---|
| 1997 | 38 | 12 | 50 | 94 | 53 |
| 1998 | 35 | 15 | 50 | 80 | 62 |
| 1999 | 33 | 11 | 44 | 74 | 59.5 |
| 2000 | 27 | 14 | 41 | 62 | 66 |
| 2001 | 30 | 9 | 39 | 67 | 58 |
| 2002 | 23 | 11 | 34 | 48 | 70 |
| 2003 | 18 | 5 | 23 | 46 | 50 |
| 2004 | 26 | 8 | 34 | 49 | 69 |
| 2005 | 18 | 7 | 25 | 49 | 51 |
| 2006 | 13 | 4 | 17 | 44 | 40 |
| 2007 | 13 | 4 | 17 | 25 | 68 |
| 2008 | 13 | 7 | 20 | 33 | 60 |
| Total | 287 | 107 | 394 | 671 | 59 |

The condition of strata and the stress environment around any working place is always dynamic in nature. No two working place are having identical strata condition. It is therefore essential to assess the roof condition of the working places at regular intervals by scientific methods. The analysis of the accidents, observations of the DGMS officers during the inspection of mines revealed that a system of monitoring of strata movement was not in vogue. Most of these accidents can be prevented by effective monitoring the strata movement and implementing SSR. Therefore, it is essential to further emphasis on the issue of strata control mechanism to reduce the accidents due to strata movement (fall of roof & sides).

In every coal mining company, strata control cell shall be established at corporate and area levels within one year as per recommendations of the 10th National Conference of Safety in Mines held at New Delhi 26-27th Nov, 2007. However, till now strata control cell not establish in all the coal mining areas as required. This may be attributed partially due to lack of proper responsiveness among the officials of some coal mining Industries. Strata control cell in coal mines can assist mine managers, for formulation of Systematic Support Rules, monitoring strata control measures in a scientific way to ensure efficacy of support system and, for procurement/supply of quality supporting materials. This issue can be addressed by proper monitoring of strata and taking adequate control measures in time. Geotechnical instrumentation although has been extensively used in the coal mines, still there is no standard procedures for undertaking the investigation as well as type of instrumentation for monitoring of the strata behaviour. Keeping this in view, two short term courses were held at NIT-Rourkela on “Trends in strata control techniques and instrumentation for enhancing safety in coal mines” during July 28th--31st, 2008, and Nov 19th - 22nd, 2009. The Mining Engineering department of NIT-Rourkela also conducted Workshop/ Training programs in coalfield areas of M/s SCCL, SECL, WCL, MCL etc under the TEQIP sponsored by the World Bank through National Project Implementation Unit during Oct-Dec’08. Strata control technologies have undergone considerable change and it is pertinent that the field engineers must be trained in the state of the art instrumentation for effective implementation of the strata control measures in coal mines.

OPENCAST MINING – SAFETY ISSUES

The economic concerns and operational problems associated with unstable slopes state the need of suitable slope monitoring and management measures. Available Geotechnical sensors include vibrating wire piezometers, wire line extensometers, borehole extensometers, inclinometers; tilt meters etc. for sensing the changes in slope conditions, besides widely practiced total station monitoring. These geotechnical instruments are monitored by technicians in the field. Figure 2 shows the Slope Disaster at Rajmahal opencast mine, Eastern Coal Limited (ECL), India on 29-12-16 and Bingham Canyon Mine, southwest of Salt Lake City. The analysis of accident in open pit mine publicized that slope failure and dump failures have upward trends in the recent time[1]. Few examples of fatal accident involving slope and dump failure are mentioned in table 2. Available electronic instrumentation includes vibrating wire piezometers, wire line extensometers; borehole extensometers, electrolytic bubble Inclinometers and tilt meters for sensing the changes in slope conditions, besides widely practiced total station monitoring. Technicians in the field can monitor these instruments. This research work is focused on the application of electronics and communication work deals with the elimination of manual slope monitoring in the industry with the help of Wireless Network Infrastructure replacing the need for physical cables. Fig 3 shows Status of benches in typical opencast mines prone for cracks and failure



Fig.2 Slope Disaster at Rajmahal opencast mine, ECL, India on 29-12-16 and at Bingham Canyon Mine southwest of Salt Lake City, USA on 10-04-13.

Table.2. Few Examples of Fatal Accident involving Slope and Dump Failure

| Date | Name of Mine | Incidence | Fatal |
|-------------|---|--|--------------------------------|
| 24.06.2000 | Kawadi Open Cast (OC) Mine of M/s Western Coalfields Limited(WCL) | Slope failure of 31m high OB benches. | 10 |
| 09.12.2006 | Tollen Iron Ore Mine of M/s Kunda R Gharse in Goa | Failure of Slope 30m to 46m high Dump. | 06 |
| 17.12.2008 | Jayant OC Project of M/s Northern Coalfields | Failure of Dragline Dump. | 05 persons 01 Shovel Buried |

| | Limited(NCL) | | |
|----------------|---|---|--|
| 04.06.20 09 | Sasti OC Mine of WCL. | Dragline OB dumps of 73m height failed and slid down the pit. | 02 Persons 02 Excavators Buried |
| 25.02.20 10 | Hansa Minerals and exports Granite Mine. | Granite mass slid along an inclined joint plane and failed from height varying from 10m to 55m. | 14 Persons |
| 22.06.20 14 | Amlai Opencast Mine, South Eastern Coalfields Limited (SECL). | Dump failure due to sudden development of cracks in the embankment and Unstable Ground Conditions | 2 Persons 1 Dumper 1 Dozer 1 Crane |
| 29.12.20 16 | Rajmahal OCP of Eastern Coalfields Ltd(ECL) | Dump failure due to development of cracks and Unstable Ground Conditions | 23 Persons 12 Tippers 6 excavators & 1 dozer |



Fig 3: Status of benches in typical opencast mines prone for cracks and failure

Although extensive instrumentation for strata monitoring has been carried out to know the support-strata response at various mines, still some more innovative techniques are required for identification of cracks in mines. Continuous monitoring of strata behaviour in terms of convergence of openings in advance on either side of the extraction line, and stress levels over pillars, stooks in advance of the extraction and ribs in the goaf was required through remote monitoring instruments for understanding the strata mechanics at critical conditions of roof falls. Continuous monitoring of support pressures was attempted to investigate the rock mass response to mechanised pillar extraction (Follington IL and Huchinson, 1993). Integrated Seismic System (ISS) was introduced for an experimental trial at Rajendra mine, SECL, for prediction of strata movement during coal extraction by longwall mining. The system developed by South Africa works on the principle of monitoring microseismic activities through geophones. The concept of tele monitoring or online monitoring is yet to be established to improve the safety aspects in underground coal mining. The use of Borehole TV Camera for caveability studies is the need of the hour for detailed analysis of strata behaviour during mining.

GROUND CONTROL AND GEOTECHNICAL INSTRUMENTATION

Geotechnical instrumentation although has been extensively used in the coal mines, still there is no standard procedures for undertaking the investigations as well as type of instrumentation for monitoring the strata behavior. Over the years, geotechnical instrumentation and strata control technologies have undergone considerable change and it is pertinent that the field engineers must be trained in the state of the art instrumentation for effective implementation of the strata control measures in coal mines. Purpose of the instrumentation should be clear for the planners before commissioning any instruments for understanding strata behaviour. Inadequate number or improper selection of instruments may lead to unsafe decisions by mine planners, while more than required number/type of instruments, not only lead to confusion but also uneconomical. Therefore, experienced strata control engineers with proper understanding of the field problem, and sufficient knowledge on interpretation of the so generated data are primary requirements for a successful instrumentation program. Some of the common requirements for use of the strata monitoring instruments in underground coal mines are as follows:

Comparison of effectiveness of different strata control practices:

Qualitative as well as quantitative nature of strata behaviour was monitored in the development galleries. Details of the strata monitoring instruments, namely, convergence stations, extensometers and Tensmeg strain gauged cables along with other type of strata monitoring instrumentation are presented elsewhere (Jayanthu et al., 1998, CMRI, 1997, NIRM, 1997, 1998, 1999). These monitoring stations installed at about 10 m interval along the galleries and in junctions of the development workings with different type of supports could be used successfully for understanding the effectiveness of the support system with cable bolts and roof bolts.

Prediction/warning of roof falls:

Prediction of strata behaviour by theoretical analysis become unreliable due to almost impossibility of simulation of the real field conditions in mathematical, physical or numerical models. Thus, empirical formulation, based on in-situ measurements of strata behaviour parameters, is an accepted way to estimate the strata behaviour.

Critical conditions of strata behaviour invariably occurred in Indian geomining conditions after extraction of two rows of pillars with 50 – 60 m span, and at an area of extraction of 4,000 - 6,000 m² including the ribs in the goaf. Therefore, strata pressure and its manifestation in terms of convergence need intensive monitoring at these conditions. Attempts made for warning of such condition include measurement of convergence of galleries around the extraction line on daily basis, but indices formulated in terms of rate of convergence per day appeared to be useful for 60% of the cases. Continuous monitoring of strata behaviour in terms of convergence of openings in advance on either side of the extraction line, and stress levels over pillars, stooks in advance of the extraction and ribs in the goaf was required through remote monitoring instruments for understanding the strata mechanics at critical conditions of roof falls. Continuous monitoring of support pressures was attempted to investigate the rock mass response to mechanised pillar extraction by many investigators (Follington IL and Huchinson, 1993). Convergence of advance workings in depillaring panels has been widely believed to be a reliable indicator for warning of goaf falls. However, misconception on the limitations of the warning limits, interpretation of the convergence data caused confusion in taking the decisions on safety of the workings and the face workers in many situations of depillaring. Thus, the design and successful implementation of the warning system as part of the mine production cycle pose a stern challenge to mine managements. It is a challenge that will require adoption of a multi-disciplinary approach.

Many accidents in depillaring panels in recent times are self revealing and emphasizes the need of proper education to the concerned on the limitations and applicability of the existing guidelines and further studies required for the purpose. Many a times, the rate of convergence in advance galleries/workings exceeding 2

mm/day has been adopted for prediction (probable warning) of goaf falls in depillaring panels in Indian coal mines (Anon, 2001). The term, “prediction” may not suite well to the situations with uncertainty of input data such as; geo-mechanical properties, variation of different parameters from site to site etc (Peng et al, 1998). Therefore, use of only the term “probable warning” of goaf falls is emphasized in this paper. Prediction (probable warning) of goaf falls based on convergence data was discussed by many investigators (CMRI, 1987; Maity et al, 1994; NIRM 1997). However, its applicability in varying geomining conditions was not widely evaluated. As a result, applicability of such guidelines to the situations of some of the accidents, resulted in conclusion of the strata mechanics analysis as “a gods act”, in view of the “art” of mining still taking over the available “Science” of mining. In all, strata movement has been accounted for about 30% of the total underground accidents due to fall of roof (Jayanthu et al, 1998). Nearly 50% of the accidents are in depillaring areas, and about 15% are due to abutment pressure. On the whole, 1/6th of the accidents are attributable to lack of prior knowledge of unsafe conditions and unavoidable. This indicates the need of detailed technical examination of methods of extraction, formulation of reliable guidelines for warning of roof falls, and strategies to be adopted for improved safety, productivity and conservation.

Generation of data base/formulation of guidelines/ Evaluation of applicability of existing guidelines:

Technically, observational approaches for strata control have been widely thought over but limited attempts were made due to need of additional instruments for the purpose of monitoring of the roof behaviour. Various instruments visually showing bed separation, etc, are used in UK, USA etc, to evaluate the effectiveness of the support/stability of roof. Modifications in the support systems were made based on the data from these instruments. A typical instrumentation at par with the International standards has been suggested for recent trials at some of the Indian mines, where the pillaring is critical due to difficult strata conditions (Fig 4).

Probable issues inhibiting formulation of reliable guidelines may be due to widely varying site conditions from one panel to another, limitations of the existing instrumentation, practical problems of commissioning and maintaining the instruments, collection of the monitoring data, lack of proper experience/exposure of the investigators/front line supervisors to understand and infer the data, which may misguide the miners and probably create confusion on taking proper decisions based on such guidelines. Consequently, a permanent loss of the property or life is imminent in view of improper understanding of the limitations of the instruments, reliability of the data and the probably misleading inferences. Keeping these issues in view, an attempt is made to study the applicability of the existing guidelines for warning of roof falls based on convergence data with respect to the experimental studies in a bord and pillar panel at New Chirimiri Ponri Hill (NCPH) mine, Chirimiri area of South Eastern Coalfields Limited (SECL) (Jayanthu, 1999). Based on the available convergence data of four experimental panels, attempt was made in the beginning to derive warning limits based on application of the existing guidelines for warning of major roof falls.

About 250 records of convergence were available for different monitoring stations before local/major falls in the four depillaring panels. The distance between the monitoring station and the goaf edge was in the range of 5 to 50 m, and about 30 records were also available for the convergence inside the goaf. Maximum convergence recorded in panel #15, #16, #17 and #18 in advance workings/split/galleries was 26 mm, 20 mm, 28 mm, and 37 mm respectively (Jayanthu,etal 2004). Statistical analysis was conducted on the data eliminating the readings of some of the disturbed stations. Maximum rate of convergence before the major roof fall increased upto 4 mm/day within 10 m from the line of extraction, while it was within 1 mm/day beyond 50 m in advance of line of extraction. It also indicated poor probability of warning of roof falls on the basis of cumulative convergence or the rate of convergence on daily basis. However, based on this data it can be said in general terms that cumulative convergence exceeding 20 mm has a probability of 80% for warning of fall, while the rate of convergence exceeding 1.5 mm/day has 60% probability of warning the major roof fall in case of the instruments located within 60 m in advance of line of extraction. The present practices and purpose of some of the strata/support monitoring instrumentation is as follows:

Extensometric Monitoring

Multi-point magnetic-ring extensometers will be used to monitor the bed separation up to 8 - 10 m in the roof at a few selected locations. A few Tell Tale instruments will also be installed for estimation of bed separation in the roof. Extensometers may also be installed in the floor, to determine the extent of floor heave. Similarly, the sides also will be monitored to assess the movements within the pillars. Based on the data recorded, the horizon of the weak planes along which bed separation or fracture is taking place, will be identified.

Strain in the Bolts

Instrumented bolts will be installed in the roof. These instruments will provide information about the strain or load developed along the length of the grouted bolt at different portions. These instruments will also be used in the sides of the pillars/floor to estimate the thrust

Load on Bolts

Anchor load cells will be installed along with the freshly installed bolts. These load cells will indicate the total load exerted by the strata along the bolt length.

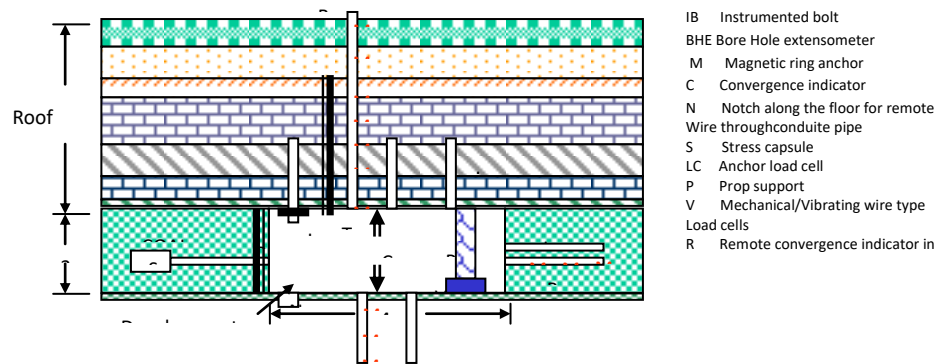


Fig 4: Typical instrumentation for strata monitoring around underground workings.

Stress Changes

The change in stress with the extraction process will be monitored using stress gauges installed in the pillars. They will be installed at suitable depths inside the pillars, and they will be monitored as the drivages progress.

Roof-to-Floor Convergence

Convergence points would be installed at suitable locations for recording roof to floor movements at different stages of depillaring. The telescopic rod convergence meter measures the distance between two pegs, one in the roof and the other on the floor vertically below it. Remote convergence stations function on the principle of change of resistance due to convergence.

Following text gives the latest developments in crack/fissure identification & monitoring in tunnels and mines. Literature survey reveals that research in this specialized field is very limited and no published report is available in National context.

The dielectric properties of anthracite and bituminous coals were investigated in the terahertz (THz) frequency region from 100 GHz to 500 GHz (C.J. Huber et.al., 1999). Two types of THz material measurement systems that can be operated in this frequency region, including one based on a vector network analyzer (VNA) with frequency extension modules, and another based on a THz time-domain spectroscopy (TDS) system has been developed. Employing the free-space configuration, variation of dielectric property of coals in the frequency region of 100–500 GHz has been obtained. By comparing the VNA and TDS systems, we evaluated the continuity and consistency of the two systems and verified the dielectric property measurement results of coal in the entire frequency region. The paper first outlined the fundamental theory of dielectric property with both methods, followed by estimating the measurement error in consideration with the system stability, the time span of the time-domain gating, and measurement uncertainty. The study evaluated the dielectric property of coal samples through the measured results of the VNA and TDS systems. Comparison is also made of the variation of measured dielectric property with the lower THz frequency region (W-band) in previous work. The results show that different coal type exhibited different variation with increasing frequency in the THz band considered.

A surface-breaking hairline crack or a narrow slot in a metallic specimen when scanned by an open-ended rectangular waveguide probe influences the reflection-coefficient properties of the incident dominant mode. Subsequent recording of a change in the standing-wave pattern while scanning such a surface results in what is known as the crack characteristic signal (Wei Fan et.al., 2017). Since microwave signals penetrate inside dielectric materials, this methodology is capable of detecting cracks under dielectric coatings of various electrical thicknesses as well. To electromagnetically model the interaction of an open-ended rectangular waveguide with a surface-breaking hairline crack under a dielectric coating, the dielectric-coating layer is modeled as a waveguide with a large cross section. Thus, the problem is reduced to a system of three waveguides interacting with each other while the location of the crack is continuously changing relative to the probing waveguide aperture (a dynamic scanning problem). An analysis of modeling the dielectric-coating layer as a dielectric-filled waveguide with a large cross section is given, and its comparison with radiation into an unbounded medium is presented. For obtaining the reflection coefficients of the dominant and higher order modes, the electromagnetic properties of the probing waveguide—dielectric coating layer junction and the dielectric-coating layer—crack junction are separately analyzed. For each junction, a magnetic current density M is introduced over the common aperture. Subsequently, the junction formed by the two respective waveguide sections is separated into two systems. A numerical solution employing the method of moments is obtained, and the properties of the junctions are expressed by their respective generalized scattering matrices. Consequently, the generalized scattering matrix for the total system can be evaluated. The convergence behavior of the system is studied to determine an optimal set of basis functions and the optimal number of higher order modes for a fast and accurate solution. Finally, the theoretical and measured crack characteristic signals are compared.

To study the mechanism of surface collapse and crack evolution in a roadway chain failure process in the pillar recovery of Hongling lead zinc ore in Inner Mongolia Province, China, micro seismic monitoring technology, moment tensor theory, and numerical simulation are used for the inversion of rock mass fracturing, the destruction type classification of crack, and the mechanism of surrounding rock (G. Hu *et. al.*, 2017). Research shows the following: (1) the rock mass fracturing is first produced within the +955 m level, before extending through the hanging wall to the ground surface. (2) The mechanism of surface collapse is as follows: after the recovery of pillars in the +905 m level, tensile cracks generated in the top of orebody #2 extend upwards and obliquely. (3) The mechanism of crack evolution is as follows: after the recovery of 5107 pillars, the footwall haul road in the +905 m level was damaged and collapsed by the cut-through cracks. Those cracks then continue to extend upwards and converge with the slanting shear cracks in the +905 m level, which form a triangular failure in the footwall rock. Finally, the failure causes

the tensile and shearing cracks in the haulage way of the +955 m level to extend and connect, which forms the haulage way chain failure.

Being the key unaddressed problem in unmanned mining condition, a new method for the coal-rock interface recognition was proposed in the study (Xin Wang, et al., 2016). Firstly, terahertz time-domain spectroscopy (THz-TDS) was employed to measure 10 kinds of coals/rocks which were common in China. Secondly, the physical properties of coals/rocks such as absorption coefficient spectra, refractive index, and dielectric properties in THz band were studied. The different responses in THz range caused by diverse components in coals/rocks were discussed, and the dielectric property of coals/rocks in THz band was well fitted by the Lorentz model. Finally, by the means of principal component analysis (PCA), support vector machine (SVM), and THz spectral data, the recognition rate of coals/rocks reaches to 100 % and the recognition rate of different bituminous coals reaches to 97.5 %. The experimental results show that the proposed method is fast, stable, and accurate for the detection of coal-rock interface and could be a promising tool for the classification of different bituminous coals.

The dielectric properties of Shanxi anthracite and Shandong bituminous coals in China are investigated in the low-terahertz (THz), W-band of frequency from 75 GHz to 110 GHz for the first time. In this frequency range, the complex dielectric constant of coal samples is obtained using the free space method. It is found that both the real parts of the dielectric constant for bituminous and anthracite decrease considerably with increasing frequency from 75 GHz to 110 GHz (Wei Fan et al., 2015). The dielectric properties of all the coal samples are strongly dependent on the moisture content of the coals. Increasing moisture content leads to higher complex dielectric constant values. The effect of moisture on the dielectric properties of coals depends substantially on the influence of moisture content on the transmission and reflection of THz wave in the coals. The results show that the transmission coefficient of anthracite and bituminous exhibits an exponentially decreasing trend with increasing moisture content (from 0% to 10%). However, the reflection coefficient seems to follow a Gaussian-like changing trend with increasing moisture content, reaching a maximum around 4.5%.

INNOVATIVE APPLICATION OF T-RAY IMAGING TECHNIQUE –A PROPOSAL

Although, many types of instruments as above are being used for understanding ground behaviour in mines, the efforts to give sufficient warning of instability of underground or opencast workings/formation of cracks etc to improve safety of persons and equipments. Few techniques such as T-Ray appear to be useful and proposed to experiment in mining conditions. T-Ray imaging has not yet been employed for identification of crack. As a better replacement of conventional invasive and non-invasive techniques, in terms of low cost and accuracy, this project, for the first time, is proposing a cost-effective T-Ray imaging technique for precision detection of crack (open/hidden) in Mines. The output of the Phase I will be coupled with Phase II as a starting point. The author will study the potentiality of the designed T-Ray sources to detect abnormalities in the sample on permittivity difference and thermal imaging between normal and fissure structure. In this method a quasi 3D Mine sample (Coal / Metal) model will be developed with source and detector array arrangement around it through COMSOL MULTIPHYSICS software compiled with MATLAB. The sample under test will be illuminated by designed T-Ray source array (which will act as radiator) and received waves, i.e. the reflection/refraction from scatterers, at detector array will then be analyzed in order to construct a map of sample's dielectric properties using various signal reconstruction methods that includes: Analytical, Thresholding and 'Hit and Miss Algorithm'. Raster scanning method will be applied. However, in the absence of crack, the scattering in the sample is due only to non-homogeneities which will be considered as noise. To differentiate between proper signal and noise a simple tricks will be adopted, i.e. if a particular sample is submitted to continuous monitoring in a regular intervals the previous images could be used as reference signal. To obtain information about the crack (hidden) location, analysis will be done in three cases: no crack,

centric location and eccentric location. In all cases, average power/heat generated on the surface of all detectors will be calculated using COMSOL thermal mapping tool. Expected results will show that output power/heat mapping is considerably different in the three cases (as a result of presence of water there), and later analysis can extract dielectric properties mapping, which will help in identifying the location of the crack. Fig 5 shows working plan of a typical underground panel with pillars for experimental trial of detection of cracks in pillars by T-Ray.

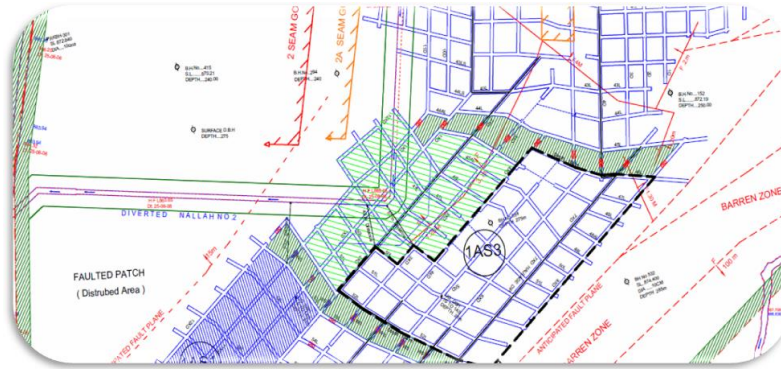


Fig 5: Working plan of a typical underground panel with pillars for experimental trial of detection of cracks in pillars by T-Ray

Thermographic detection of surface temperature variations in presence of the crack/fissure is possible after exposing heating. An approximate line source of heat is used to produce an inplane flow of heat in the sample under test. A crack in the sample perturbs the inplane flow of heat and can be seen in an image of the surface temperature of the sample. An effective technique for locating these perturbations will be presented which reduces the surface temperature image to an image of variations in the inplane heat flow. This technique will greatly increase the detectability of the cracks. This thermographic method has advantages over other techniques in that it is able to remotely inspect a large area in a short period of time. The effectiveness of this technique depends on the shape, position and orientation of the heat source (T-Ray) with respect to the cracks as well as the extent to which the crack perturbs the surface heat flow. The relationship between these parameters and the variation in the heat flow will be determined both by experimental and computational techniques.

In the proposed model T-Ray device matrix/array will emit the T-Ray and a matching matrix will be kept in a “V” position to get the reflectance information, the fraction of incident electromagnetic power that is reflected back (Fig 6). The matching matrix consists of T-Ray array detectors which will work as sensors (low cost pyroelectric sensor could also be employed in this part). An imaging algorithm would be developed so that any abnormality/deviation from reference value could get noticed. Thresholding Program in a Microcontroller unit would be suitable for such analysis. It is expected to be an effective solution towards crack identification for Mining safety.

CONCLUSIONS

Although, many types of geotechnical instruments are being used for understanding ground behaviour in mines, the efforts to give sufficient warning of instability of underground or opencast workings/formation of cracks etc to improve safety of persons and equipments. Compared to conventional invasive system, the proposed system is more accurate and having high-resolution, room temperature operation, compact

and easy to use easy to deploy in underground mine. Conventional systems of crack identification / monitoring with various type of invasive and non-invasive schemes have inherent problem of loss of image resolution, poor contrast, failure in identifying thin underlying crack, requirement of trained manpower and huge dimension of the system thus portability is less. The proposed T-Ray-Thermal imaging and Electromagnetic analysis tool could be used with less complexity, more accuracy and non-destructive analysis of even very thin underlying crack in metal/coal and this in turn with enhance the mine-safety. Meticulous analysis of data through sampling/raster scanning & imaging could lead to formulation of guidelines, for warning of mine accidents due to crack and associated explosion, through continuous monitoring of crack/fissure/deformation by T-Ray non-hazardous imaging. Experimental trials in the laboratory and mining field are required to implement solid-state T-Ray source and detector array in the wideband (75 GHz to 0.75 THz) tunable frequency range network along with Network analyzer and thermal spectrum analysis algorithm based on the imaging data for warning of mining accidents. The novelty of the project is that for the first time solid-state T-Ray source and detector array based imaging tool will be used for crack identification in Mines (coal / metallic sample) by studying /mapping variation of dielectric properties and thermograph images at a time.

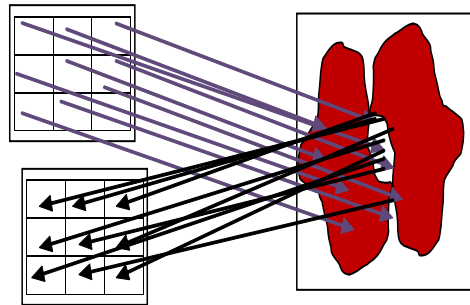


Fig .6: Proposed Scanning Mechanism in crack identification

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