Material Property Detection by Mining Pick Resonance

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ABSTRACT

The characteristics of geological materials being mined can be determined from the audible acoustic response of the picks on the cutting head of the mining machinery. Research has indicated that a simple adaption of existing sound measurement equipment could provide miners with feedback on the hardness and rip ability of the material being mined. This would provide the mining personnel with a non-intrusive device providing immediate feedback on hardness variation allowing the mining personnel to modify their operations accordingly. It has been described as the final step to full automation.

HISTORY & CONTEXT

At the beginning of the last century, much mining was done by hand utilising hand-held picks and shovels. Major mechanisation was a distant prospect. Within that environment, miners had one major feedback mechanism that is missing from current mining operations.

It was in that environment that the sound was dominated by the "ringing of the picks", the sound of metal on stone. It was this sound that provided the miner with feedback on the hardness of the material they were mining.

Even today miners speak of listening to the mine. Away from the face, they will listen to the creaking and cracking of the rock and to the sounds of mine props as stresses are redistributed over time. A creaking mine prop can be a warning of imminent failure with the possibility of cave-in.

Move forward in time, to the end of last century.

The handheld pick and shovel have been replaced by huge mechanised mining machines that rip and gather the ore. The pit pony has been replaced by motorised shuttle cars that shuttle back and forth between the mining machine and the nearby conveyor belt boot.

In this new mechanised environment, the mining operation is dominated by the revving and roaring of mining machinery.

It was in this environment that a simple question was asked in relation to coal mining operations.

The question was "How do the operators tell when they are mining in the coal?"

It was a rather off-hand response by a researcher (in a related field) that initiated the subsequent research. The response was "but you can hear the difference".

Thus it was that six months later that I found myself hundreds of metres underground, covered in coal dust, microphone in hand, standing only metres, from the rotating cutting head of a continuous roadway mining machine.

The aim was to determine whether this statement was true, and if true, whether it could be used to indicate the location of the rock / coal interface.

RESEARCH

Field Work

The field work was carried out in the underground mines in the Illawara and Lake Macquarie coal mining areas.

For each measurement period, all of the equipment had to be conveyed underground at "start of shift".

The recorder and 'barrier box' were set up in the nearest 'safe area', and the extension cable slung from the roof bolts all the way into the area of mining with the "intrinsically safe" hand-held microphone was on the other end of the 100 metre extension cable.

The barrier box prevented any high voltage entering the mining area where methane levels can often exceed explosive levels.

An audio recording was recorded directly on a cassette tapes. The cassette recorder could not be taken to the working face as it was not certified for operation in a methane gas environment.

The mines where the measurements were obtained were all noted by the miners as being amongst some of the most gaseous mines in Australia.

All coal contains some methane gas. It is released by simple diffusion, and by the mining process as the coal is fractured. If the concentration of methane gas in the atmosphere exceeds 5%, it can be ignited.

Mine ventilation is used to dilute the high methane gas concentrations that can occur at the coal face, to less than 5%, well away from the coal face.

If ignited, the fire can spread mine-wide, as the turbulence of the flame front lifts and ignites the ever-present coal dust, leading to a self-propagating coal dust explosion.

It is a major fear amongst the miner at the coal face that the gas mixture could be ignited by either electrical fault or by sparking as the cutting picks encounter the coal/rock interface.

Each cutting session was recorded throughout the shift.

The microphone could not be mounted on the operating mining machine. The microphone had to be hand held within the metre wide gap between the side of the operating mining machine and the side wall, about 3 metres from the coal face.

All incidents of contact between the picks and the coal/rock interface were reported via mine radio.

In this environment, after the initial ‘sumping in’, the whole coal face would often become completely obscured by dust.

A half hour prior to end of shift, all cables and equipment had to be repacked prior to returning to the surface.

Acoustic Environment or Soundscape

The noise of the mining operation is a cacophony of sounds.

At the beginning of the each cut, the mining machine moves forward in a procedure known as ‘sumping in’, pushing the rotating cutting head into the coal face. The cutting head then lifts up the coal face. At the top of the cut, the mining machine again ‘sumps-in’, and the cutting head descends down the coal face. In following that arc, the cutting head either operated from the coal / rock interface to a ‘set’ distance from the interface, or between the roof interface and the floor interface.

In the mining operation, the picks on the rotating cutting head impact with, and fractures, the coal. This fractured coal cascades down to the ground in front of machine. At the front of the machine, the coal is gathered by gathering arms.

The gathering arms pull the coal back onto a central chain conveyor that takes the broken coal up and over the body of the mining machine. At the rear, a second chain conveyor discharges the coal to a shuttle car.

This process continues until the shuttle car is full, or enough of the unsupported roof is exposed that rock bolting is required.

To the casual observer, the scene is dominated by engine noise, by chain conveyor noise, by the cascading coal, and by the impact noise of rock and coal within the chain conveyor.

The Landscape within the Seam

Coal seams and ore seams are not laid out in the perfectly flat planes shown in text books.

The seams follow the terrain of the landscape in which they were laid down and the distortions of the strata in the intervening years.

In underground mines, the ancient terrain will cause the seam to rise and fall as it follow the ancient landscape, as it existed millennia ago. Distortion of the strata will cause the seams to tilt right or left, fore or aft.

At one measurement site, recording had to be deferred as the continuous mining machine negotiated an ancient creek bed.

Over a distance of about 20 metres the floor and roof dipped down several metres and rose again on the other side. The only sign of this feature (initially) was the sudden increase in rock being extracted from the roof.

Coal miners are in the job of extracting coal, not rock. Extended contact with, or excursion into the rock, carries with it the danger of extended sparking. Extracted rock also has the effect, downstream, of excessive wear and tear on conveying equipment and other processes.

It was suggested that at one port each shipment coal can contain up to 10% rock, which later has to be removed and dumped.

Laboratory Analysis

The cassette tapes from each measurement period were taken back to the laboratory for analysis.

Due to equipment limitations, analysis was limited to those frequencies below 2,000 Hz.

The recordings were initially played through an FFT analyser whilst observing the output on a one-third octave band basis.

It was very easy to identify cutting and non-cutting episodes.

It was only when the recordings were observed using the frequency analysis function of the FFT analyser that the interface contact became very clear.

By observing the FFT output, it also became clear, when the cutting head was approaching, or in contact with, the coal-face.

In the working environment, at the coal face, this was not always as clear. It was important to clearly identify each and every interface contact.

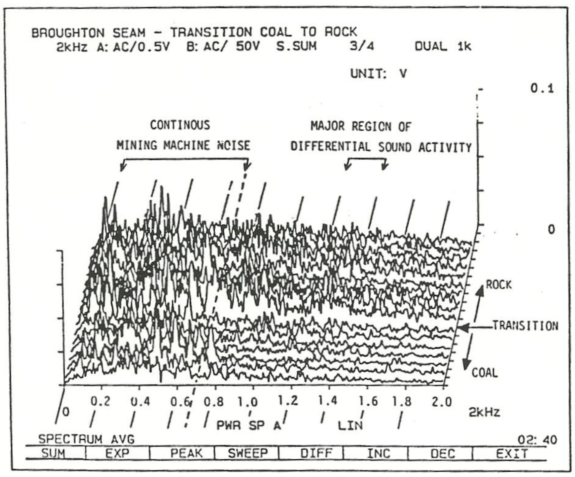

Figure 1. Waterfall representation of transition

After weeks of observing the changing spectrums, and from data obtained at further mines, it became clear (while viewing the FFT output), that there was significant activity occurring in the upper frequencies. This had previously been almost lost in preliminary one-third octave analysis.

Figure 1 shows a waterfall output of one of the contacts.

Below 700 Hz, the spectrums were all dominated by coal on conveyor noise, and by variations in engine noise.

There were at least three active regions above 700 Hz. The relative amplitudes of these regions varied with the relative hardness of the coal and rock. These appeared to be related to specific frequencies.

Sound Source

It was postulated from the 'time of occurrence' and from the 'rise and fall' of these specific frequencies, that the frequencies noted were directly related to the cutting picks.

The cutting head rotates at 50 to 60 rpm. The cutting head has about 230 to 260 cutters, giving about 200 to 260 impacts per second. The testing occurred across a range of machines but pick type and size appeared to be the one constant.

The picks are loose fitting within a pick holder welded directly to the cylinder of the cutting head. Each pick is one solid piece of metal consisting of a conical section leading into cylindrical section, a cylindrical collar, and a shaft for insertion into the holder. The pick is held in the pick holder by a spring loaded locking device.

As the cutting head rotates, each pick is brought into hard contact with the rock or coal surface at about 4 metres per second. This impact appears to be sufficient to cause the pick to 'ring' in its various vibration modes. Wear on the picks only related to the tungsten tip of the conical section.

What was being picked up was the 'chiming' of the picks, at a rate of up to about 260 impacts per second.

Alternate Technologies

In reviewing the literature, there were no references to this phenomenon being previously observed within acoustic research within the mining industry. Acoustic research within the mining area is very limited.

Research in this area for "seam location" has been dominated by geotechnical approaches. What acoustical research had been undertaken was limited to assessing occupational health and safety noise levels using dose meters, and simple dB(A) sound meters.

Several lines of research attempt to map the gross dimensions and direction of the seam ahead of the mining machine, but none indicate the fine detail of what is happening at the point of contact between the cutting tool and the coal / rock.

Each of these alternate approaches requires the mining operation to be stopped whilst the measurements are being undertaken, and even then only provide a large scale view ahead.

Acoustic measurement within the underground mining area is usually confined to surface equipment, in well-ventilated areas, away from the mine portal.

Feedback by Experts in Mining

The work has been discussed with several current leading figures in mining research. It was hailed by several experts (in private discussions) as "a major breakthrough", providing the equipment operators with valuable feedback on the seam characteristics in real time, revealing again the 'sound of the picks', that for generations, been obscured by the 'sounds of mechanisation'. Others have described it as, the final step to full automation in underground coal mining.

One of the reasons given for having the machine operator close to coal face has been the need for the operator to be able to 'see and hear' the coal face.

It was also suggested that it had the potential to radically cut the annual death toll that plagues underground coal mining operations.

If the operator could be removed well away from coal face and the unsupported roof, there is the potential to significantly reduce loss of life from rock fall and coal gas outbursts. Potentially, the operator could operate the machine from a remote location. Currently, the many operators mine by remote control but within line-of-sight, typically 10 to 20 metres from the coal face.

Current Research

The original research was limited by funding and access to sites and equipment.

Further research in this area is limited by availability of access to fully operational mining machines, by limited access to operating mines, and by mine safety concerns of mine operators.

Attempts have been made to bring together acoustic equipment suppliers and equipment manufacturers.

Acoustic equipment manufacturers have expressed reluctance to adapt existing equipment, unless there they can be shown that there is a proven market. Their market penetration into the mining industry has been minimal and mainly in the surface mining area.

Mining equipment manufacturers have expressed reluctance to trial the technology, unless the equipment can be supplied ready to operate, direct from a known and respected acoustic measurement equipment supplier.

Mine operators have expressed reluctance to all the access of new unfamiliar equipment into their underground mining operations, unless that equipment is proven to be 'intrinsically safe' and 'explosion proof' by the acoustical equipment suppliers, and with full endorsement of the mining machine manufacturers.

Alternate Applications

Other areas of application have also been investigated.

The basic operation of the cutting head and picks appears in other areas of mining, such as strip mining.

At one surface mining operation site, variations in ore body hardness, over very short distances, causes firstly the fracturing of picks, followed shortly thereafter (unless mining is stopped) by the ripping off of the pick holder from the cutting head. If the machine is stopped in time, pick replacement could be carried out in less than 30 minutes. If not, the machine was out of operation for up to a day, with all of the associated losses to production.

In a more mundane area, there are potential applications in the road stripping machines that regularly strip and replace the asphalt from our roads.

Future Research

During the original analysis, there appeared to be a trending in the amplitude of the 'chiming' across seam.

Across the centre portion of the cut, the relative levels would remain relatively constant, with sporadic bursts associated with inconsistencies within the seam. These sporadic bursts could be time filtered to avoid false indications of coal /rock interface contact.

The relative levels would then increase smoothly as the cutting head approached the coal / rock interface, with a 'step' increase only occurring in very close proximity to the actual coal / rock interface. This trending appeared to be associated with the variation in stress patterns occurring naturally around the void opened by the mining operation.

This trending hinted at the possibility to extract far more information about the coal seam characteristics.

Practical and Economic Benefits

Application of this technology has been assessed (by others) as having the potential to producing extraction saving in the order of hundreds of millions through refinement of the mining operation, and by reduction of mining equipment downtime. These figures have been provided by mine operations and maintenance personnel.

By enabling the removal of the machine operator from the immediate vicinity of the operating coal face, the application of this technology has been assessed (by others) as having the potential to significantly reduce the number of mine deaths that occur annually.

It has been suggested (by others) that with this last refinement, the mining operation could make the final step to fully automated mining, with the machine operator located above surface, providing only minimal guidance in a stress free environment.

Whilst not as obvious, the environmental benefits could be of a similar order of magnitude. By reducing the rock content of the mined coal, the energy costs / carbon footprint of downstream coal treatment (washing) can be reduced. It should also reduce the inadvertent transportation of thousands of tonnes of waste rock around the world that currently occurs.

Acoustic research within the mining area has been severely limited by the lack of exposure within that industry, to the potential benefits modern acoustic research. Where acoustics has been applied, it has been mainly in the application of environmental acoustics to above ground operations.

Conclusions

The air borne noise emissions of mining picks, during actual mining operations, have been found to be a direct real-time indicator of both hardness and rip ability of material being mined, at the point of contact, as the mining is occurring.

By three-dimensional plotting of the relative emission levels from the picks, as mining operation progresses, would also enable plotting of the progressive changes occurring in in-seam hardness, enabling the operator to extrapolate those characteristics into the seam ahead of the mining operation.

This patented approach offers a non-intrusive, non-contact means of assessing the ore body (in this case coal) at the very point of extraction.