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POTENTIAL TUBE BUNDLE IMPROVEMENTS

Larry Ryan[1], Martin Watkinson[2]

ABSTRACT: The gas monitoring system in an underground coal mine is an integral part in creating a safe work environment for the coal mine workers. The gas monitoring system provides feedback on the effectiveness of the ventilation system, gas drainage system, seal integrity of goafs and gas make on the active face/development panel.

The aim of this paper is to provide a number of examples, where possible improvements can be made to Tube Bundle monitoring systems. Two of the Tube Bundle systems biggest limitations are slow response times to changing gas conditions underground and the high cost of tube installation underground. This paper will discuss two possible step change improvements with the aim to address these limitations to make the Tube Bundle system more responsive and provide greater coverage underground for lower cost outlay. This paper will also explore the use of automation to reduce the cost of Tube Bundle system maintenance while improving reliability.

DECREASE PURGE DELAY TIME – TUBE BUNDLE SHED

A typical Tube Bundle system in an underground coal mine consists of 20 – 40 tubes, each approximately 5 km long, sampling various areas underground on a continuous basis with each tube being either 12.5 mm (½") OD (Outside Diameter) or 15.9 mm ($^{5}/_{8}$") OD. Most mines have moved to 15.9 mm ($^{5}/_{8}$") tube as this allows for longer runs of tube underground, up to 12 km due to the lower resistance in the tube.

Unfortunately, the longer the tube the greater the vacuum required to drawn the same gas sample flow (litres/minute) to the surface. In addition, the longer the tube, the further the gas sample, from underground, needs to be transported to reach the surface. Hence a longer time is required to get the sample from underground to the surface for a long tube vs short tube. An analogy for a simple Tube Bundle system would be sucking air through a straw. If you had a standard straw, then it is quite easy to draw some air through the straw by sucking on it (applying a vacuum). However, if the straw is made twice as long, it becomes more difficult to draw air through the straw. If the long straw, above, is changed to a thick straw with a larger Cross Sectional Area (CSA) then the resistance is reduced and it is easier to draw air through the straw again.

Hence to combat the greatest liability of a Tube Bundle system, the time delay from sample collection underground to sample analysis in the Tube Bundle shed, the system needs to increase the sample flow. More sample flow can be brought to the surface faster by either increasing the vacuum applied to the tube or lowering the resistance of the tube. Using the straw analogy, more sample flow can be achieved by either sucking harder or using a thicker straw with a larger CSA.

The mining industry has investigated these two approaches in the past and has opted to lower the tube resistance by using a tube with larger CSA, namely moving to 15.9 mm ($^{5}/_{8}$") tube instead of 12.5(½") tube. If the tube vacuum were increased, then the Tube Bundle system maintenance/installation would be more onerous as every joint/connection would need to be of a higher standard/quality in order to maintain the higher vacuum. In addition, a higher vacuum Tube Bundle system would be more susceptible to gas leaks.

It has been identified that 12.5 mm (½") tube is actually more robust and as a result is more likely to survive an explosion underground (Queensland Mines Rescue Service et al, 2015). The survivability of the Tube Bundle system needs to be forefront as post explosion, all power underground is likely to be lost (the Realtime system, if it survived, will be running on Uninterruptable Power Supply (UPS) with limited uptime) and hence the Tube Bundle system

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will form part of the re-entry strategy. Hence, ideally the Tube Bundle system should use 12.5 mm (½”) tube from a survivability perspective while a 15.9 mm ($^5/_8$”) tube is better from a purge delay perspective.

For tube runs up to approximately 6 km, 12.5 mm (½”) tube is recommended while over 6 km, 15.9 mm ($^5/_8$”) tube is better from a purge delay perspective. As the purge delay is the biggest disadvantage of a Tube Bundle system, the correct tube size selection and installation are paramount for a minimal purge delay time. However, a Tube Bundle system has more components than simply the underground tube and there is reason to believe that the infrastructure inside the Tube Bundle shed itself may contribute significantly to the purge delay time as shown below in Figure 1.

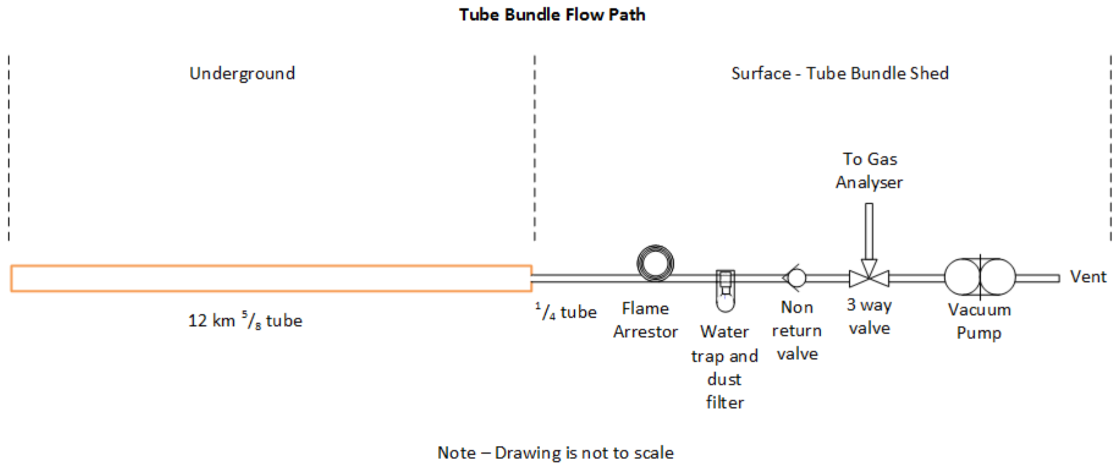

Figure 1: Tube Flow Path

Once the tube, from underground, enters the Tube Bundle shed, the tube size typically drops to 6.25 mm (¼”). The CSA of a 6.25 mm (¼”) tube is much smaller than 12.5 mm (½”) or 15.9 mm ($^5/_8$”) tube and hence the resistance will be much higher. As the tubes total resistance is the sum of all the various parts, the 6.25 mm (¼”) tube inside the Tube Bundle shed could add considerably to the total resistance of the tube run. In addition, the tube typically goes through a flame arrester, water traps, filters, a check valve and other various valves before finally being drawn on and exhausted by the purge pump. Each element in the tube flow path will add to the tube’s total resistance and the higher the resistance, the lower the sample flow, hence the longer the purge delay.

In order to bring a sample, from the end of line filter to the Tube Bundle shed, the volume of the 12.5 mm (½”) or 15.9 mm ($^5/_8$”) tube needs to be drawn out of the tube or purged. As the tube could be 12 km in length, the volume of gas that needs to be evacuated is quite large and any additional resistance by the various Tube Bundle shed components will only add to the tube purge time.

As stated above, the total resistance of the Tube Bundle purging flow path is the sum of the resistance of the tube underground and the resistance of the 6.25 mm (¼”) tube/components inside the Tube Bundle shed.

The total resistance of all the components inside the Tube Bundle could be reduced by using the following:

1. 12.5 mm (½”) or larger tube inside the Tube Bundle shed.
2. 12.5 mm (½”) or larger valves inside the Tube Bundle shed.
3. Lower resistance flame arrestors
4. Lower resistance filters

A flame arrestor, which has a lower resistance, could be of the same conventional design but have a wider CSA so the resistance to flow is reduced. Alternatively, a new large CSA, low resistance flame arrestor may need to be designed for this application.
It is proposed that if the resistance of the tube/components inside the Tube Bundle could be reduced then the purge delay times will be reduced. A smaller purge time would lead to the Tube Bundle system being more responsive to changing underground gaseous conditions and hence safer outcomes for the mine workers. The sourcing of parts, construction and testing of this particular potential improvement is beyond the scope of the current paper unfortunately.

AUTOMATION OF TUBE BUNDLE SYSTEMS

Tube Bundle systems have a high initial cost and maintenance requirements. In order to reduce the total cost of ownership, this paper will propose five ways that automation can either extend the functionality of the Tube Bundle system or reduce the labour required for maintenance.

Tube Monitoring Expansion

The high cost of installing a Tube Bundle system is made up of two major hardware components:

5. Surface infrastructure – Tube Bundle shed containing the various pumps, valves and analysers,
6. Underground infrastructure – marshalling panels, multicore tube bundle and single core tube.

A significant proportion of the cost of installing a Tube Bundle system is for the multicore and single core tube run underground. Once all the tubes have been run underground to meet the maximum capacity of the Tube Bundle system, expansion of the Tube Bundle system or the number of monitoring locations is difficult.

Each tube being monitored by the Tube Bundle system needs to run from the Tube Bundle shed, at the surface, to the monitoring location, underground several kilometres away, as one continuous tube. Hence, each tube needs to run down a bore hole or drift (generally as multicore) to a location central to the area to be monitored and at this point, individual single core tubes are run to each discrete monitoring location. Depending on the mine and the area to be monitored, the multicore run could be two or more kilometres in length before the individual tubes branch out toward their particular monitoring location.

The multicore tube run that is common to all the tubes destined for monitoring in a particular area represents an opportunely to use automation underground via Pneumatic (compressed air) to either:

7. Expand the number of locations that can be monitored
8. Decrease the purge delay times

If the control system, in the Tube Bundle shed, was upgraded to control a number of pneumatic lines going underground as well as the standard valves, the opportunities outlined above could be realised. Instead of just using each individual tube in the multicore to monitor just one location underground, it would be possible to have a pneumatic valve switch between two or more tubes. The basic principle is to use a single tube, in the multicore bundle, to transport the gas sample from more than one location underground to the surface as shown below in Figure 2.

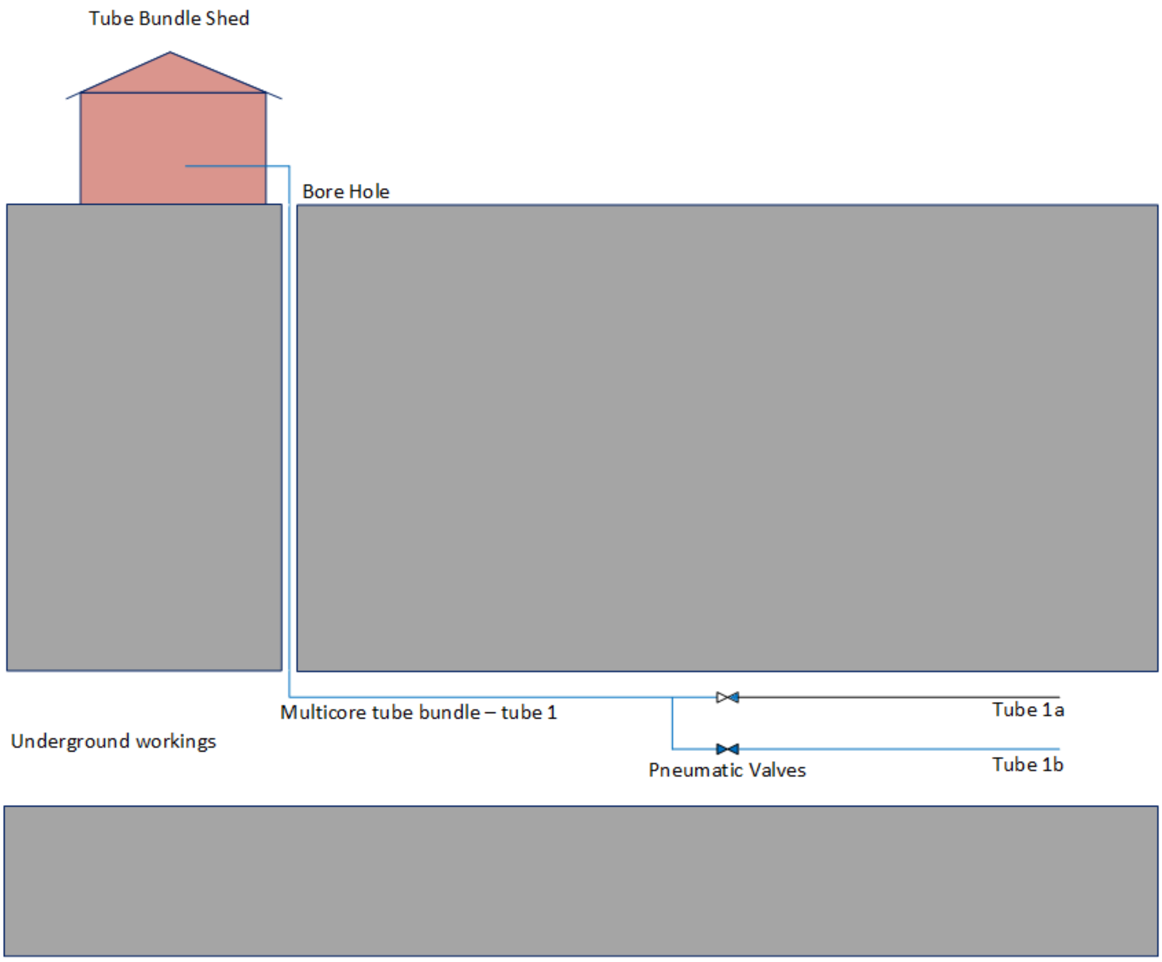

Figure 2: Multi Location Sampling

However, in order to achieve this outcome, the following requirements will need to be met:

9. Each tube connected to a pneumatic valve needs to be purged long enough to completely flush the previous tubes' gas sample from the common multicore tube. Using the new sample to flush out the previous tube's sample is the same principle that is used in the Tube Bundle shed to flush the analyser's flow path.
10. The control of the tube sampling order needs to be tightly controlled to ensure that the common multicore tube is flushed long enough to remove all residual gas from the previous tube.
11. The tube delay time from the pneumatic valve to the surface needs to be found to assist in the calculation of the time required to flush the old tube sample out. For example, it may be found that the common multicore tube needs to be flushed three times to remove all evidence of the previous sample (the time or flushing cycle involved to flush the previous sample, whether it is dirty air, high CH4 or high CO2 is beyond the scope of the current paper unfortunately).
12. The maintenance of the Tube Bundle system in relation to the common area pneumatic tube panel would need to be of a high standard.
13. Tube integrity testing would need to be undertaken to ensure that the system operated correctly and that the flushing time of the common multicore tube is long enough.
14. Water cannot be allowed to pool in the common multicore tubes as high CO2 samples will dissolve in water and then degas into another sample.

The pneumatic air lines would need the run to the central location and probably the best way to achieve this would be by having the air lines as part of the multicore bundle. Hence, the multicore bundle is run to the central location where there is a panel, similar to a marshalling panel, containing the pneumatic valves to control the switching of the tubes. Using the pneumatic valves, two or more tubes are to connect to a single multicore tube that then transports the gas sample to the surface.

Decrease Purge Delay Time – Underground Tubes

Another, slightly more complex variation of the tube monitoring expansion principle outline above, is to use two or more common multicore tubes in parallel to reduce the purge delay as shown in Figure 3. Due to the complexity of managing the pneumatic valves and flushing times, the usage of parallel common multicore tubes will probably be limited to longer tube runs (the time or flushing cycle involved to flush the previous sample, whether it is dirty air, high CH_4 or high CO_2. is beyond the scope of the current paper unfortunately).

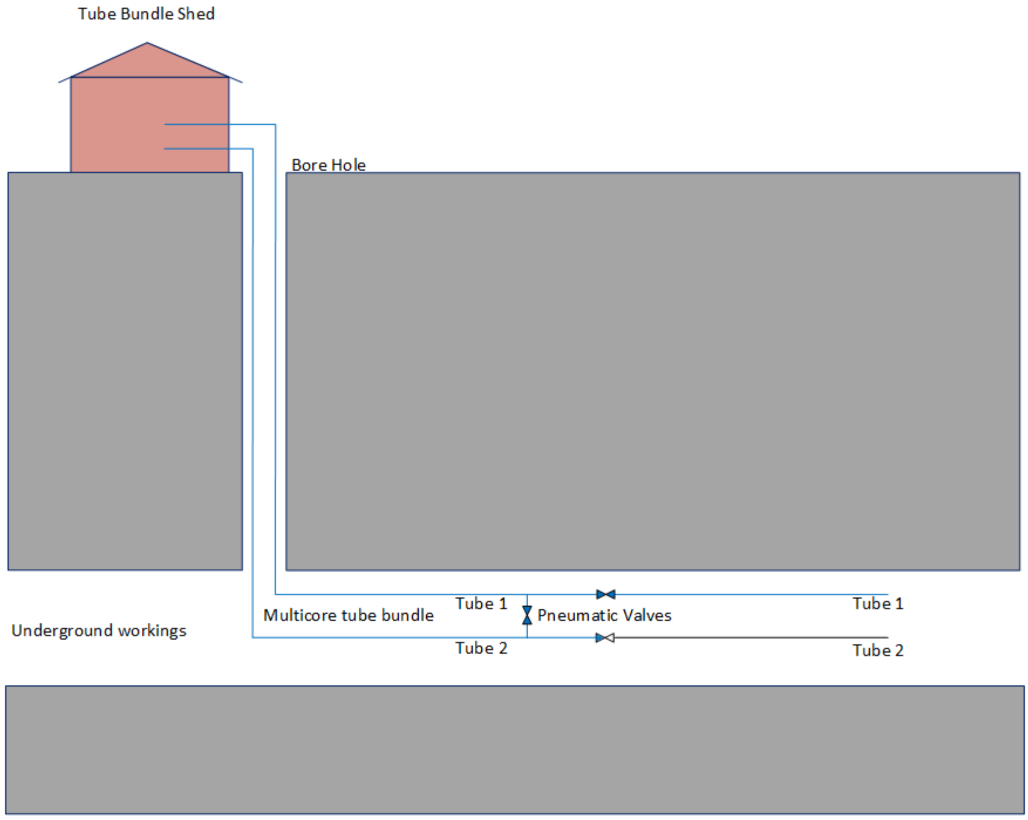

Figure 3: Parallel Flow Path

Automated Blow Back

While not common, there are Tube Bundle systems in use that incorporate automated blow back functionality. Automated blow back provides a scheduled, low maintenance method of ensuring that minimal water is collected in the tube as this tends for increase the purge delay times. The other advantage of automated blow back over manual blow back is there is no need to disconnect and then reconnect the tubing which has the potential to introducing sample leaks.

As the blow back functionality uses high pressure air/N_2 to blow the water out of the Tube Bundle system, there is potential that high pressure air/N_2 could damage other sensitive equipment (for example, the gas analyser). Hence, the design of the automated blow back system needs to ensure that high pressure air/N_2 cannot be released in the same flow path as the gas analyser and other pressure sensitive items.

Automated Tube Integrity Testing

The monthly tube integrity testing process is a high maintenance task that can take a long time to complete (especially if sample leaks are found). Currently, an automated tube integrity system has been developed where N_2 is injected down the tube and then the N_2 is drawn back to the surface via the Tube Bundle system. If the gas sample drawn back is purely N_2 then the tube doesn't have any leaks. The automated tube integrity system cannot confirm that the tube located at a particular location underground has not been swapped with another. Tube identification requires a known gas to be drawn at end of the tube and then a matching gas sample found at the surface to positively identify the tube.

Automated Analyser Calibration

Various Tube Bundle systems incorporate automatic analyser calibration to minimise the maintenance requirements. Generally, in order to calibrate the analyser automatically, the calibration cylinders need to be left on which could pose a health and safety hazard. In addition, some of the calibration gases are special mixtures and could take up to six weeks to be made. If the calibration gas line had a small leak, leaving the calibration gas cylinder on could cause the cylinder to be empty when required. In the worst case, the automatic calibration may be attempted using an empty cylinder which would result in a bad calibration and if no spare cylinders were available, leading to a period of time where the analysis of that particular gas would be unreliable.

There are analysers on the market that insert a glass gas calibration reference cell into the light path of the analyser; hence an internal reference is used for the calibration rather than an external gas source. The use of an analyser with this internal calibration capability provides an opportunity to capture the benefits of automation without introducing potential gas hazards.

Automation Safe Guards

While the automation of routine maintenance for a Tube Bundle system certainly has benefits, there needs to be a series of checks and balances to ensure that the task/maintenance is being carried out correctly and there are no unintended side effects.

As mentioned above, automated blow back has the capability to destroy various Tube Bundle components (for example, the gas analyser), if there is an uncontrolled release of gas pressure. Automated calibration has worked so well, in the past that no site inspections/maintenance of the Tube Bundle system was being undertaken. Unfortunately, when no regular maintenance of the Tube Bundle system is being performed, small maintenance issues were left unresolved which has then led to catastrophic failures (for example, water in the gas analyser). There is also a concern that the automation of Tube Bundle systems will lead to the mine's personnel having diminished knowledge as they lose their familiarity with the Tube Bundle system. In addition, as the more routine tasks are automated (for example blow back, tube integrity checks and analyser calibration) the support/breakdown issues remaining will be more challenging for the personnel on site to resolve.

Maintaining a close working relationship with the original equipment manufacturer (OEM) would be of assistance with support/breakdown/parts replacement in the future. In addition, if the six monthly NATA calibrations are performed by an experienced service person, maintenance can be undertaken and any issues identified can be rectified at the same time.

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