Case Study

Utilizing thermal inclinometers in an underground coal mine

This paper describes the installation of Control Plus thermal inclinometers on a longwall shearer in an underground coal mine. Comparisons are obtained between the performance of the thermal inclinometers and high end inertial navigation units.
www.controlplus.biz/inclinometer.html

Coal mining has been around for hundreds of years. In the present day the coal is won from the earth using large powerful automated machines. The days of pick and shovel over. This paper discusses the implementation of thermal inclinometers on a longwall shearer. More information on longwall mining can be found at the following:- http://en.wikipedia.org/wiki/Longwall_mining.

Figure 1 – A typical longwall shearer in operation underground.

A longwall shearer is a large powerful machine designed to cut coal at up to 5000 tonnes per hour. There are a number of shearer manufactures around the world but all machines follow the same basic configuration. The body of the shearer contains the electrical power and control panels, hydraulic power pack and haulage drive that allow the shearer to traverse the coal face.

On both ends of the shearer are the ranging arms. These arms are fitted with cutting drums up to 4m in diameter and 1000kW 3 phase induction motors powered at 3300 volts.

Figure 2 – Bucyrus EL3000 shearer in the workshop

The challenge for this project was to mount 3 inclinometers on the shearer to sense the absolute angle of both ranging arms and the body of the shearer. From these 3 angles the position of the cutting drums can be calculated and then controlled by the automation software.

This general concept is not new. Many patents have been obtained over the years for the automation of a shearer, what this project set out to prove was that thermal inclinometers are robust enough to survive in this harsh environment and can provide a level of accuracy only seen from very expensive and large sensors.

The actual shearer used for this project was a Bucyrus EL3000 shearer. This machine is powered at 3300 volts 50Hz 3 phase. It has a 850kW 3 phase induction motor in each ranging arm, 2 x 125kW induction motors powered from variable voltage variable frequency (VVVF) drives and a 40kW pump motor. The machine is 14.7m between drum centers and weights a total of 85 tonnes.

To make this project even more difficult, coal is full of methane gas, and when the shearer cuts the coal the methane gas is released along with coal dust. Special ventilation arrangements are used to dilute and remove this potential explosive atmosphere but to be on the safe side all the electrical circuits must be explosion protected. The most common method to achieve this is to use flameproof enclosures.

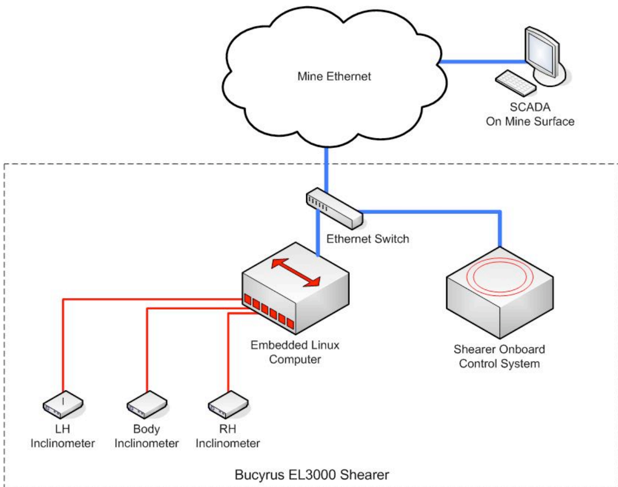

Figure 3 – Block diagram of data connections.

Figure 3 shows the block diagram of the design. The 3 thermal inclinometers are connected via their RS232 port to a single board embedded linux computer. This small computer was used to poll the 3 inclinometers and make the data available on the shearers on board ethernet. The embedded linux computer implemented the ethernet/IP protocol more details of this protocol can be obtained from www.odva.org.

All automation data from the shearer is trended on the mines SCADA system located on the surface of the mine. Data for this paper was obtained from this system which is based on ConsultantX running on MacOSX.

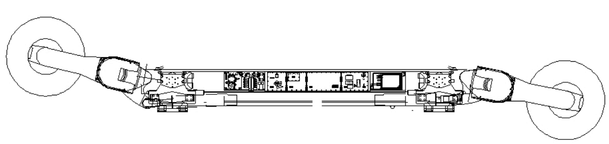

Figure 4 – Shearer general layout.

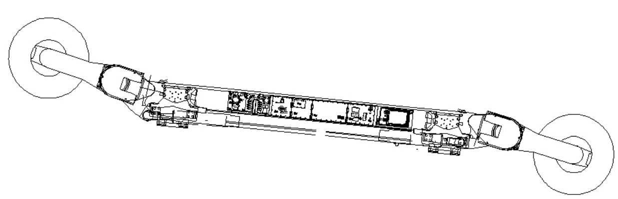

Figure 5 – Shearer general layout operating on an incline

The inclinometers are used to determine the cutting height of each arm. Figure 5 shows the shearer operating on an incline. The 3 inclinometers are used to calculate the relative angle of an arm to the body of the shearer.

LHa = LHi – Bi

RHa = RHi + Bi

Where
LHa = the relative angle of the left arm to the shearer body.

LHi = the absolute angle of the left arm as measured by the thermal inclinometer.

RHa = the relative angle of the right arm to the shearer body.

RHi = the absolute angle of the right arm as measured by the thermal inclinometer.

Bi = the absolute angle of the shearer body

Once these relative angles are known some simple maths can work out the height of the top of the drums. Accuracy is very important in this application. 1 degree of arm movement is equal to 50mm of cutting height. The desired accuracy is 0.1 degree which is equal to 5mm of cutting height. Inaccuracy of cutting height can cause equipment damage and a diluted product.

The locations available to mount these thermal inclinometers are very limited. The inclinometer to sense the shearer body angle had to be mounted inside the main electrical control enclosure which is right next to the electrical enclosure that houses the VVVF drives for the haulage motors. VVVF drives are notorious for the generation of electrical noise and harmonics. The body thermal inclinometer and the embedded linux computer were bolted down on the radio chassis.

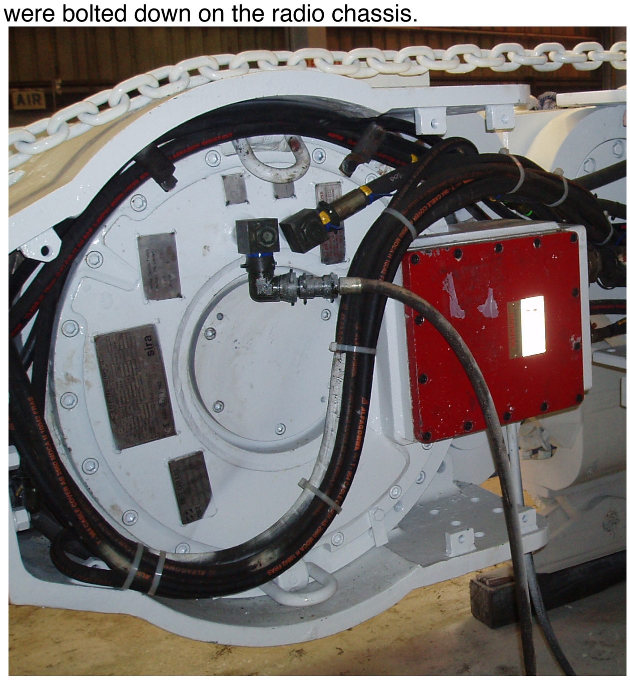

Figure 6 – 850kW cutter motor, jbox is has the red cover

The thermal inclinometers for the 2 ranging arms proved to be a real challenge. These sensors had to be mounted in the jbox on the 850kW cutter motor. The main purpose of this jbox is to connect the 3300 volt supply cable to the motor. This was of great concern because of the close proximity to the high voltage cables and also the fact that these motors run very hot during normal operation. These motors are started direct on line which results in approximately 1000 amps following for approximately 1 second.

Figure 7 shows the thermal inclinometer mounted in the jbox of an 850kW 3 phase induction motor powered at 3300 volts. The large red white and blue conductors are the 3300 volt cables supplying the motor. The thermal inclinometer had to be tucked into a small space behind these high voltage conductors.

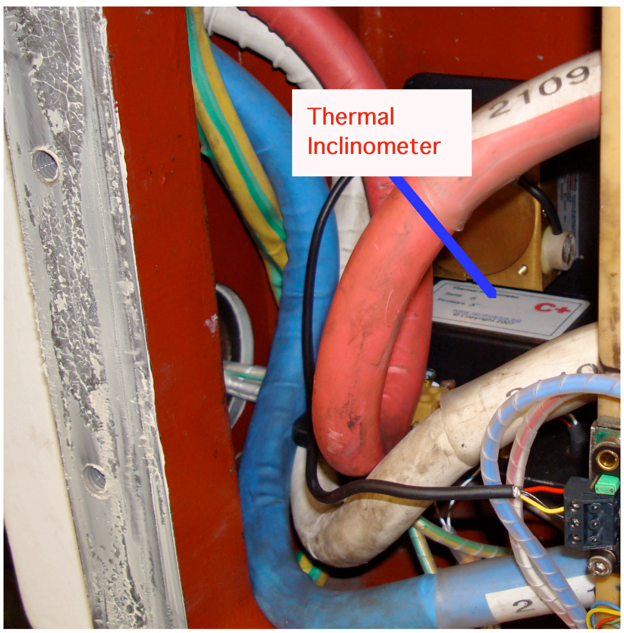

Figure 7 – Thermal inclinometer mounted in the Jbox of the 850kW cutter motor.

Other makes of inclinometers had been trailed in this location by others with very limited success. The only unit that had proven reliable in this hostile electrical environment was a very simple pendulum based inclinometer. The sensor has a simple mass hanging on an arm which is housed in an oil filled bath. The position of the arm is sensed by a wiper contact on a potentiometer. The output signal is a simple 0 to 10 volts. Because this sensor is so simple it can survive in this hostile environment however the accuracy and noise immunity is relatively poor. The biggest problem with this sensor is the pendulum sticks in place until a large change in angle occurs and the output voltage signal tends to be corrupted by electrical noise.

The thermal inclinometer uses thermal convection to sense angles. Inside the sensor is a small gas chamber with a heating element in the center. Equally spaced around this heater are 4 temperature sensors. If the sensor is level then all 4 temperature sensors will read the same temperature. As the inclinometer is tilted the temperature gradient changes and the four temperature sensors will read differently. The thermal inclinometer then has a 32 bit micro controller on board to calculate a stable output angle. There is also sophisticated temperature compensation on board.

Results were initially very good. The thermal inclinometers performed from the first day and provided stable angular measurement. After a week of data trending it was decided to change the default parameters in the incinlometers. Table 1 shows the changes to the parameters. Due to the nature of the machine the body inclinometer required to be damped more than the inclinometers in the ranging arms. All other parameters were left at default.

Parameter	Default	Body	Arm
3	100	300	200
6	100	300	200

Table 1 – Parameters inside the thermal inclinometers that were changed to suit the application.

The parameters control the behavior of the Kalman filters in the 32 bit micro-processor inside the thermal inclinometer. The ability to change the internal parameters on the fly was a great benefit for this project. The behavior of the pendulum inclinometer can be changed by changing the viscosity of the oil in the chamber. This is of course impossible to do on the fly and just very messy.

The shearer was also equipped with a Litton LN270 inertial navigation unit. This unit is a very large and expensive but it does provide very stable and accurate angular data. Figure 8 shows a comparison of the thermal inclinometer, the LN270 and the standard pendulum inclinometer.

The X axis is time of day, the Y axis is degrees. If the LN270 is assumed as absolutely correct then the thermal inclinometer is very close. The pendulum inclinometer on the other hand is very noisy and inaccurate. The inclinometer mounted in the body of the shearer is used as a reference by the other two inclinometers in the arms, thus any noise and in accuracy in this signal effects the accuracy of both arms.

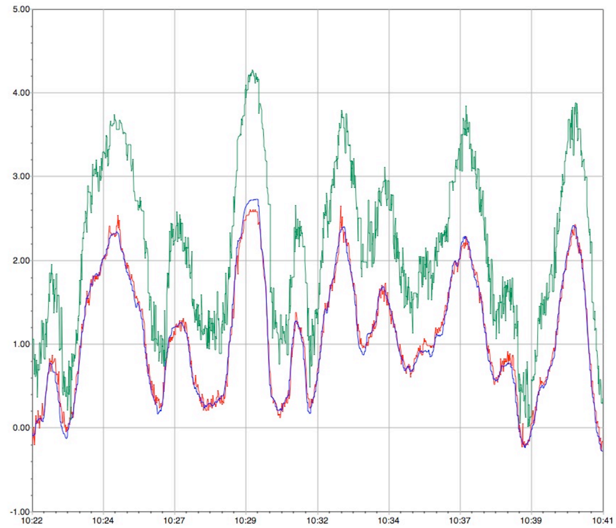

Figure 8 *Thermal inclinometer RED, Litton LN270 BLUE, Pendulum inclinometer GREEN*.

Figure 9 shows the thermal inclinometer mounted in the left hand ranging arm cutter motor. This figure shows degrees on the Y axis and time of day on the X axis. This data was captured during a normal production cycle.

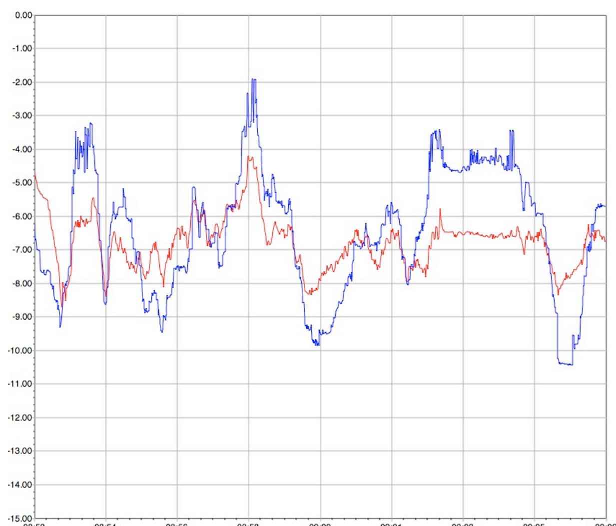

Figure 9 *Thermal Inclinometer RED, Pendulum inclinometer BLUE*

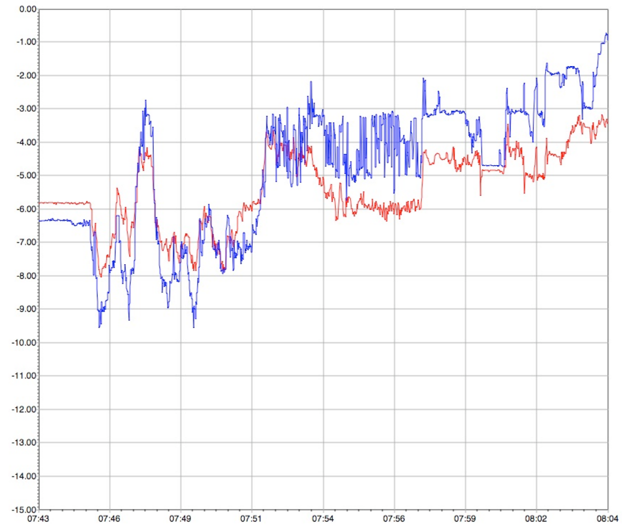

Figure 10 – Comparison of the Pendulum inclinometer BLUE v thermal inclinometer RED in the right arm during heavy cutting. Y axis degrees, X axis time of day

Figure 10 shows the performance of the thermal inclinometer during heavy cutting. The blue trace shows how the pendulum inclinometer is affected by cutter drum vibration while the thermal inclinometer holds a fairly steady signal. This is a good example of how the Kalman filters inside the thermal inclinometers can be tuned to filter out unwanted vibrations.

After an initial trial period of approximately one month the reliability and accuracy of the thermal inclinometer was monitored. During this time it became clear that the performance of the thermal inclinometers was far superior to the pendulum inclinometers and approached the performance of the LN270. The mine then swapped the to using the thermal inclinometers in the automated control of the ranging arms.

Conclusion

The Control Plus thermal inclinometers have proven to be very accurate and reliable in the hostile environment of an underground coal mine. The performance of the thermal inclinometer approached that of a LN270 inertial navigation unit that cost approximately 50 times and has export restrictions from the US military. Thermal inclinometers are recommended for any application that requires high performance, low cost and reliability.