University of Southern Queensland

Faculty of Engineering and Surveying

<u>"Effects and Controls of Lateral Refraction in Underground Coal Mines"</u>

A dissertation submitted by

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Abstract

Environmental conditions in underground coal mines effect lateral refraction when surveying with a regular theodolite. Xstrata Coal's Oaky North Mine situated 26Km east of Tieri in Central Queensland's Bowen Basin has overcome these environmental conditions by utilising gyrotheodolites to control the underground survey network. This project studies the environmental conditions effecting lateral refraction and how Oaky North Mine utilises gyrotheodolites to control the underground survey network.

Oaky North Mine is an underground longwall coal operation, producing approximately 5 million tonnes of sub-bituminous, medium volatile coal per annum. Two pairs of parallel tunnels (gateroads) with cross cuts every 100m are driven using a continuous miner for a length of approximately 3.4 Km. These gateroads form the maingate and tailgate of the longwall block.

The demand for an accurate underground control network is high. Typically, accuracies of ±50mm are expected allowing a breakthrough tolerance of ±100mm. The ability to establish accurate control networks and perform associated surveys is restricted by lateral refraction. The path of light through the atmosphere is influenced by the inhomogenities of the refractive index. This refractive effect deteriorates the pointing accuracy of survey lines. Currently, there is no available method to accurately correct these systematic errors.

This project investigates whether literature research supporting the use of a gyrotheodolite, will improve breakthrough errors of an open ended traverse or when compared to the readings from TCRA 1203 vary sufficiently to be outside accepted tolerances.

Specifically, in this project, the gyrotheodolite used is the DMT (Deutsche Montan Technologie) Gyromat 2000, permanently fixed to a Wild T2 theodolite. The Gyromat 2000 is a fully automated high precision (1.5cm every 1Km) surveying gyroscope with a measuring time < 10mins.

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Certification

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Student Number: w0029287

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Signature

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Date

Acknowledgements

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Abbreviations

The following abbreviations have been used throughout the text and references:-

DMT   Deutsche Montan Technologie

PGD   Personal Gas Detector

SMG6   South Main Gate 6

UPEE   Uncertified Portable Electrical Equipment

SLAM   Stop, Look, Assess and Manage

Chapter 1

Introduction

1.1 Outline of Study

As many surveyors know, atmospheric refraction is the ultimate nemesis – the limiting factor in obtaining accurate results. (Wilkins, 2004)

The above statement suggests the need for research into lateral refraction and how its effects can be overcome or rectified in underground surveying. The scope of this study is detailed in 1.5 Research Aim and 1.6 Research Objectives.

1.2 Introduction

Some of the hardest conditions a surveyor is likely to encounter are those associated with an underground coal mine environment. It is the very nature of underground coal mining, which dictates surveyors work in confined spaces, with conditions that are less than ideal for accurate control surveys, as evidenced in Figure 1.1 below.

Figure 1.1 Surveying underground at Oaky North Mine

Within an underground coal longwall operation, surveyors regularly traverse three to four kilometres underground, without a closing to another line.   The area specifications for the tunnel network identified in Figure 1.2 below of 4 Km long by 5.2m wide are a clear indicator of the lengthy underground traverses experienced by surveyors.

`   1
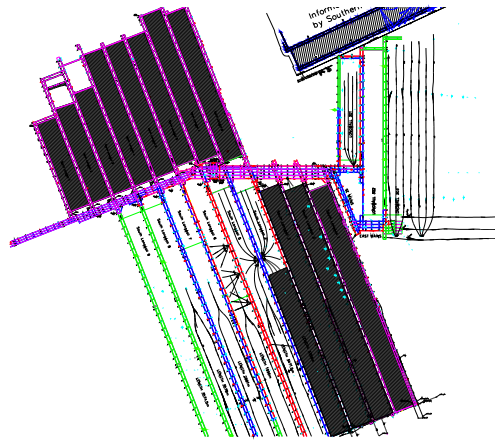
Figure 1.2 Oaky North mine layout

Environmental conditions that constantly affect these long traverse lines include; turbulent air flow created by the forced ventilation systems. Furthermore, the uneven mixture of gases and temperature variances in the air associated with nearby plant cause light rays to be refracted from the direct line of sight intended for observation. (Hutchison, 2006) Subsequently, the compounding factors listed above required an investigation into possible solutions, in order that a surveyor can attain more accurate readings.

This project will investigate a solution to the variances in readings caused by lateral refraction by utilising the DMT (Deutsche Montan Technologie) Gyromat 2000 gyrotheodolite. The resultant information gained from the DMT Gyromat 2000 will be compared with a Leica TCRA 1203 totalstation and analysed to identify errors associated with lateral refraction. Following the analysis, the findings will inform the design of a methodology and guide recommendations, with a view to minimising the problem of refractive errors, in underground surveying.

1.3 The Problem

Surveyors in underground tunnels experience difficulties obtaining an accurate reading, because their line of sight is affected. Hutchison (2006), identifies the cause stating;

> variation in density along the line of sight causes the light rays to be refracted from the direct line of sight intended to be observed.

`

This phenomenon poses problems such as; misaligned tunnel heading directions and incorrect underground locations. In terms of an underground coal mine, these misaligned tunnel heading directions and incorrect underground locations seriously impact on a mine's productivity in the current commodities market boom. Competitiveness within the commodities boom has evidenced the emergence of at least 14 satellite operations in the Central Highlands region of the Bowen Basin capitalising on the boom (Central Queensland News, 2007).

In such a highly competitive market, the mines operations manager deems it essential that accurate surveys are carried out in a timely manner, in order to minimise production disruption associated with revisiting, due to errors. The seemingly high costs associated with carrying control underground are insignificant, when compared to the cost of lost production for a multimillion dollar operation. Engineering issues associated with the inaccurate headings, caused by lateral refraction, result in the conveyor being unable to track in a straight line. Associated with the necessity for straight tracking is the issue of a longwall's roof supports becoming wedged between diverging gate roads. As this machine cannot be driven backwards, production ceases instantly, until a salvage operation is mounted to remove the roof supports and shorten the face width, to allow mining to recommence. Such a stoppage effectively ceases production for a month.

1.4 Justification

In daily operations underground, mine surveyors are required to provide accurate heading directions for mining operations. It is of the utmost importance that these tunnel heading directions are straight, to allow for continued production and correct orientation, thereby avoiding inaccurate cuts which create revenue loss through wastage or holing into abandoned workings. Potential safety hazards associated with holing include water and gas inrush. Gas inrush is particularly prevalent in goaved workings where methane is released from abandoned or unmined coal reserves. Similarly, large volumes of fast flowing water can flood a working face in a matter of seconds. A point in case would be the Gretley Mine disaster of 1996, in which abandoned workings were holed into, resulting in the drowning deaths of 4 miners. Subsequently, two mine managers and the surveyor were prosecuted (Sydney Morning Herald, 2004).

Holing into abandoned workings is an occupational health and safety issue, potentially risking miner's lives and mine closure, whereas delays in continuous longwall production due to inaccurate headings, at current market prices, cost an operation approximately $100,000 an hour in lost revenue. There is also the increased possibility of a strata failure that could halt production, from a few weeks to several months. A strata failure has the potential to halt the longwall, and once stationary for a period of time, the weight from the goafing roof throws weight forward, resulting in shield convergence and face fracturing.

1.5 Research Aim

The aim of this research is to determine the accuracy of results obtained from a DMT Gyromat 2000 in relation to those obtained from a Leica TCRA 1203 in overcoming lateral refraction effects in underground surveying.

1.6 Research Objectives

To achieve the research aim, this project will employ the following objectives:

1. Evaluate current control surveying methods used within the coal mining industry generally and specifically at Oaky North Mine.
2. Identify the conditions that cause lateral refraction in underground mines and analyse the effects of lateral refraction
3. Collect and analyse gyroscopic information and calculate variance to tunnel heading directions in comparison with those readings from a Leica TCRA 1203
4. Determine if the readings gained by a Gyromat 2000, compared to the readings from TCRA 1203 vary sufficiently to be outside accepted tolerances.
5. Make recommendations that counteract the effects of lateral refraction in underground mines.

1.7 Conclusion

This dissertation aims to investigate the suitability of a DMT Gyromat 2000 as a means of reducing the effects of lateral refraction in an underground coal mining environment. In doing so, current underground coal surveying techniques, within the Bowen Basin

Central Highlands region, will be investigated in relation to control traversing and the use of gyrotheodolites.

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Chapter 2

Literature Review

2.1 Introduction

In order to better understand the effects of lateral refraction on an underground mine survey and consequently determine the suitability of a DMT Gyromat 2000 for reducing lateral refraction's effects, this chapter will review pertinent and where possible current literature, relevant to both lateral refraction and the DMT Gyromat 2000 in underground tunnelling as opposed to a Leica TCRA 1203.

2.2 Defining Lateral Refraction

In order to understand the effects of lateral refraction, the terminology needs to be defined.

2.2.1 Refraction

Refraction is the change in direction of a wave due to a change in its velocity. This is most commonly seen when a wave passes from one medium to another. Refraction of light is the most commonly seen example, but any type of wave can refract when it interacts with a medium, for example when sound waves pass from one medium into another.
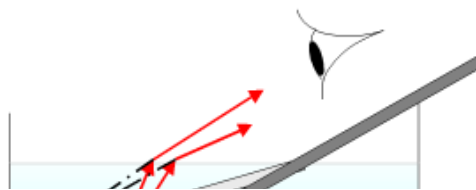
Figure 2.1 Refraction

In optics, refraction occurs when light waves travel from a medium with a given refractive index to a medium with another. At the boundary between the media, the wave's phase velocity is altered, it changes direction, and its wavelength increases or decreases but its frequency remains constant. For example, a light ray will refract as it

enters and leaves glass; understanding of this concept led to the invention of lenses and the refracting telescope (Wikipedia, 2006).

2.2.2 Refractive Index

The refractive index of a material is the factor by which the phase velocity of electromagnetic radiation is slowed in that material, relative to its velocity in a vacuum (Wikipedia, 2006). If a ray of light is incident at an angle to the surface the ray is bent as it enters the new medium. The angle $\theta 1$ is the angle of incidence and the angle $\theta 2$ is the angle of refraction (Giancoli, 1998). This refractive index explains how varying temperatures and air compositions distort light rays during lateral refraction.
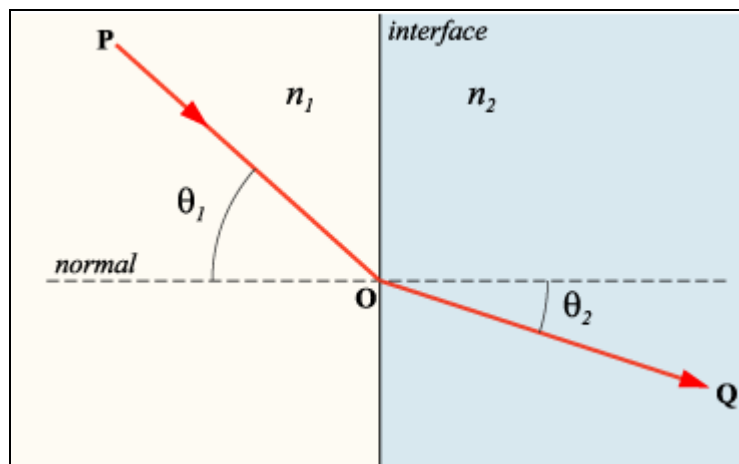
Figure 2.2 Measuring angular refraction

2.2.3 Lateral Refraction

Lateral refraction is not a commonly understood phenomena among surveyors and therefore its effects are not widely known. Johnston (1997) states;

  lateral refraction is due to lateral temperature gradients,

with contributing factors recognised as being variances in air temperatures created by free and forced convection. Furthermore, Johnston (1997) explained the heading variance of 1.2m left of design that occurred in the construction of The Channel Tunnel on the English side as being directly attributed to lateral refraction.

2.2.4 Horizontal Refraction

Korittke (1996), identified the influence of horizontal refraction, related to errors evidenced in the construction of The Channel Tunnel and provided an azimuth determination using a DMT Gyromat as evidenced in Figure 2.3 below.
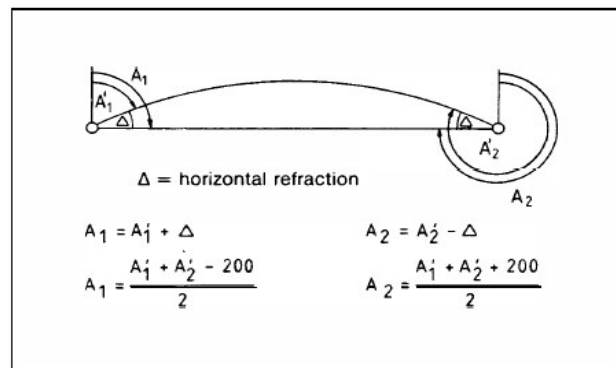
Figure 2.3 Measuring horizontal refraction

Kahem and Faig (1988), also recognised the effects of refraction for surveyors in tunnels and recommended the use of various instruments including a gyrotheodolite. In order to determine the suitability of a DMT Gyromat 2000, the underlying principle of a gyroscope is explained.

2.3 The Gyroscope Principle

The gyroscope as seen in Figure 2.4 below consists of a perfectly balanced wheel, which is arranged to spin symmetrically at high speed about an axis. By suspending the mass of the wheel, or rotor, in a precisely designed gimbal arrangement, the unit is free to move in two planes, each perpendicular to each other as well as to the plane of spin. This grants the gyroscope freedom to move in three dimensions (Lewen, 2006).
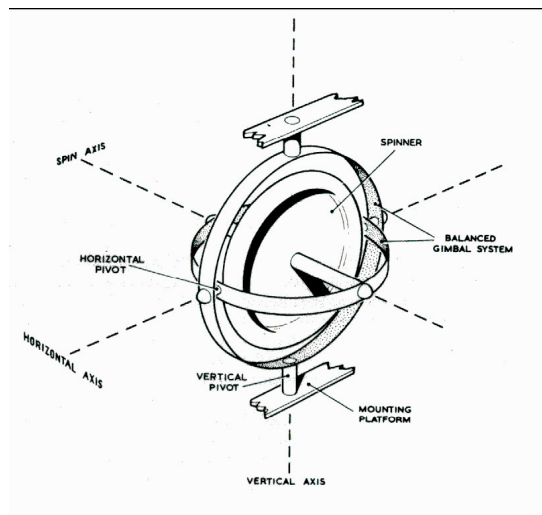
Figure 2.4 Gyroscope

2.3.1 Precession – Gyroscope Principle

Precession is the term used to describe the movement of the axle of a gyroscope under the influence of an external force. If one, for reasons of simplicity, compares a gyroscope with a toy top, we know that the top at rest will fall down on the ground due to the gravitational force exerted on the top. However, if the top is rotating around its symmetry line, then the top will not fall down and the symmetry rotation axis will move in a conic around a vertical line. This well-known phenomenon is called regular precession of a top. If a force is applied to the spinning rotor of a gyroscope by moving one end of its axle, the gyroscope will be displaced at an angle of 90 degrees from the applied force (Lewen, 2006).

2.3.2 North Seeking Gyroscope

The gyro spin axis can be made meridian seeking (maintaining the spin axis parallel to the earth's spin axis) by the use of a pendulum acting under the influence of earth's gravity. The pendulum causes a force to act upon the gyro assembly that will precess under its influence. Precession enables the instrument to become north seeking. As the pendulum swings towards the centre of gravity a downward force is applied to the wheel axle, which in turn causes horizontal precession to occur. Thus gravitational force acting downward on the spinner axle causes the gyroscope to precess horizontally to maintain the axle pointing towards true north. (Lewen, 2006)

2.4 The DMT Gyromat 2000

Deutsche Montan Technologie (DMT) is the market leader in gyrotheodolite technology. The Gyromat 2000 is fully automated and is a single handed operation (Korittke, 1997). The following information from Kroittke's FIG-Symposium paper (1997) gives a synopsis of the Gyromat 2000 identified in Figure 2.5 below and its capabilities.

Figure 2.5 a Gyromat 2000 underground

As opposed to previous north finding gyrotheodolites that use reversing point and time difference methods to observe discrete oscillation points, the Gyromat 2000 runs continuously and automatically measures one gyroscope oscillation at small amplitude. The process is measured by an opto-electronic pick-up over a period r, and integrated as shown in Figure 2.6 below.
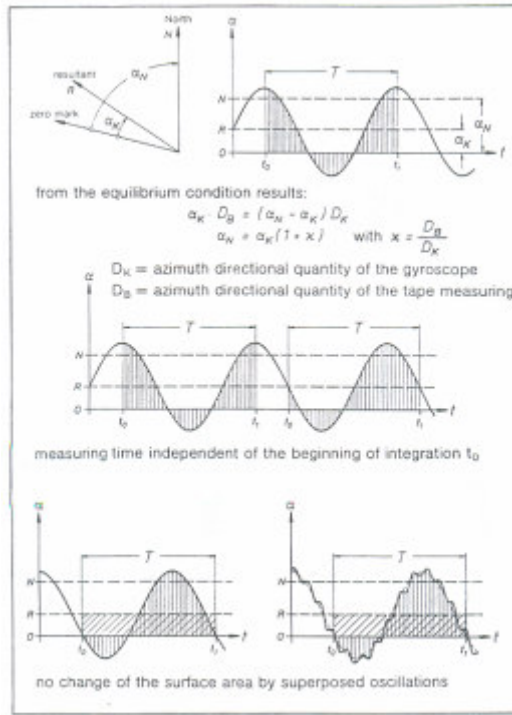
Figure 2.6 Integration method for Gyromat 2000

The zero mark of the pick-up, after iterative preliminary orientation, still shows a deviation α.K relative to the resulting oscillation centre R (= the resultant of tape-induced and gyroscope-induced torque) and an orientation deviation α.N relative to the geographical north. The orientation deviation α.N results from the equilibrium condition of torques, e.g. between the gyroscope-induced directional torque and the tape-induced torque. The amount of the integral yields O.K. The orientation deviation α.N is calculated by simple multiplication of α.K by (1 + K) [KORITIKE, 1988].

The amount of the integral is independent from the time of beginning of integration. There is no need for a preferred point of the curves constituted by oscillations. The measuring time therefore is only one oscillation period T independently on the momentary oscillation figure, and thus constitutes the shortest-possible measuring time for an automatic gyrotheodolite.

The measuring time T is only dependent on the geographical latitude B, for example:

$$B = 0° \qquad , \qquad T = 150 \text{sec.}$$
$$B = 55° \qquad , \qquad T = 170 \text{sec.}$$
$$B = 75° \qquad , \qquad T = 210 \text{sec.}$$

The amount of the integral of the oscillation and thus of the values UK and aN is not changed by superposed natural oscillations as identified in Figure 2.6.

This means the area of integration is not affected by natural oscillations such as the case of equipment vibrating the floor, in an underground coal mine.

If the gyro is bumped or the rectifier detects movement, it induces an oscillation drift.

A GYROMAT 2000 measuring procedure is run fully automated as follows:
- preliminary orientation   1 minute
- tape zero position integration   1-2 minutes
- iterative precise orientation   2-3 minutes
- gyroscopic integration   3minutes
($B = 45°$ to $60°$)

The deviation from north of the graduation ring is thus shown on the display after a total measuring time of approximately 8 to 9 minutes.

Because the Gyromat 2000 has short measuring times, measurements should be performed twice for redundancy.

GYROMAT 2000
65 Jobs
665 Mean values
1.728 Measurements
$_{SA} \sim \pm\, 0,7$ mgon $== 2^{11}$

Table 2.1 Measuring accuracies of Gyromat 2000

A Gyromat 2000's accuracies shown above in Table 2.1 indicate that using the results from tunnels and mines, a standard deviation SA for a single azimuth determination can be calculated Korittke (1997).

As a fully automated piece of equipment, operation of the instrument is such that, it is orientated in an approximate north direction. Ideally, the closer the machine is to north, the shorter the measuring time. The survey is started by selecting a measure program and pressing run. Generally the measurements can take up to 8mins, although this time varies with latitude. The gyro is integrated with a total station horizontal circle to display true azimuth.

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2.5 Accuracy Comparison with Other Instruments

There are some instruments that are unsuitable for underground surveying and will automatically be precluded from the comparison as listed in Table 2.2 below.

INSTRUMENT	UNSUITABILITY REASON
GPS	Obstructed view of the sky
3-D Laser Scanner	Not orientated towards traversing Can not change battery underground

Table 2.2 Instruments unsuitable for underground surveying

Hathaway and Slaton (2004: 6), reporting on the Nancy Creek Sewer Relief Project in Atlanta used a DMT Gyromat 2000, as they believed it was the most accurate machine available and recognised the gyrotheodolite's ability to produce an azimuth determination underground due to the non viability of GPS. Recognising previous research on lateral refraction by Chrzanowski (1981) and Heister (1992), Greening *et al* (1993) concluded that a DMT Gyromat 2000 was the optimum piece of equipment to overcome refraction errors, recommending;

> a zig-zag traverse with reciprocal gyrotheodolite measurements on every leg provides the best insurance against the accumulation of refraction errors. A similar assessment was reached at the SSC, where it was anticipated that the zig-zag traverses and reciprocal gyro-azimuths will ameliorate the refraction problem. The underground measurements and their accuracies are summarized below:
>
> - Azimuths: measured twice in both directions for every leg of one of the zig-zag traverses and assumed to have accuracy of $\sigma\alpha = 3.0"$ for a single measurement.
> - Directions: $\sigma\delta = 0.7"$ for the mean from 3 sets.
> - Distances: $\sigma\delta = \sqrt{(0.5mm)^2 + (1ppm)^2 S^2}$ measured in both directions with several electronic pointings.
> - Zenith Angles: Measured in two sets to support the three dimensional adjustment."

2.5.1 Totalstation Positioning Systems

The following Table 2.3 of information on Leica's 1200 series totalstations compares each instruments capabilities (Leica Geosystems, 2007).

Angle measurement

		Type 1201	Type 1202	Type 1203	Type 1205
Accuracy (standard deviation, ISO 17123-3)	Hz, V	1" (0.3 mgon)	2" (0.6 mgon)	3" (1 mgon)	5" (1.5 mgon)
	Display resolution:	0.1" (0.1 mgon)	0.1" (0.1 mgon)	0.1" (0.1 mgon)	0.1" (0.1 mgon)
	Method:	absolute, continuous, diametrical			
Compensator	Working range:	4' (0.07 gon)	4' (0.07 gon)	4' (0.07 gon)	4' (0.07 gon)
	Setting accuracy:	0.5" (0.2 mgon)	0.5" (0.2 mgon)	1.0" (0.3 mgon)	1.5" (0.5 mgon)
	Method:	centralized dual axis compensator			

Distance measurement

Range (average atmospheric conditions)	Round prism (GPR1):	3000 m
	360° reflector (GRZ4):	1500 m
	Mini prism (GMP101):	1200 m
	Reflective tape (60 mm x 60mm):	250 m
	Shortest measurable distance:	1.5 m
Accuracy / Measurement time (standard deviation, ISO 17123-4)	Standard mode:	2 mm + 2 ppm / typ. 1.5 s
	Fast mode:	5 mm + 2 ppm / typ. 0.8 s
	Tracking mode:	5 mm + 2 ppm / typ. < 0.15 s
	Display resolution:	0.1 mm
Method	Phase measurement (coaxial, invisible infrared laser)	

Table 2.3 Total station positioning systems specifications

2.5.2 Alternatives to the Current Oaky North Survey Process

Of the theodolites investigated, the most suitable alternative to the one currently used at Oaky North would be the Leica TCRA 1201 which is a 1" totalstation with specifications evidenced in Table 2.3 above.

2.6 Control Survey Method at Oaky North Mine

All survey stations are installed from a working survey. This process includes backsighting an illuminated hanging backsight, double plunging to a hanging Mini 360° prism foresight. These control surveys, done with a TCRA 1203 are performed to check working survey stations. This process involves traversing to every third station, a distance of approximately 300m. The purpose of this traversing is to give longer sight lines and reduction of errors in setups. These control stations are run down the centre line of the heading in the roof. Circular prisms on legs are set underneath the stations using the Zenith Plummet at the backsight and foresight. This procedure creates more accurate centering in a ventilation turbulent environment (1.8m/sec velocity) than a hanging plum bob.

`

Greening *et al* (1993) as stated in Chapter 2.5 recognises the value of zig-zag traversing as a means of overcoming lateral refraction in tunnel surveying. This is however, not possible in an underground coal mine because as vertical stresses increase, as a result of the mining process, ribs spall (crush out), effectively destroying any wall stations.

2.7 Traditional Survey Methods in Surrounding Mines

While the literature supports the use of a gyrotheodolite as a means of overcoming the effects of lateral refraction, it is pertinent to review surveying practice in surrounding underground mines. Through communications with the local surveying network and personal experience, knowledge of surveying practice in other mines was gained. Rio Tinto's Kestrel mine utilises a Wild T1000 for its underground network while BMA Crinum and Gregory mines use TCRA1103 as does Oaky No1. These mines experience reading variances of 10 – 30" which they directly attribute to lateral refraction. Coincidently, these mines all avail themselves of the services of C R Hutchison & Co's Gyromat 2000 on a rotational basis when in the Bowen Basin, as a means of correcting reading errors associated with lateral refraction (Morris, 2006).

2.8 Deficiencies in the DMT Gyromat 2000

DMT do not publish any literature relating to deficiencies with their Gyromat 2000, however, the following were issues raised in research:

1. Hathaway and Slaton (2004), recognised that the instrument is relatively sensitive, in that takes 45 minutes to acclimatise each time it is taken underground.

2. Hamilton (2002), identified prohibitive cost as a drawback to regular use of a gyrotheodolite.

3. From an Australian perspective, Hutchinson (2006) advised that he has the only two Gyromat 2000 theodolites in the country, hired at a costing of $3000 per day.

4.   The Gyromat 2000 is battery operated and is therefore required to be signed into the Uncertified Portable Electrical Equipment (UPEE) register before being taken underground. Consequently, the operator/supervisor must carry a Personal Gas Detector (PGD) at all times in accordance with SOP0202OCN refer to Appendix C.

5.   In the event of the Gyromat 2000 being damaged on site or in transit, it has to be returned to Germany for repairs. As the repair process can feasibly take up to 3 months, there is potential for project delays or the risk of exacerbating refraction errors if solely reliant on readings from a regular theodolite.

2.9 Conclusion

Available literature recognised that lateral refraction impacts on sighting accuracies in underground tunnel projects. Although the causes of lateral refraction are not widely understood, there is consensus that atmospheric conditions are responsible for the phenomena. Having compared the capabilities of producing accurate readings of various theodolites, a Gyromat 2000 is considered the most suitable theodolite available, to counteract lateral refraction errors in underground surveying.

Chapter 3

Methodology

3.1 Introduction

The findings of the literature review in Chapter 2 have been considered in developing the best approach to achieving the project's objectives previously outlined in Chapter 1. Based on research findings, a Gyromat 2000 is considered the most effective technology available with which to achieve these objectives. While conducting this survey project with a Gyromat 2000, the obtained data will be cross referenced against data from a traditional survey. The data from both surveys will be compared to determine if variances in readings vary sufficiently to be outside accepted tolerances. By doing the comparison in reading variances, the efficiency of a Gyromat 2000 over a traditional survey will either be confirmed or disproved. The literature review has confirmed a procedural format and project methodology

3.2 Procedural Format

a. Research:

- lateral refraction theory, so as to understand the phenomena's effects on underground surveying. The findings of the research have been identified in Chapter 2.2 - 2.3.2. as being that lateral refraction is a phenomenon that effects traverse lines in tunnels.

- theodolites generally, to determine those that are suitable for underground surveying as opposed to those that are not. The findings of the research have been identified in Chapter 2.4 - 2.7. Specifically, theodolites suited to underground surveying include totalstations as opposed to GPS and laser scanners.

b. Research Analysis:

- identify the machine most suited and available for the purposes of the project. The proposed machine was identified in Chapter 2.8 as being the Gyromat 2000. This equipment is considered the most suitable instrument to detect erroneous readings due to lateral refraction.

c. Strategy:
- develop a cost analysis for utilising a Gyromat 2000 over 12 hours
- secure the services of C R Hutchison & Co. As they own the only Gyromat in Australia, this will take some organising
- complete a risk assessment for underground use of the battery operated Gyromat 2000 (Appendix B)
- complete equipment inventory

d. Data Collection:
- conduct the trial survey, recording data from the Gyromat 2000. At the same time consideration will be given to atmospheric and locational conditions

e. Data Analysis:
- Compile the data obtained from both surveys and do a comparison analysis of the results from both machines using Star*Net.   T-test analysis can be used for data analysis for the purpose of this project.
- Cross reference the results analysis against literature review findings to determine accuracy and validity

f. Conclusion:
- Reflect on results obtained and make recommendations regarding the control of lateral refraction in underground coal mines

3.3 Research Method

The research method will commence at Procedural Format item c. – Cost Analysis

3.3.1 Cost Analysis

As a checking mechanism, Gyro surveys are budgeted for every 6 to 9 months. Before the project can commence, a purchase requisition is raised against the survey budget then approved by the Technical Services Manager (Appendix D).   This particular campaign was for two days divided into one day on the surface observing surface baselines, and one day underground at Oaky North Mine. Once approval was granted,

the proposed booking was confirmed with C R Hutchison & Co. to hire the Gyromat 2000.

In order to reduce costs associated with the hire, transport and operation of the Gyromat 2000, to Central Queensland from Newcastle, surrounding operations are queried as to whether they will be able to utilise the services of the Gyromat 2000, while in the area.

3.3.2 Risk Assessment

The Coal Mining Safety & Health Regulation (1999) Section 202 outlines the procedures for taking Uncertified Portable Electrical Equipment (UPEE) underground. This requires a risk assessment to be completed prior to development of a standard operating procedure (SOP).

As the practical component of the project will be conducted in the underground environment, all necessary OWPHS procedures will be followed. Furthermore, the operator will need to show proof of a current negative drug screen and hold a current underground contractors induction certificate.

A risk assessment (RA0202OCN) has been carried out to assess the hazards associated with the use of UPEE in the underground environment at Oaky North Mine, aimed at reducing the risk to a minimum (Appendix B).

Prior to the commencement of any new or different tasks, a SLAM (Stop, Look, Assess and Manage) or formal SLAM is carried out to identify any possible hazards associated with carrying out the task. The SLAM booklet involves some tick questions and writing down observed hazards and controls.

3.3.3 Equipment Inventory

The equipment need to successfully run the project includes:

- Hire Gyromat 2000

- Accommodation and transport for gyro operator

- Computer with Microsoft excel

- 50hrs staff time

- 2 sets of legs – 1 for target and 1 for backsight

- Leica ZNL plummet

- Targets

- Umbrellas to stop wind buffeting the Gyromat 2000

Of the equipment identified, accommodation is the most lucrative. Due to the commodities boom, demand for accommodation far outstrips supply. This necessitates all planning for data collection to pivot around accommodation availability. Unfortunately if the operator cannot be provided with accommodation, the gyro survey cannot take place.

3.3.4 Data Collection

Before the Gyromat 2000 arrives on site, the co-ordinates for the proposed lines are sent to the survey consultant, thereby allowing the calculation of grid convergence for each line. Once the observation lines have been agreed, a notification is placed into the weekly plan that the surveyors will have the section closed for the duration of the survey.

Once on-site, the Gyromat 2000 will be setup over two previously observed points to gain a current site swing. Before the Gyromat 2000 can go underground the batteries are discharged then recharged. This process ensures maximum time underground with fully charged batteries, as the NiCd batteries were nearing the end of their service life.

On this campaign, the T2 mounted Gyromat shown in Figure 3.1 below was used. Following the surface observations the Gyromat 2000 will be very carefully loaded into the back of the Technical Support department's ranger and taken underground. Once, underground, the Gyromat 2000 must sit for 20 minutes, in order to acclimatise.

Figure 3.1 Gyromat 2000 with top mounted T2

3.4 Surveys

For the purposes of this project a surface baseline and two separate underground baselines were surveyed using the Gyromat 2000.

3.4.1 Surface Baseline

As mentioned in 3.3.4, a surface base line survey is conducted to orient the machine to the site and establish a site specific correction value.

The surface baseline was surveyed early in the morning to minimise temperature change on the Gyromat 2000 and reduce the effects of heat shimmer. The Gyromat was setup over RHB2 sighting RHB3 at 7:00am. The weather was sunny with a light breeze.

The first measurement resulted in a temperature warning light so this measurement was repeated. This was most probably due to the Gyromat being stored in an air conditioned

office overnight the next two measurements at RHB2 were completed by 7:45am with no temperature warnings and the gyro moved to RHB3.

The first measurement at RHB3 commenced at 8:20am and was complete by 8:40am. Once the gyro temperature had stabilized there were no temperature warning lights and the two drops at RHB3 were completed within 20 minutes with no problems.

3.4.2 Underground Baselines

Of the two survey lines to be observed, the first was in a standing panel that has been left (SMG6) while another area of the mine is developed. This is ideal for the survey as there will be no traffic trying to pass the instrument and legs.

Once at the site the Gyromat 2000 case is opened to allow the units temperature to equalise with the ambient temperature. The survey legs were setup with the zenith plummet and tribrach underneath the control station. Once a close position was found using the plumb bob the plummet was used to move directly under the station. The plummet was then removed and replaced with the Gyromat cradle. The cradle was levelled using an engineer's spirit level. The gyro was then lowered into the cradle so that the reference arrow was orientated towards north.

Once the gyro is levelled and screwed down it is turned on and the latitude of the station is entered in through the menu. Once the target has been setup under the foresight station the gyro is turned on and the automated program is run. During the next 7 – 9 minutes the gyro moves though each of the four steps to orientate itself towards true north. Due to the mine site latitude being approximately S23.05° the oscillation time of the gyro is faster than at lower latitudes. This saw measurement times of approximately 7.5 mins.

On the front panel there are two warning lights that indicate a temperature warning or a drift warning. A temperature warning light means that the temperature has changed by more than 0.3°C and the resulting data may be inaccurate and should be used with

caution. In the case of either a temperature or drift warning light the measurement should be taken again. This instance saw no warning lights, confirming a successful reading.

The second survey line is in a current priority panel (300 Panel) that can not be stood down. Planning with the development coordinator saw that the survey was able to complete the gyro readings, with no disruption from vehicle movements.

At each survey line the conditions will be noted, along with any plant and ventilation control devices in the area. On completion of the survey campaign, preliminary results will be supplied, to give a close approximation of the observed azimuths. The final results will be posted to the survey department within two weeks. These results will show the deviation and observed azimuths for each gyro line. If any differences are found the station data base will be adjusted using an angular adjustment weighted on distances.

It is expected to find that as the ventilation in the headings passes the section transformers, it changes the refractive index of the air due to increased temperature and turbulence. It is also expected to find that mobile plant parked on the rib line interferes with the flow of the ventilation and temperature to produce the same effects as transformer cut throughs.

3.5 Conclusion

Once the data from both surveys has been collected and processed using the Star*Net package, the results will be used to adjust the bearing of the panel check surveys so that the distances will be held fixed and the angles adjusted. This process is currently used at Oaky North mine, for the adjustment of tunnel heading bearings for direction. Conclusions will then be drawn as to where the largest discrepancies were found and what conditions resulted in the least deviation from the observed check survey lines.

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Chapter 4

Results and Analysis

4.1 Introduction

The object of this chapter is to compare the resulting azimuth observed using the Gyromat to the azimuth carried forward using traditional survey traversing. The two traverses will be processed using a least squares adjustment in the Star*Net Package. Each network will be processed first with the conventional traversing method before being processed holding the gyro observations fixed. Once all traverse observations have been entered into Star*Net, the network is processed and errors for the observations and points are calculated.

The data will be analysed in accordance with Chapter 1.6 objectives 2 -5, as a means of verifying or refuting research data supporting Gyromat 2000's accuracy in counteracting the effects of lateral refraction. Particular interest will be given to whether the readings gained by the Gyromat 2000, compared to the readings from a TCRA 1203 vary sufficiently to be outside accepted tolerances.

4.2 Surface Baseline Results

These observations are performed between two known surface primary control points to allow the Gyro operator to gain a site specific swing correction value. After reading between RHB2 and RHB3 a site swing of -14.6" was established to correct Gyromat 2000 readings to align with the mines grid datum.

4.3 The Networks Analysed

For the purposes of this project, two traverse lines were resurveyed over one leg of the check survey, a distance of approximately 300m. These traverse lines are known as South Main Gate 6 (SMG6) and 300 Panel. Check survey stations are working survey stations that have been reread at a later date that are spaced at generally 300m dependent on sighting ability. The setups under the roof stations are performed using a

Leica ZNL plummet, to give better position accuracy, rather than using a plumb bob on a string as used for working surveys.

4.4

 Network Analysis without Gyro Observation

The following Figures 4.1 and 4.3 graph the standard deviations of the stations easting and northing for SMG6 and 300 Panel, starting with SMG6.

4.4.1 SMG6 Development Panel

As previously identified in Chapter 3.4.2, this development panel has been left while another area of the mine is developed. This development panel had advanced approximately 2.7km before the Gyromat 2000 was ordered to come on site. Figure 4.1 below indicates there were ten check survey stations that had been read to, since the previous gyro observation.
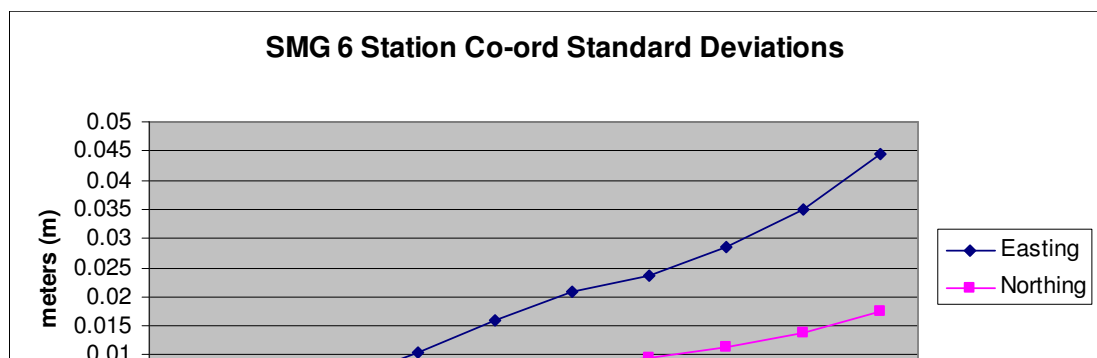

Figure 4.1 SMG6 Standard Deviations

Figure 4.1 above identifies that the coordinate deviations are greater in the easting. This is due to the panel heading being near 158° which means that any angular errors will affect the easting more so than the northing.

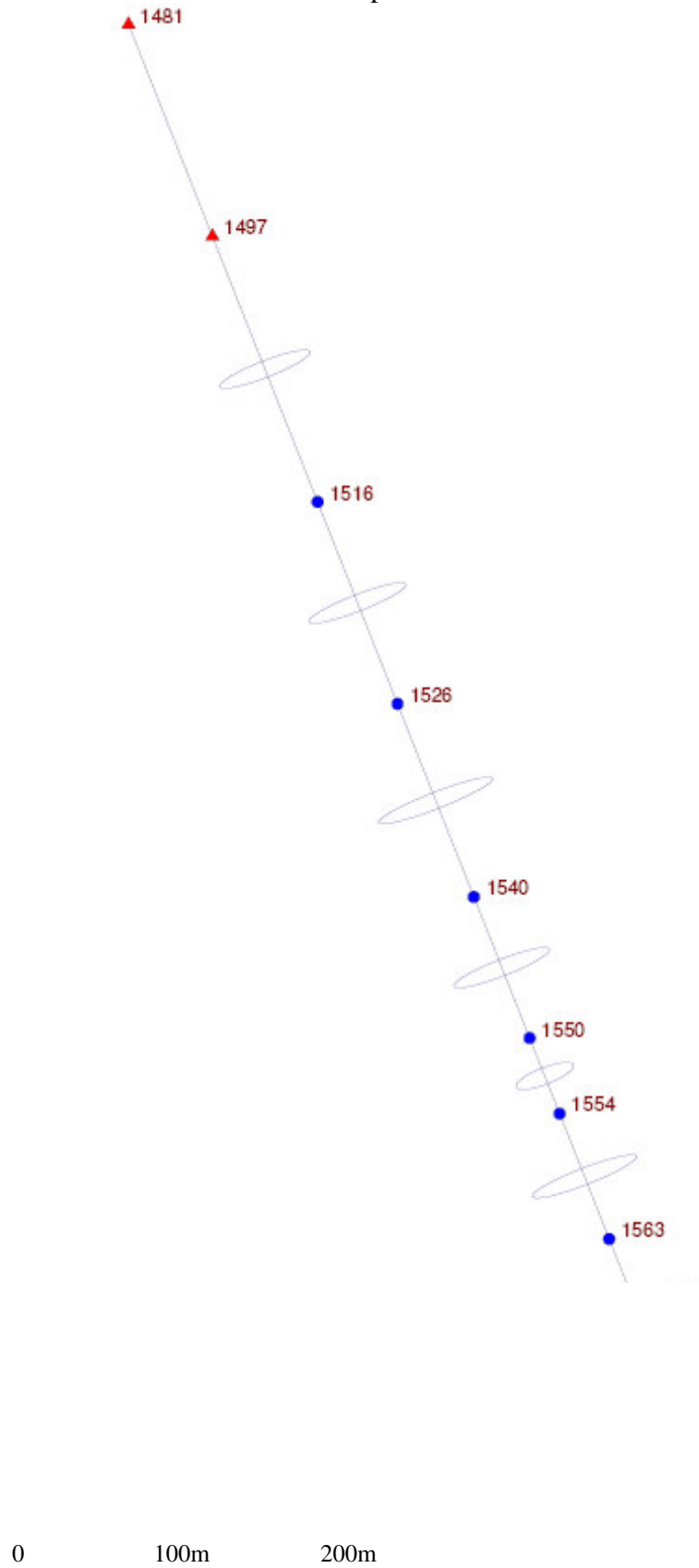Figure 4.2 below shows the error ellipses for each stations observation.

Figure 4.2 SMG6 Adjustment without Gyro observations.
Ellipse exaggeration = X5000

4.4.2 300 Panel

In Chapter 3.4.2, this development was identified as a current working panel. 300 Panel is the latest development heading started. Due to the short length of this block and the short period of time it has been operating, the panel had only advanced 500m when the gyro was brought on site. As identified in Figure 4.3 below, there were six check survey stations having been read to, with no previous gyro observation.
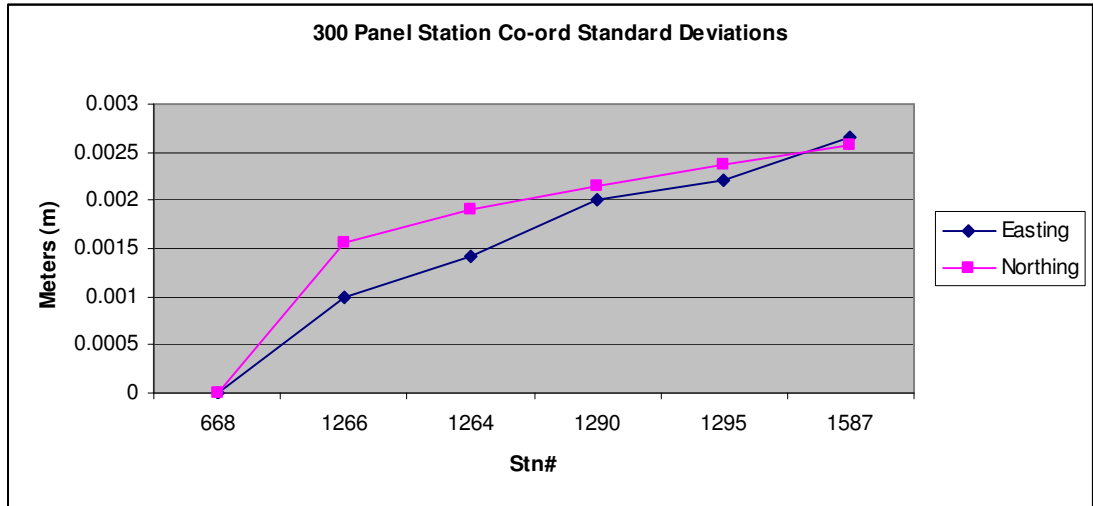

Figure 4.3. 300 Panel standard deviations

Figure 4.3 identifies that due to the low number of check stations and short distance of the traverse, there has been limited deviation. Figure 4.4 below shows the error ellipses for each stations observation is small because it was very close to a previous gyro line in the mains, approximately 300m.
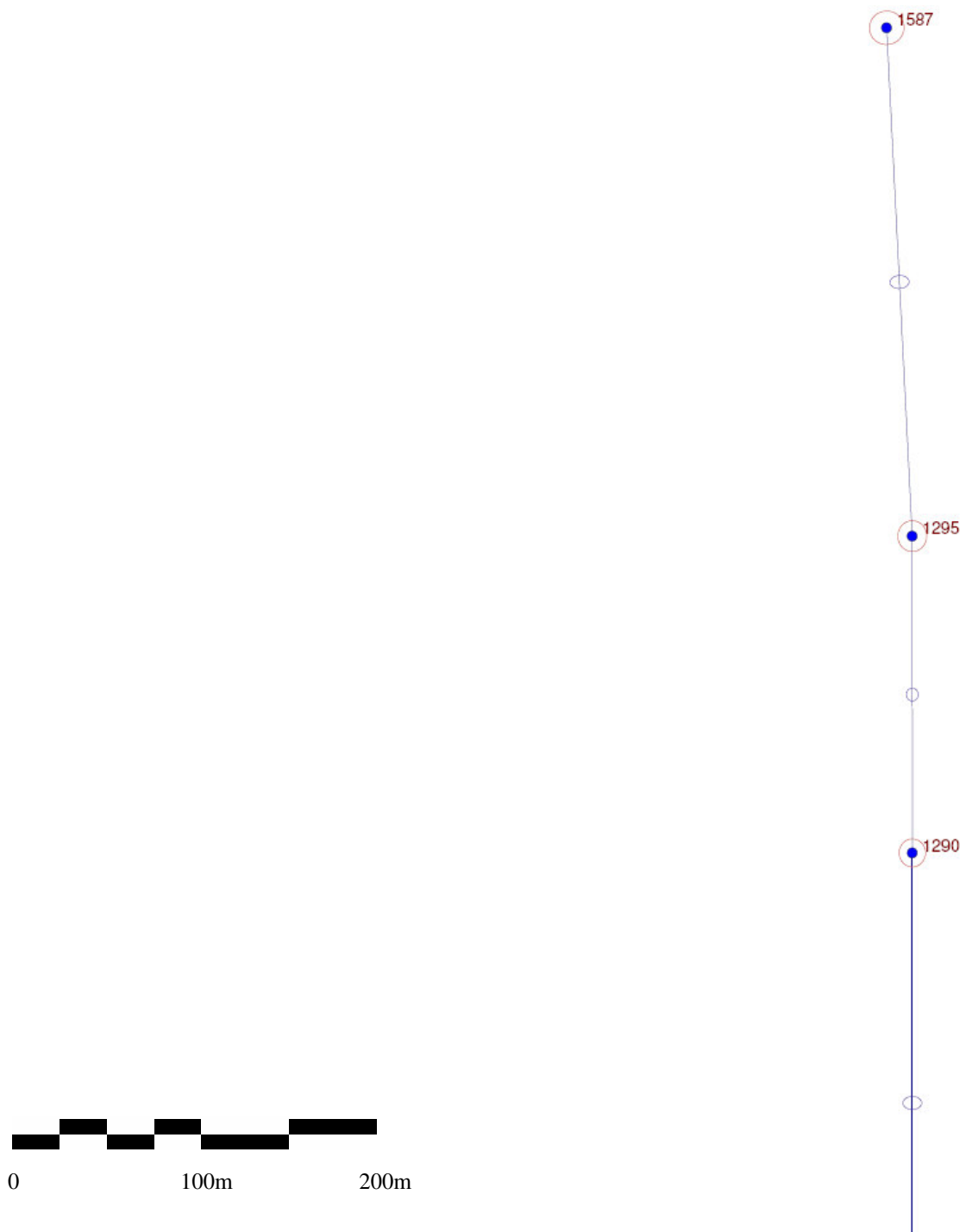
Figure 4.4 300 Panel adjustment without Gyro observations
Ellipse exaggeration = X5000

4.5 Network Analysis with Gyromat 2000 Observation

As mentioned previously, gyro observations will be added to the network adjustment as a fixed observation line. The data used to adjust the previous networks will remain with the exception of the addition of the gyro observations as an additional control file.

The main reason for including the gyro observation is to adjust the traverse line leading to the observed gyro line. With the addition of the gyro observation new corrected values for the bearings and resultant coordinates will be generated as part of the list file.

Due to time constraints there is only ever one set of gyro observations performed in each panel. This consists of two gyro measurement performed at each end of the observed line. The claimed error of the Gyromat 2000 is 1mgon (0.3") which through extensive use the operator believes to be achievable (Hutchinson, 2006).

Surface baseline calibrations showed that the observed direction between RHB2 and RHB3 had an accuracy of 2.9" this is well above the stated1" accuracy of the Gyromat 2000.

4.5.1 SMG6

The Gyro observation in the SMG6 panel showed that the bearing between the observation stations was in fact 21.4" less than the gyro observation. This error would equate to approximately 200mm over the 2Km length of the panel. With a deviation tolerance of 150mm, this deviation is outside the accepted tolerance.

This deviation is of significance in open ended parallel traverse tunnels, as it is important that the tunnel does not merge at the longwall installation face and form a trapezoidal block. From an engineering perspective, the longwall installation requires the longwall belt to be parallel to the heading design centreline, to avoid any tracking issues with the belt, prevent the maingate from contacting the rib once production starts.
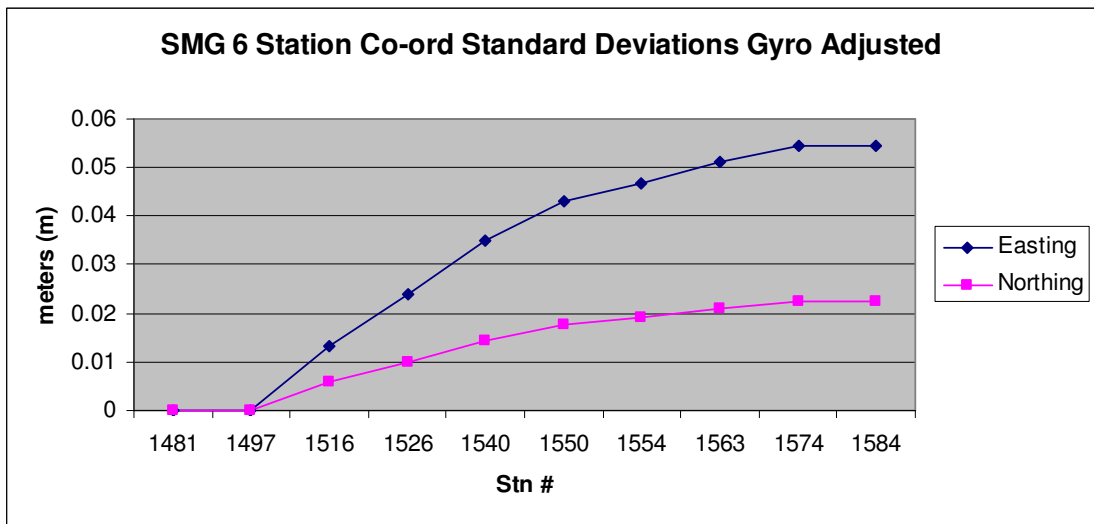
Figure 4.5 SMG6 standard deviations with Gyro observations

Figure 4.5 shows that the stations have deviated from the design centreline. However, with the addition of the Gyromat 2000 observations to the list file, the deviations are no longer increasing and become static. This is in line with processing the network adjustment while holding the gyro observation as a fixed azimuth.
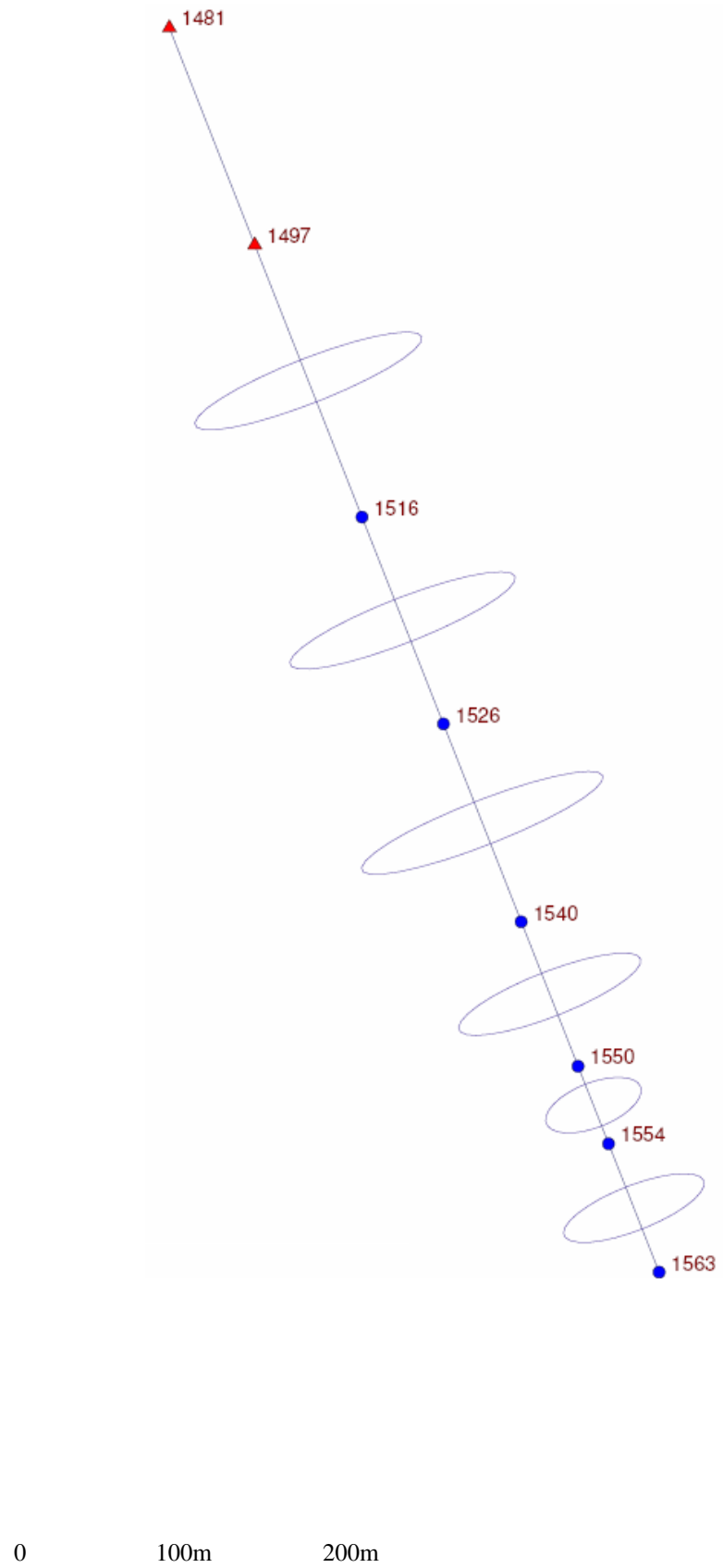
0   100m   200m

Figure 4.6 SMG6 adjustment with gyro observations
Ellipse exaggeration = X5000

4.5.2 300 Panel

With the relatively short distance that 300 Panel had advanced before the gyro was bought on site, there was a 7.7" variation between the control survey value and the observed gyro value. Again the control survey value was less than the gyro value. This tends to indicate that working surveys have a tendency to move to the right when heading inbye (mining terminology for looking into the pit). 7.7" in angular deviation relates to 18mm after 500m which is well within mining tolerances.
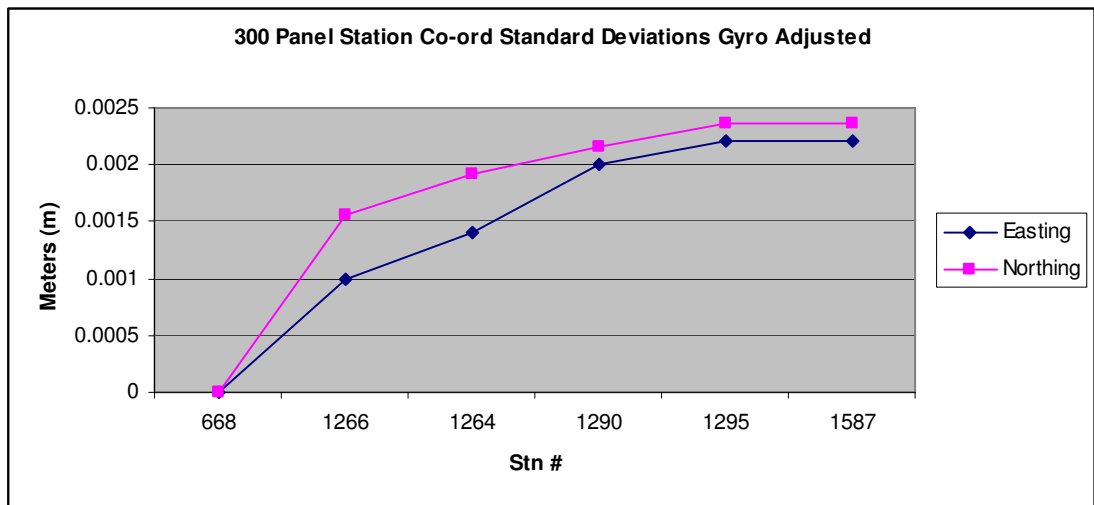
Figure 4.7 300 Panel standard deviations with Gyro observations.

Figure 4.7 identifies that with the addition of the Gyromat 2000 observations added to the adjustment file, the deviations of the stations from the centreline are no longer increasing. This would be expected with the Gyromat azimuth observation being held fixed.
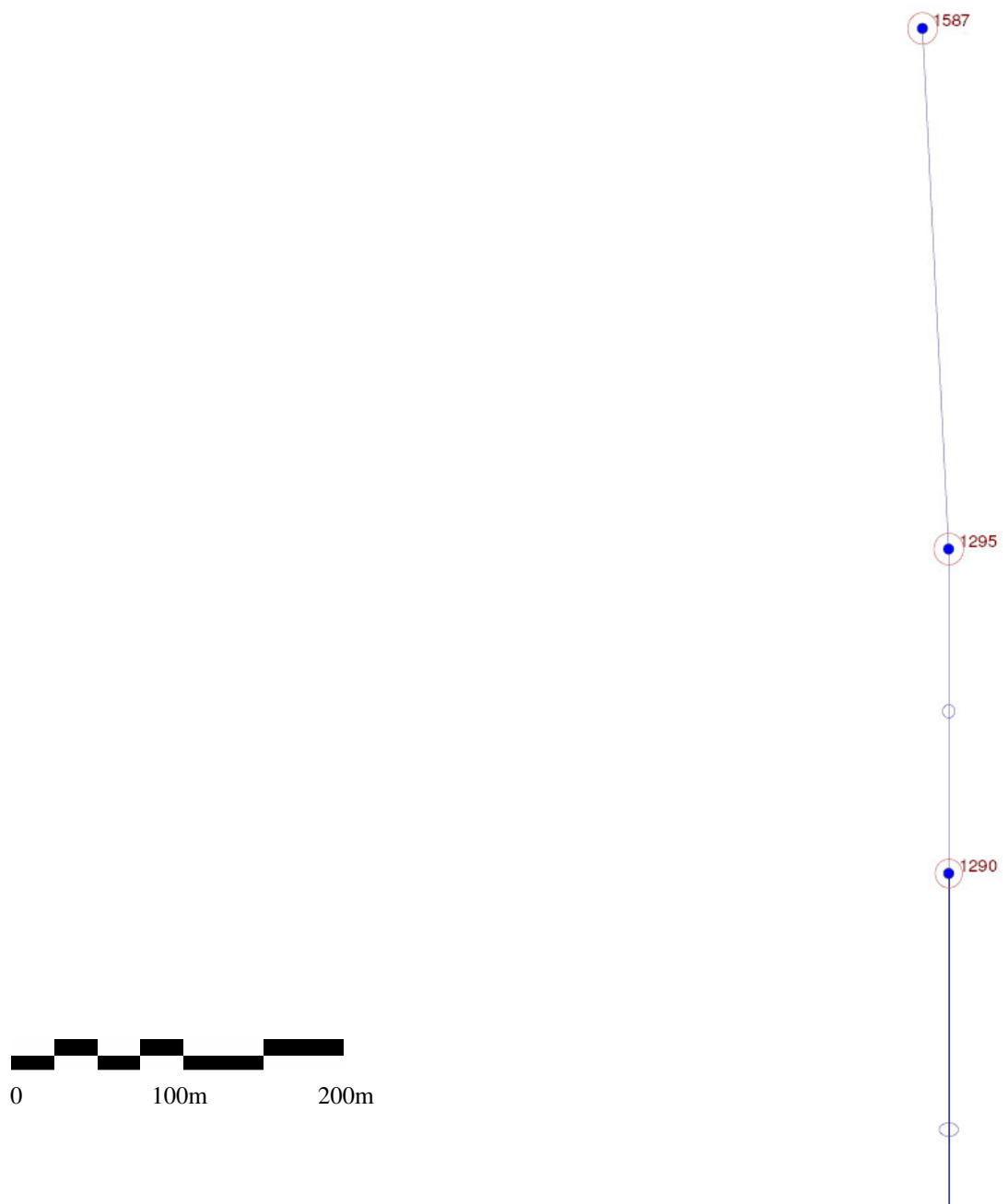
0   100m   200m

Figure 4.8 300 Panel adjustment with Gyro observations
Ellipse exaggeration = X5000

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4.6 The Suitability of a Gyromat 2000 as a Lateral Refraction Control

As previously stated, based on the literature review, a Gyromat 2000 was deemed the most accurate machine for use in underground tunnels, toward the control of lateral refraction. The results obtained and analysed above in Chapter 4 show that the use of a Gyromat 2000 provides an effective control of lateral refraction in underground coal mines. The variances obtained in the surveys using a Leica TCRA 1203 compared to the Gyromat 2000 were determined using a t-test with a confidence level of 95%. It was found that the Gyromat 2000 had a standard deviation of 1.3" which is 0.3" greater than the stated achievable accuracy compared to the TCRA1203's standard deviation of 2.8" which is less than the stated 3" accuracy (Appendix E). These values confirm that the Gyromat 2000's ability to detect reading errors, makes it an effective control mechanism for lateral refraction in an underground mine survey.

4.7 Conclusion

Having compared the data gained from SMG6 and 300 Panel surveys by the mine surveyors with those gained by the Gyromat 2000, the evidence suggests that lateral refraction is affecting panel traverse lines to a degree that is not within acceptable tolerance. With variances outside acceptable tolerance, the survey team at Oaky North mine are required to rectify the errors caused by lateral refraction. The Gyromat 2000 is the most suitable, available device for indentifying these errors and allowing accurate determination of underground azimuths, toward rectification of lateral refraction effects.

Chapter 5

Conclusion

5.1 Summation

The gyrotheodolite has been utilised in many tunnelling activities in the past and has recently been implemented into some underground coal mines on the premise that it is a valuable tool to control open ended traverses. This project showed that, by using a Gyromat 2000 to measure sight lines independent of previous traversing, the effects of lateral refraction can be corrected. These corrections can be applied to the traverse lines after the Gyromat data has been used in the Star*Net adjustment for the panel and new station coordinates will be calculated.

However, the gyrotheodolite is not intended to detect gross or systematic errors. This means, emphasis must be placed on good survey practice, as there is a reduced availability of redundant checks. If gyro observations are to be used in improving a control network, it is imperative that the observations themselves are corrected and computed in a manner that will minimise gross and systematic errors. One possible way to correct gross errors would be top use the totalstations ability to store all underground survey stations and use the Leica sets of angles program to read check survey angles. This program is an automated reading program that allows the user to specify the number of angles to be read and the stations to be read to.

Much of the available literature is based upon wall mounted stations, and as such, the ability to create a redundant network like this is not the case in underground coal mines, due to the susceptibility of rib spall (wall failure). There is scope to investigate a better roof station layout suitable to underground coal mining that allows for increased redundancy.

From the results shown in the network adjustments, it is conclusive that lateral refraction is affecting sight lines by approximately 2" per 100m. This is only an averaged value that cannot be used as a standard correction to compensate for lateral

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refraction. As the discrepancy of 2" is smaller than the stated 3" accuracy of the TCRA 1203, the surveyors are unable to measure more accurately than the error.

Currently, Oaky North mine's lateral refraction control methodology is to hire the services and Gyromat 2000 of C.R. Hutchison and Co. This is done on a needs basis, associated with the availability of the Gyromat and the status of current mining operations, dictating when access to the panels can be gained.

5.3 Recommendations

Through the research and practical work carried out in the completion of this project I have found that there are many variables that require further study. One significant area for further investigation in developing a methodology to overcome lateral refraction would be strategies to minimise the conditions which cause lateral refraction in underground tunnels, as identified in the Chapter 2 literature review. This topic was outside the scope of this project but there is a need to gain a better understanding of temperature gradients in order to produce a methodology that will allow refraction to be corrected.

Because of the dynamic nature of the underground mine, the tunnel configuration relating to transformers, air pumps and venturi positions is constantly changing. Consequently, because of the temperature gradient for the tunnel cross section and the turbulence created from such devises, any correction values would need to be measured at the time of each measurement. This would prove to be very time consuming and would add to the amount of time a production panel is held up while surveys are performed. As this delay is not a viable option Oaky North mine will continue to utilise the Gyromat 2000 in order to fix the error after we have progressed down the heading.

As identified above in 5.2, current techniques employed at Oaky North underground help to reduce the effects of lateral refraction by sighting along the heading, keeping lines of sight centralised within the tunnel thereby avoiding cross tunnel turbulence. It is also recommended that full use of the current Leica TCRA 1203's Automatic Target Recognition be utilised to reduce sighting errors and over longer distances in the

reduced light environment. This machine is currently being under utilised because the users are not fully conversant with the machines capabilities and therefore reluctant to optimise its capacity.

It is further recommended that a trial be conducted with a 1" totalstation that would tighten the angle readings on check survey traverses. This would then be compared to the Gyromat 2000 readings on the next campaign. The objective would be to eliminate the need to hire a gyrotheodolite.

5.4 Conclusion

This project has confirmed that in the current survey industry, particularly in the Bowen Basin, control surveying methods rely on a gyrotheodolite to detect pointing errors caused by lateral refraction from a totalstation. The specific gyrotheodolite utilised, the Gyromat 2000 is able to produce readings within accepted mining tolerance, as a lateral refraction control in underground mine surveying.

While this project's objectives were addressed, the end result is that there is scope for a whole other project. A project aimed specifically at researching and developing strategies toward a methodology which negates the need for a gyrotheodolite to control the effects of lateral refraction on a totalstation survey.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
Project Specification

FOR: Logan Mohr

TOPIC: Effects and Controls of Lateral Refraction in Underground Coal Mines

SUPERVISOR: Shane Simmons

ENROLMENT: ENG4111 – S1, X, 2006
                        ENG4112 – S2, X, 2007

PROJECT AIM: The aim of this project is to investigate a suitable methodology to reduce the
                        effects of lateral refraction in an underground coal mining environment.
                        Current underground coal surveying techniques will be investigated in relation
                        to control traversing and the use of Gyrotheodolites

PROGRAMME:

1. Evaluate current control surveying methods used within the coal mining profession.
2. Determine the conditions that cause lateral refraction in tunnels and analyse the effects of lateral refraction
3. Analyse and collect gyroscopic information and calculate variance to tunnel heading directions.
4. Develop a suitable methodology to reduce lateral refraction in tunnels.
5. Write a dissertation.

AGREED / DISAGREED

STUDENT: . . . .   DATE   /   /

SUPERVISOR: . . . .   DATE   /   /

Appendix B

Formal Risk Assessment for Using Portable Electrical Equipment

Appendix C

Standard Operating Procedure for Using Portable Electrical Equipment

Appendix D

Work order to hire Gyromat 2000

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Appendix E

T-test analysis

Gyromat 2000 Observations	TCRA 1203 Observations
157.1977	157.1967
157.1983	157.1985
157.1975	157.1971
157.1975	157.1974

Gyromat 2000

The hypothetical mean is 157.197600
The actual mean is 157.197750
The difference between these two values is 0.000150
The   95% confidence interval of this difference:
From -0.000452 to 0.000752

Mean   157.197750

   SD   0.000379

SEM   0.000189

   N   4

TCRA 1203

The hypothetical mean is 157.197600
The actual mean is 157.197425
The difference between these two values is -0.000175
The   95% confidence interval of this difference:
From -0.001403 to 0.001053

Mean   157.197425

   SD   0.000772

SEM   0.000386

   N   4