# A New Weighting Model of Gyro-Sides in Under-ground Surveying

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**Abstract:** The traditional method divides the underground control network into various direction connecting traverses. When Gyro-sides are added, condition equations are needed and the approximate coordinates of Gyro-sides are recalculated with the increased condition equation. However, it is not rational for the traditional method considering the gyroscope orientation sides as the steady line. According to the analysis of long-term data collection and processing, a weighting model of additional Gyro-sides is proposed. It is more theoretical because of the integrity of the whole control network. Meanwhile, the swing of control network caused by the precision of Gyro-sides is avoided by the new model. Multiple of experiments show that the new weighting model can get higher positioning precision and reliability. It provides strong theoretical basis for the routine production.

**Keywords:** Gyro-side; underground control network; weighting; adjustment; precision

## 1 Introduction

Underground horizontal control survey plays an important role to the production and safety of mine. With the development of modern construction of mine, some important issues are to be faced, such as the faster promoted speed of workface, gradually increasing area of mine and mining depth. And the accuracy and reliability of the underground point decreases with increasing distance, the coordinates of surface-underground have shown the inconsistency. It produced great difficulties for mine rescue and other applications. Therefore, how to improve the accuracy of the coordinate system in the underground, provide the accurate and reliable coordinates of surface-underground, have shown the great significance for the safe production in mines and mine rescue.

Traditional geometric orientation methods of the underground control survey have been influenced by some factors: visibility condition, dust, water vapor etc. Generally, the side of length is short, and the errors of accumulation and transmission are evident.

In order to improve reliability of the underground network, we always add a survey of gyrostatic orientation line in every 1.5 ~ 2Km. Without increase the measurement accuracy of wire angle and change the form of traverses, gyrostatic orientation line not only reduces the cumulative errors of direction, but also improves the reliability of the wire network.

The traditional approaches adopt gyrostatic orientation line as strong side with known direction, and then survey adjustment into subsection ones. Zhu has investigated these studies deeply in 1970s. However, subsection adjustment is more complex, there will be one more condition for each additional gyrostatic orientation line and it need to be calculated the priori coordinates of gyrostatic orientation lines again. Moreover, treating gyrostatic orientation line as known is not strict in theory. If the gyrostatic orientation lines result in lower accuracy or gross errors, it will affect the reliability of measurement results significantly. Feng and Chen (1993) discussed the algorithms for additional survey of gyrostatic orientation line in two wells and proved that it is unreasonable to regard the gyrostatic orientation line as strong side.

Gao et al (2006) analyzed the weight determination of gyrostatic orientation lines through Helmert variance component estimation methods and the accuracies of endpoints can increase 60%. Nevertheless, it can be deduced that the measurement accuracy largely depends on the selection of the observation weight matrix through rigorous adjustment.

The additional gyrostatic orientation lines can greatly improve the reliability of the control network in direction through the analysis of optimal precision allocation problem. But how to select the gyro weight matrix and the impacts of different weights on the accuracy and reliability of the entire control network are not investigated.

Based on the analysis of measured data of mines, we propose a new approach of weight determination of gyrostatic orientation lines and study the impact to the accuracy of underground control network. The proposed method can provide a theoretical basis for the adjustment of underground control network survey and guarantee the consistency of coordinate system in surface-underground. The rest of this paper is organized as follows. Section 2 and 3 give the details of the traditional and proposed methods. Experiments and discussion will be shown in Section 4. We will present the conclusion of the related work in Section 5.

## 2 Tradition methods

Ref [2] gives the description of the determination of gyrostatic orientation lines and weights. In generally, it always regards the gyrostatic orientation line as strong side and subtracts the line into several ones to survey the adjustment of side and angle. The current algorithm is a simple one which is popular in the processing of production.

Underground tunnels are often views as the straight wires. We assume that the additional gyrostatic orientation line is joined between knows points A and B. The coordinates of A and B are $x_A$ and $x_B$ with the azimuth angles $\alpha_A$ and $\alpha_B$ .

$$\boldsymbol{AV - W = 0} \tag{1}$$

where： $A = [A_1 \ A_2 \ A_3]$

$$A_1 = \begin{bmatrix} \cos\alpha_1 & \cos\alpha_2 & \cdots & \cos\alpha_n \\ \sin\alpha_1 & \sin\alpha_2 & \cdots & \sin\alpha_n \end{bmatrix}$$

$$A_2 = \frac{1}{\rho}\begin{bmatrix} y_A - y_1 & y_A - y_2 & \cdots & y_A - y_{i-1} & y_B - y_i & \cdots & y_B - y_{n-1} \\ x_A - x_1 & x_A - x_2 & \cdots & x_A - x_{i-1} & x_B - x_i & \cdots & x_B - x_{n-1} \end{bmatrix}$$

$$A_3 = \frac{1}{\rho}\begin{bmatrix} y_A - y_B \\ x_A - x_B \end{bmatrix}$$

$$V = [V_1 \quad V_2 \quad V_3]^T$$

$$V_1 \ = [V_{l1} \quad V_{l2} \quad \cdots \quad V_{\ln}]^T$$

$$V_2 \ = [V_{\alpha 1} \quad V_{\alpha 2} \quad \cdots \quad V_{\alpha \mathrm{n}-1}]^T$$

$$V_3 \ = [V_\beta]^T$$

$$W = \begin{bmatrix} W_x \\ W_y \end{bmatrix} \ = \begin{bmatrix} x_A - x_B + \sum_{i=1}^{n} l_i \cos\alpha_i \\ y_A - y_B + \sum_{i=1}^{n} l_i \sin\alpha_i \end{bmatrix}$$

Where, $\boldsymbol{A_1}$ is the coefficient matrix of observed angles, $\boldsymbol{A_2}$ is the coefficient matrix of observed sides, $\boldsymbol{A_3}$ is the coefficient matrix of gyrostatic orientation line, and $\boldsymbol{V_1}$ ,$\boldsymbol{V_2}$ , $\boldsymbol{V_3}$ are the corresponding corrections.

According to the conditional adjustment, the corrections and normal equations can be listed in the following:

$$\boldsymbol{V = P^{-1}A^T K} \tag{2}$$

$$\boldsymbol{NK - W = 0} \tag{3}$$

Where $\boldsymbol{N = AP^{-1}A^{\mathrm{T}}}$

$$\boldsymbol{K = N^{-1}W} \tag{4}$$

Furthermore, from equations (1-2) and (4):

$$\begin{bmatrix} \boldsymbol{V_1} \\ \boldsymbol{V_2} \\ \boldsymbol{V_3} \end{bmatrix} = \begin{bmatrix} \boldsymbol{P_1} & & \\ & \boldsymbol{P_2} & \\ & & \boldsymbol{P_3} \end{bmatrix} \bullet \begin{bmatrix} \boldsymbol{A_1} \\ \boldsymbol{A_2} \\ \boldsymbol{A_3} \end{bmatrix} \boldsymbol{K} \tag{5}$$

Where, $\boldsymbol{P_1}$ , $\boldsymbol{P_2}$ , $\boldsymbol{P_3}$ are the weight coefficient matrix of angle, side and gyrostatic orientation line.

From the above equations, this model avoids the precision inconsistencies of stepwise adjustments and the entire control network keeps maintain integrity. On the other hand, the selection of weight coefficient matrix plays a vital role to the results of adjustment, and the reasonable of weight determination can reduce the distortions caused by the improper selection of the weights. Therefore, how to determine the weight is the key of this model.

## 3 Weight determination model of gyrostatic lines

For the unequal model, such as corners network adjustment, the general idea is to set the angle as the unit weight, and the weights of the side length can be defined as follows:

$$P_{2_{i,i}} = P_{S_i} = \frac{m_\beta^2 \bar{S}}{m_s^2 S_i} \tag{6}$$

There are no deeply studies of the weight determination approaches and influences of gyrostatic lines to adjustment results. Some traditional approach can be directly adopted:

$$P_{3_{i,i}} = P_{\alpha_T} = \frac{m_\beta^2}{m_{\alpha_T}^2} \tag{7}$$

Where, $m_{\alpha_T}^2$ is the measurement variance of gyro.

The objective of additional gyrostatic lines is to obtain the reliable direction values. Generally speaking, the underground measurement variance is greater than the one of direction. The weights of gyrostatic lines acquired from Eq(7) is obvious less than 1. It significantly decreases the influence of gyrostatic lines to direction corrections and unreasonable without rational optimization of observations values of different types.

Variance component estimation method can reduce the impact of given unreasonable initial weights to a certain extent, but the shaped swing of control network is still existed when the weights are manifestly unreasonable.

According to the long-term observation of mines, the gyrostatic lines are treated as the observation values. We change the weights of gyrostatic lines in person and obtain the weakest point of network adjustment.

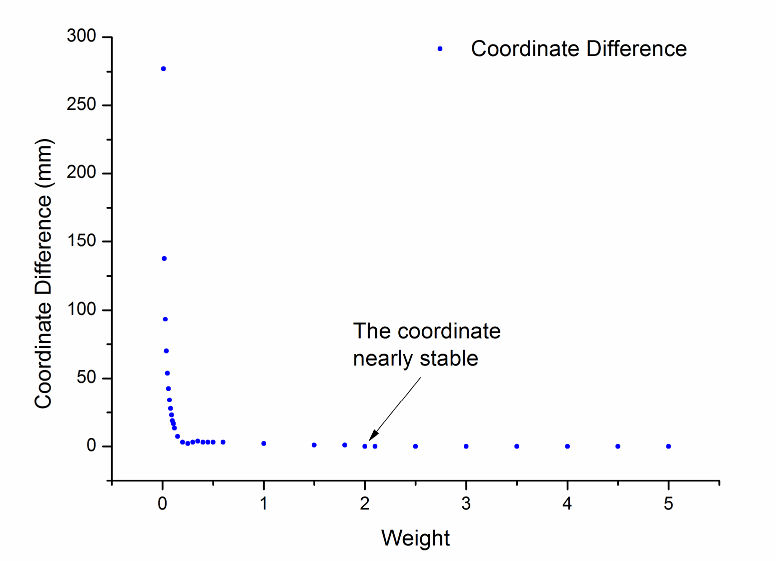


**Fig.1 The influence of the most weakness point coordinates by different weight**

From Fig.1, it can be seen that the weakest point generates a bit of decimeter influence when the weight is less than 0.3, and the entire control network exist the obvious shaped swing.

With the increase of the weights, the coordinates of weakest point become large rapidly. And a significant fluctuation occurs in the weight of 0.3. When the weight is greater than 2, the position of weakest point tends to converge.

Therefore, it can be drawn that the approach for determining the weights of gyrostatic lines has significant impacts on the reliability and accuracy of the entire control network, and the introduction of variance component estimation can only reduce the impact of the initial weights. In order to obtain precise and reliable adjustment results and prevent the unreasonable impact on the entire net-haped caused by unreasonable weights, the appropriate approaches must be selected.

In this paper, we propose the overall adjustment scheme for weight determination of gyrostatic lines. The gyrostatic lines are adopted as the measurement value with high weight and involved the processing of adjustment calculation of the error distribution. We also introduce a parameter to Eq(7) and change the weights of gyrostatic lines:

$$P_{3_{i,i}} = a\frac{m_{\beta}^2}{m_{\alpha_T}^2} \tag{8}$$

Where, $a$ is the introduced parameter.

According to the conclusions of the weakest point's convergence, we analyze the relationship between the number of gyrostatic lines and the length of network, it is easy to find that the weights of gyrostatic lines is proportional to the length of the network and inversely proportional to the number of gyrostatic lines. It means that the longer length of network, the fewer number of gyrostatic lines, the obvious corrections of corresponding gyrostatic lines to the underground network, the greater corresponding weights in the data processing.

All kinds of observation weights must be within a certain range.The empirical model of $a$ which is summarized by Fig.1 and the forms of network in different mines, can be defined as follows:

$$P = a\frac{\sigma_T^2}{\sigma_\alpha^2}\ ,\quad a = \frac{S}{m}\ , \tag{12}$$

Where, S is the length of network, n is the number of gyrostatic lines.

Eq(7-8) are the model of weight determination of gyrostatic lines. It can be seen that parameter $a$ should be selected according to the specific condition of gyrostatic lines and estimated by the iterations of posterior variance until the value of posterior and anterior variance is less than a given value.

According to the proposed model, we can see that it only adjusts the matrix $\boldsymbol{A_3}$ and $\boldsymbol{P_3}$ with changing the number of gyrostatic lines in Eq (5), which avoid the problem that a new equation will be put in with an additional gyrostatic line or to calculate the coordinates of gyrostatic line again. Meanwhile, this model also considers the errors and characteristics of gyrostatic lines. This makes easy to apply to the theoretical and practical data processing.

4 Experimental results

In this part, we evaluate the feasibility of the proposed method using the long-term observation data of the mines from Shanxi China National Coal Pingshuo co.Ltd.

Take a well as an example (Fig.2), the entire and average length of network is 10km and 90m, respectively. The connection, ground/underground control surveys of the well are applied at first. Then we use the generated results to estimate the position of gyrostatic lines and to conduct the gyrostatic orientation survey. The measurement accuracies of gyrostatic lines are higher than 10″. Finally, according to the proposed model, we punch the holes in the weakest points and evaluate the consistency of the surface-underground coordinates.

4.1 Network adjustment with gyrostatic lines

From Fig.2, the well is an inclined shaft. There is a certain angle between each side of the underground network and the coordinate axes. According to the rules of mine survey and geometrical orientation results, six gyrostatic lines will be added and the position of these lines will equally distribute in the network.

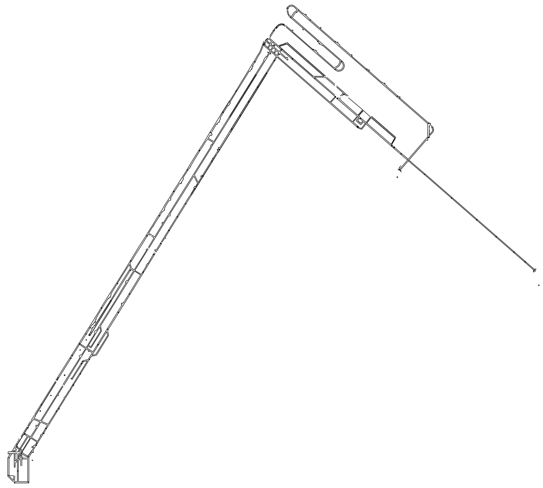

**Fig.2 Schematic Plot of Underground Traverse network**

In the data processing, we add the line corrections due to the advice of ref [7] firstly, then conduct the adjustment to the traverse network and treat the results derived from the gyrostatic lines as the most probable values. Finally, we also compare the position change between geometric orientation and additional gyrostatic lines.

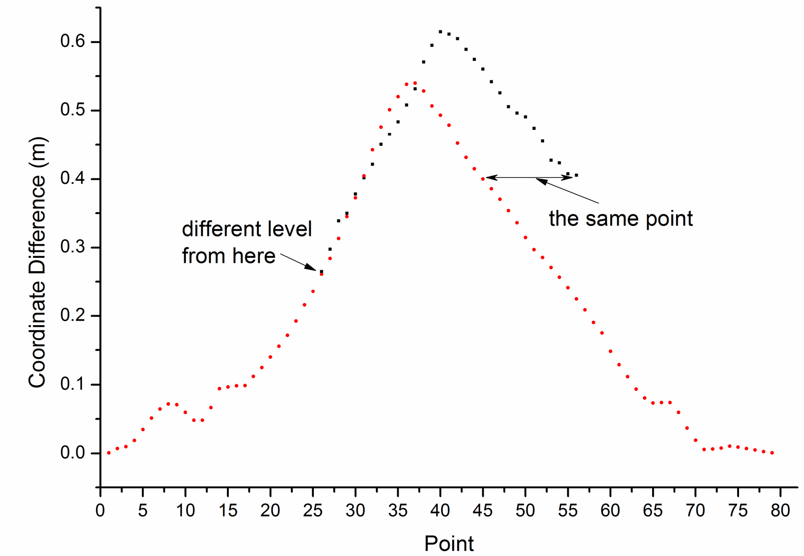


**Fig.3 Coordinate difference of two level**

The red points in Fig.3 represent the main points of the underground control points and the black ones means the points of another level in a separate zone.

From Fig.1, the errors become larger with the increasing number of gyrostatic lines and obtain the largest value at the weakest point. Then, the errors become smaller with the decreasing distance between the points and the mouth of well. It indicates that the entire control network exist the obvious shaped swing with the cumulative direction errors.

In order to evaluate the effectiveness of the proposed model, we have compared with the traditional distribution adjustment method by selecting the eight points in the neighbor of the weakest point. The results can be shown in Table. 1.

**Table 1 Comparison of different results**

| 点名 | New method compare with no gyro-side | | New method compare with traditional method | |
|---|---|---|---|---|
| | ΔX | ΔY | ΔX | ΔY |
| D1 | 0.341 | -0.368 | 0.024 | -0.016 |
| D2 | 0.351 | -0.385 | 0.024 | -0.018 |
| D3 | 0.352 | -0.407 | 0.024 | -0.020 |
| D4 | 0.344 | -0.416 | 0.023 | -0.020 |
| D5 | 0.327 | -0.415 | 0.022 | -0.020 |
| 23 | 0.328 | -0.388 | 0.023 | -0.021 |
| 24 | 0.319 | -0.377 | 0.023 | -0.022 |
| 25 | 0.311 | -0.364 | 0.022 | -0.023 |

From Fig.1, with the additional gyrostatic lines, the adjustment coordinates of the points in the neighbor of the weakest point is 0.514m, and the adjustment of x- and y-direction are 0.334m and 0.39m. The posteriori unit weight error reduces form 6.14 to 5.73. Gyrostatic lines have significantly positive effect on the improvement of the reliability and accuracy of the underground coordinates.

Comparison with the results achieve by treating gyrostatic lines as the strong sides, each side of the network involve in the calculation of error adjustment and the whole network maintains the integrity.

The adjustment of the points nearby the weakest points is 31mm, and the adjustment of x- and y-direction are 23mm and 20mm. The adjustment symbols of x- and y-direction are the same. This indicated that the proposed method can inhibit the distortion of underground control network generated by the measurement of gyrostatic lines.

4.2 Reliability analysis of surface-underground coordinates

According to the coordinate system after adjustment, we design to punch the holes in the neighbor of weakest point from surface to underground and evaluate the consistency of surface-underground coordinates. In order to ensure the location of ground point accurate, three control points nearby the opening of well are selected and participate in the unified adjustment with near-well point, and then the location of well center is determined by forward intersection.

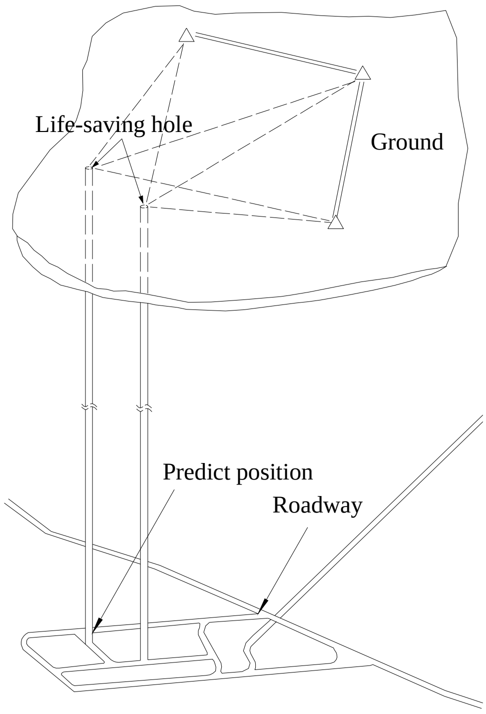


**Fig.4 Experiment of drill hole**

The effective drill of diameter is 311.15mm, the depth is 390m. The design and actual displacement is 2.35m and 2.11 m.  Ignoring the construction error of drilling, it can be seen that the proposed approach can maintain the consistency of the surface and underground coordinates.

Experimental results show that the proposed model improve the consistency and reliability of surface and underground coordinates. This model can provide the theoretical basis and data support of safety production and mine rescue. And it has significant effect in practical applications.

5 Conclusions

Through the above analysis, some findings can be concluded as follows:

For underground horizontal control measurements, we propose an adjustment model to use the gyrostatic lines as the direction observed values. The gyrostatic lines of this model involved in the error distribution. This precise theorization model can maintain the integrity of the entire control network and avoid inconsistencies in the distribution of adjustment accuracy.

The adjustment model which views gyrostatic lines as the observed direction values, has given the empirical model of weight determination, which takes into account the relationship of the network and the number of gyrostatic lines. Experimental results show that this model can avoid the shape distortions caused by direction errors to a great extent.

Through the experiments for punching the holes nearby the weakest point, the proposed method has significantly improved the reliability and consistence of the surface and underground coordinates. It can provide the theoretical basis and data support of safety production and mine rescue.

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