Adjusting wheel alignment on machinery equipment

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The majority of geodetic works in industry have the nature of specialist works. The difference between measuring in the nature and in industrial objects is the environment in which the measurement takes place, safety at work which must be given attention by the measuring group, the dimensions of the object which is much smaller than objects in the free terrain and the required accuracy which is approximately one decimal point greater than when measuring in the construction industry.

Key words: *engineering geodesy, geodesy in industry, casting machine, continuous casting of copper*

Introduction

Engineering geodesy is applied in various specialisations of human activities. Adaptation to the more and more demanding requirements in technical practice has led to specialisation of methods, equipment and the theoretical and methodological nature of engineering geodesy.

In geodetic works in industrial operations, the dimensions of the measured and staking objects are shortened compared to works in the field, but on the other hand, the requirements for accuracy of measured lengths, angles, heights, straightness, verticality and planarity are exceptionally higher. The high requirements for accuracy of measured elements require not only development and perfection in measurement methods, but also theoretical solutions for measurement and evaluation works. [5] In industrial operations, it is also beneficial to use local geodetic networks which can be levelled with great accuracy [3, 8] and in these networks, there is very high level of discovering major errors [9] Laser terrestrial systems have recently been used for 3D visualisation of industrial halls or complexes in order improve the effectiveness or modernisation of its operation [7].

Method of measuring alignment of casting machine wheels

When taking measurements in production halls, a frequent task is the adjustment of the technical parameters of various parts during their production in compliance with project documentation, inspecting the dimensions of produced parts and constructions, or adjustment of the relative positions of various parts of machinery equipment (i.e. rectification).

One such geodetic task implemented in the Kovohuty Krompachy production operation was adjusting the of alignment wheels on the casting machine for continuous casting of copper. The subject of measurement was adjusting machine equipment which consisted of an assembly of three wheels connected via a metal strip (Fig. 1, Fig. 2). The machine driving wheel was not placed vertically but with a certain, not closely determined deviation (δ) from the vertical plane which, in accordance with drawing documentation, could alternate from 0º to 5º and was fixed. The condition for adjustment and ensuring the correct running of this equipment was that all three rotation axes of wheels (drive, driven and clamping) were placed at parallel as well as all wheel centres, so-called longitudinal wheel axes (perpendicular to the rotation axes) placed in one plane. Based on these conditions, it was necessary to place the driven and clamping wheel in to the plane (μ) crossing the driving wheel.

Before taking the measurement, it was necessary to distribute surveying points on places characterising the position of individual wheels in the space. Driving and driven wheels had a diameter of approximately 2 m and the clamping wheel was 0,4 m. Surveyed points were situated at the edges of individual wheels and labelled with numbers 1 to 12. The location of points and the overall situation is shown on Fig. 1.

The machine station was selected as close as possible to the vertical plane μ crossing the system of wheels, so all surveyed points would be visible from the station. Points represented 1 x 1 reflective labels affixed on magnets (detail Fig. 1). Measurement was carried out using a Nikon DTM-332 universal measuring station (UMS) and coordinates of the surveyed points were determined in the local coordinate

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system using a polar alignment method. Since measurement was carried out in an operational hall, it was necessary to ensure illumination of these points in order to achieve the highest possible aiming accuracy.

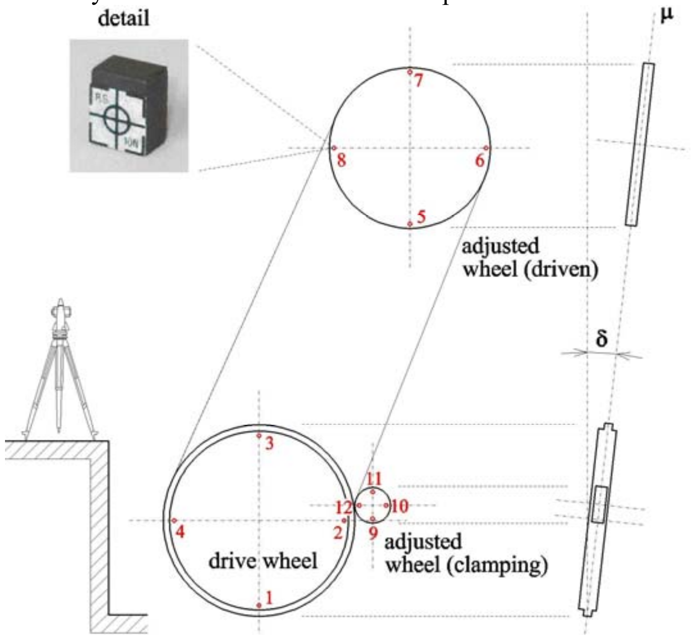

Fig. 1. Diagram of placement of the universal measurement station, wheel assembly and surveyed points in the space.

Fig. 2. Adjusted machinery equipment (part of the casting machine for continuous casting of copper)

Adjustment method

Reference plane μ was crossed by points N^{o}.1 (x_1, y_1, z_1) to N^{o}.4 (x_4, y_4, z_4), which were placed on the driving wheel and were considered as referential. The mathematic of the plane in a three dimensional space can be expressed as follows [4]:

$$ax + by + cz + d = 0\,, \tag{1}$$

where unknown coefficients *a*, *b*, *c* and *d* are calculated by the solution of 4 equations with 4 unknowns.

Subsequently, perpendicular distances d_i of points N^{o}.5 (x_5, y_5, z_5) to N^{o}.12 (x_{12}, y_{12}, z_{12}) (Fig. 3), from the plane μ were calculated using equation [4]:

$$d_i(i, \mu) = \frac{|ax_i + by_i + cz_i + d|}{\sqrt{a^2 + b^2 + c^2}} \tag{2}$$

for i = 5, 6, 7, ... , 12.

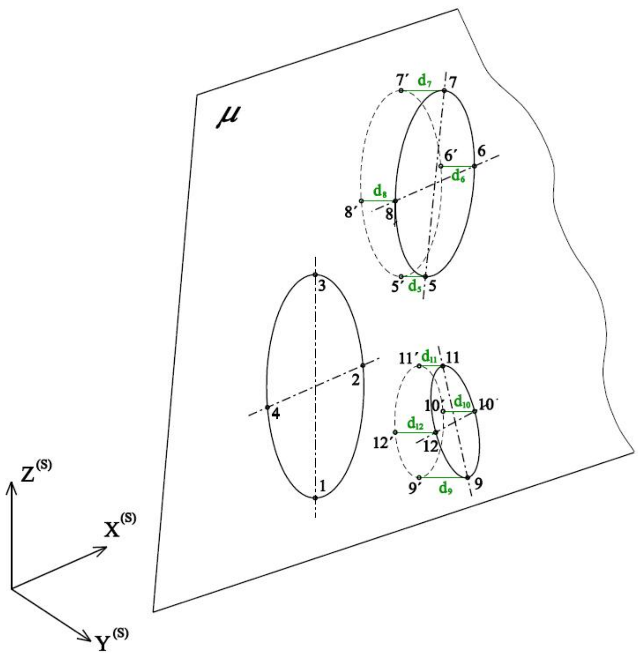

Fig. 3. Graphic diagram of perpendicular distances of points N^{o}.5 to N^{o}.12 from the reference plane μ.

Based on these distances (d_i), the deviation of the wheels from the plane μ crossing the driving (reference) wheel in locations of surveyed points was then determined and, in accordance with which, adjustment was made. The wheels were already adjusted approximately and therefore these deviations alternated in values up to 20mm from the required wheel positions. Since adjustment of the wheel positions (moving points characterising wheel positions by appropriate deviations d_i from the plane μ) was not successful the first time, measurement, calculation of the deviation and moving the wheels was repeated several times until final adjustment took place.

Analysis of accuracy

Determining the position of a point using a universal measuring station (UMS) is based on the principle of measuring polar coordinates (horizontal angle ω, vertical angle β and slope distance D). Based on the accuracy of measurement of these values, depending upon the type of equipment used, and accuracy when determining the point position in the space can be expressed by the error ellipsoid [1] (Fig. 4).

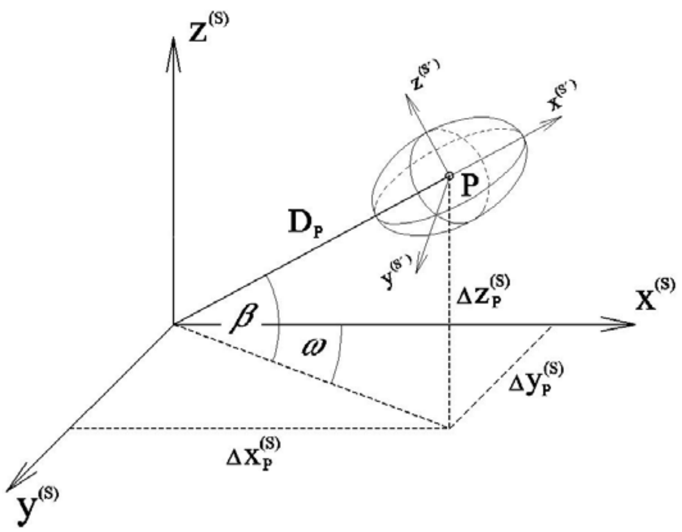

Fig. 4. Determination of point P position in the space.

The position of the error ellipsoid of point P in the space depends upon the size of the measured angles (ω, β) and slope distance D_P. If we survey the group of points, particularly their perpendicular distances d_i from a certain reference plane (in this case, plane μ), the range of rotation of individual ellipsoids of the surveyed points in relation to this plane has a decisive influence upon calculation of standard deviations of the determined distances.

Calculation of the standard deviation σ_d of the perpendicular distance of point P from reference plane μ was carried out using the following method:

1. Transformation of the coordinates of points crossed by reference plane μ into the coordinate system of error ellipsoid of point P
2. Calculation of the equation for the line perpendicular to the reference plane and crossing point P
3. Calculation of the intersection of the perpendicular line with the plane of error ellipsoid of point P
4. Calculation of the standard deviation of the perpendicular distance d of surveyed point P from the reference plane

add. 1.) Transformation of the coordinates of points crossed by reference plane μ into the coordinate system of error ellipsoid of point P

Transformation of coordinates of points of coordinate system S into coordinate system S' depends upon the size of the measured horizontal angle ω and vertical angle β (Fig. 4) which determine mutual rotation of these coordinate systems. Rotation is carried out using the equation:

$$S' = R.\ S\,, \tag{3}$$

which can be expressed in the form:

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = R(\omega).\ R(\beta).\begin{pmatrix} x \\ y \\ z \end{pmatrix}, \tag{4}$$

where:

$$R(\omega) = \begin{pmatrix} \cos(\omega) & \sin(\omega) & 0 \\ -\sin(\omega) & \cos(\omega) & 0 \\ 0 & 0 & 1 \end{pmatrix} \ and\ R(\beta) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\beta) & \sin(\beta) \\ 0 & -\sin(\beta) & \cos(\beta) \end{pmatrix} \text{ [2]}. \tag{5}$$

S' represents the ellipsoid coordinate system, S represents the coordinate system of points crossed by the reference plane and R represents rotation between these two systems (Fig. 5, Fig. 6).

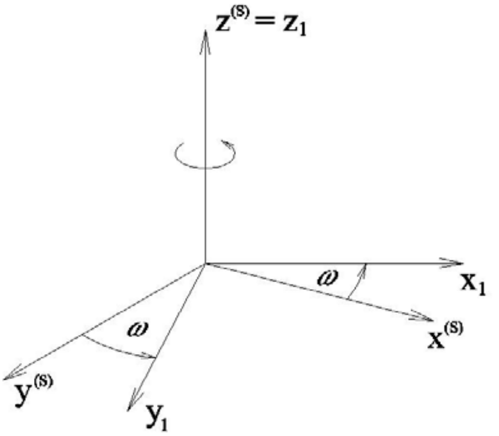

Fig. 5. Partial rotation of the coordinate axes x and y by horizontal angle ω.

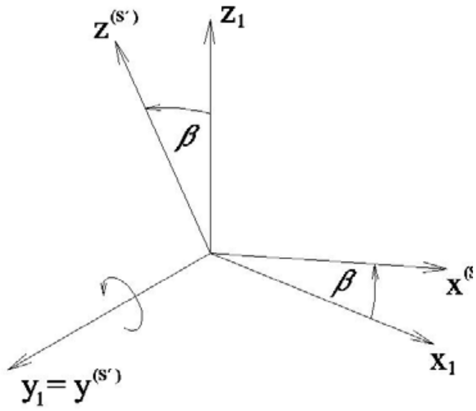

Fig. 6. Partial rotation of coordinate axis z by the vertical angle β.

add. 2.) Calculation of the equation for the line perpendicular to the reference plane and crossing surveyed point P

Each plane in the space can be described by equation (1). From numbers a, b and c, we require that at least one is non-zero. The trio (*a, b, c*) determines the vector which is perpendicular to the plane given by equation (1). Let $a = u$, $b = v$, and $c = w$. If line p is determined by point P (x_P, y_P, z_P) and vector $\overline{u} = (u, v, w)$, which is parallel to it, then the system of parametric equations of this line has the form [4]:

$$\begin{aligned} x &= x_P + u \cdot t, \\ y &= y_P + v \cdot t, \\ z &= z_P + w \cdot t. \end{aligned} \tag{6}$$

add. 3.) Calculation of the intersection of the perpendicular line with the plane of error ellipsoid

Accuracy of the point position in the space can be expressed using the equation of median error ellipsoid as follows [1]:

$$\frac{x^2}{\sigma_{xP}^2} + \frac{y^2}{\sigma_{yP}^2} + \frac{z^2}{\sigma_{zP}^2} = 1. \tag{7}$$

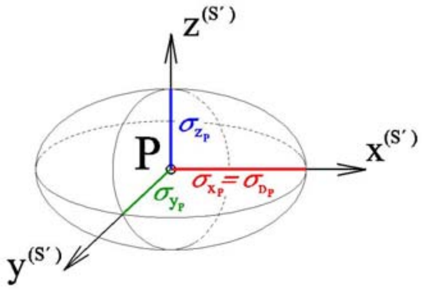

Fig. 7. Error ellipsoid of point P.

Sizes of the ellipsoid semi-axis σ_{x_P}, σ_{y_P} and σ_{z_P} (Fig. 7) are calculated using formulas (8), (9) and (10):

$$\sigma_{xP} = \sigma_{DP}$$

$$\sigma_{DP} = \pm\ 3 + 3.D_P.10^{-6}\ [mm] \qquad (8)$$

where σ_{D_P} states the accuracy of measurement of the slope distance D_P, which is input into the equation (8) in kilometres [6].

$$\sigma_{yP} = D_P.\ tg(\sigma_\omega), \qquad (9)$$

$$\sigma_{zP} = D_P.\ tg(\sigma_\beta) \qquad (10)$$

where σ_ω and σ_β determine the accuracy of measurement of horizontal and vertical angles ($\sigma_\omega = \sigma_\beta = 15^{cc}$).

Inputting parameter equations of a line (6) into the equation of the median error ellipsoid (7) and after modification, we achieve the parameter value

$$t^2 = \frac{\sigma_x^2.\ \sigma_y^2.\ \sigma_z^2}{\sigma_y^2.\ \sigma_z^2.\ u^2 + \sigma_x^2.\ \sigma_z^2.\ v^2 + \sigma_x^2.\ \sigma_y^2.\ w^2}, \qquad (11)$$

from which, after extraction and re-inputting in the equations (6), we will obtain coordinates of intersections P_1 (x_1, y_1, z_1) a P_2 (x_2, y_2, z_2) of the line p with the ellipsoid plane (Fig. 8).

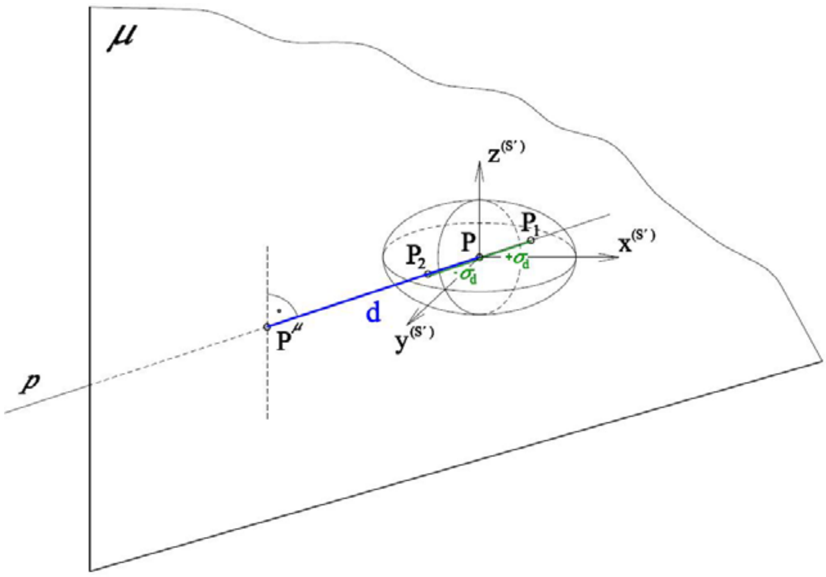

Fig. 8. Graphic display of the intersection of the line (p) with the plane of error ellipsoid of point P.

add. 4.) Calculation of the standard deviation of the perpendicular distance d of surveyed point from the reference plane

The size of the standard deviation σ_d of the distance d of point P from the reference plane μ is calculated as follows:

$$\sigma_d = \sqrt{\Delta x^2_{P,P_1} + \Delta y^2_{P,P_1} + \Delta z^2_{P,P_1}}, \qquad (12)$$

or

$$\sigma_d = \sqrt{\Delta x^2_{P,P_2} + \Delta y^2_{P,P_2} + \Delta z^2_{P,P_2}}. \qquad (13)$$

The standard deviations for determining distances d_i of the post-implementation measurement of adjusted wheels are stated in tab. 1.

Tab. 1. Values of variables ω, β, D and σ_d.

N°.	**ω** [g]	**β** [g]	**D** [m]	**σ_d** [mm]
5	0,0000	28,1309	6,246	0,15
6	0,2717	32,1267	7,495	0,18
7	0,0112	42,4938	7,237	0,17
8	399,6249	40,7597	5,926	0,14
9	0,4199	5,3950	5,021	0,12
10	0,4566	2,9963	5,165	0,12
11	0,5354	4,5606	5,365	0,13
12	0,5021	7,1829	5,231	0,12

Conclusion

The deciding factor influencing the results of measurements in industrial operations is the selection of measurement gauges, methods and the methodology of measurement. When measuring in such an environment, the measurement process is influenced by many factors which can distort the measured values and therefore unfavourably influence the results of the entire works. Measurement often takes place in tightly enclosed areas, at heights, under insufficient lighting or with vibrations caused by the operation, making measurement more difficult. Therefore, selection of equipment and measurement method very often depend upon particular conditions and requirements

This article pinpoints the fact that not only the accuracy grade of used equipment but also the selection of a suitable method fundamentally influence the measurement results. If placement of the equipment station was chosen perpendicular to the plane of the adjusted wheels, the accuracy of measured parameters (perpendicular distances d_i) would mainly be influenced by the error in measuring lengths, which would require the use of equipment with very accurate distance meter. If the station is placed as close as possible to the plane of the adjusted wheels, measurement parameters would mainly be influenced by the error from measuring horizontal angles. From analysis of errors (Tab. 1), it is clear that even when using equipment of a lower grade (with a distance meter measuring in millimetres) using a suitable measurement method, it is possible to achieve accuracy in the determination of geometric parameters to one tenth of a millimetre.

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