Automatic Total Station Testing

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SUMMARY

The automatic total station Leica TCA 1101 offers the possibility to observe and monitoring of dynamic processes. Determination of position of the target moved on 2D trajectory. Data collected by DocWork software. Comparison between the measured and given trajectory. Determination accuracy by dynamic tests of automatic total station. Determination of actual errors statistics distribution.

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1. INTRODUCTION

Dynamic computation made during monitoring of constructions, which are exposing by dynamic effects isn't often enough and experimental measurements are needed. Essential component of measurements is approval of dynamic attributes of these objects before initiation of construction operation. Monitoring of dynamic weighted constructions is made in moments of construction deformation and it needs really big quantity of accurate measurements during short time.

Correct choice of equipment accessories, registration of measured data, mode and processing methods are elementary factors for monitoring of constructional buildings dynamics.

2. ESTIMATION OF MOVING OBJECT TRAJECTORY

Main experiment point was determination of trajectory of moving reflection prism by means of universal total station Leica TCA 1101, comparison with given (really) trajectory and accuracy examination of its specification.

Measurement system used for trajectory determination of moving object was used as follows:

- universal total station Leica TCA 1101,
- reflection prism Leica,
- portable computer with automatic registration software – DocWork,
- preparation with mechanical movement.

Leica TCA 1101 offers automated target search and continually tracing of moving target. Instrument is characterized by accuracy of observed direction of 0.5 mgon and accuracy of observed length is 1 + 2 ppm. We can define error of observed length value as 1 mm. High frequency (1.25 Hz - 1 note/0.8 second) of records during measurement doesn't make possible a classical registration on PCMCIA card. For this reason were measured data automatically redirected and registered by DocWork program into on-line connected portable computer.

Trajectory of moving reflecting prism was simulated by appliance with mechanical movement. Appliance consists of two parts – upper movable and lower immovable part (Figure 1). Upper part enables movement of stabile reflecting prism in horizontal plain in two perpendicular directions. Movement is made manually with rotation screws. Lower part ensures a stabile fixation of appliance on tripod or pillar. Two pairs of mechanical shifting screws (scale of 25 mm) are components of lower part and enable moving of upper part. Accuracy of movement is 0.05 mm. UTS and appliance with reflection prism were stabilized in laboratory on pillars (Figure 1). Distance between total station and prism was 15.6 m.

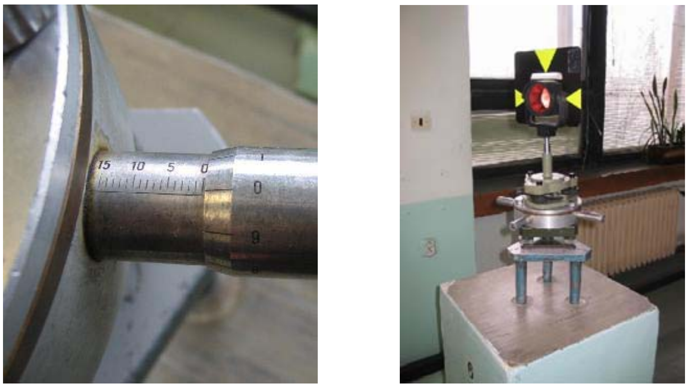

Figure 1: Detail of scale shifting screw (left) and reflection prism stabilized on appliance with horizontal movement (right)

There was made a manual pointing on prism before measuring. Total station watched target automatically in according to DocWork programme after starting of measurement and defined its position. Placed on appliance reflection prism was manually moved on known trajectory by a shifting screw (figure 2).

Reflection prism was stopped after trajectory overcame length of 5 mm for time equals to 8 measurements. Places of stoppage are marked on figure 3 with cross. Overall number of measurements, which characterized trajectory with length of 95 mm, is 720. Velocity of prism moving on trajectory parts is mentioned in table 1.

Table 1

Part of trajectory	Length of trajectory [mm]	Number of trajectory points	Average velocity **v** [$mm.s^{-1}$]	Relative average velocity **- v /v$_A$** [$mm.s^{-1}$]
A	20	126	0.019	1
C	20	121	0.020	1,04
E	20	192	0.013	0.65
G	20	160	0.015	0.79
A+C+E+G	**80**	**599**	**0.016**	**0.84**
B	5	34	0.018	0.92
D	5	56	0.011	0.56
F	5	31	0.019	1,01
B+D+F	**15**	**121**	**0.015**	**0.78**

Trajectory accuracy defined by appliance is upper order then accuracy of measured trajectory. For this reason will be this trajectory taken as given (actual) trajectory.

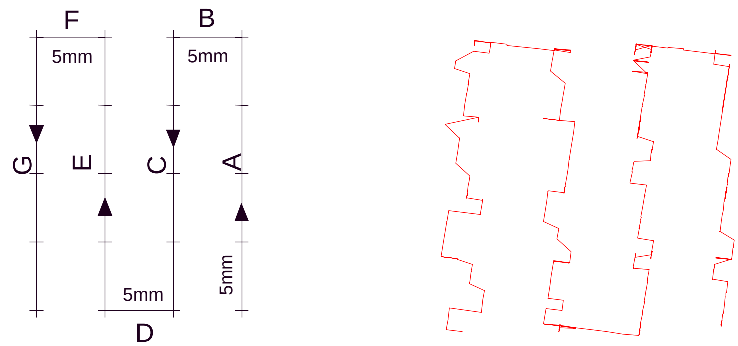

Figure 2: Trajectory of prism - moving direction and designation of parts (left) and measured trajectory of prism (right)

3. PROCESSING OF MEASURED DATA

Processing of measured data consists of measured trajectory coordinates computation, transformation of measured and given trajectory into one system of coordinates and comparison of measured and given trajectory. Shifting appliance is impossible to rotate in a position where axis of shifting screws will be parallel with system of coordinate measured trajectory. Condition – to put both systems of coordinate parallel – will be not fulfilled. For next calculation and processing will be defined two rectangular coordinate systems with the same orientation of coordinate axis (Figure 3).

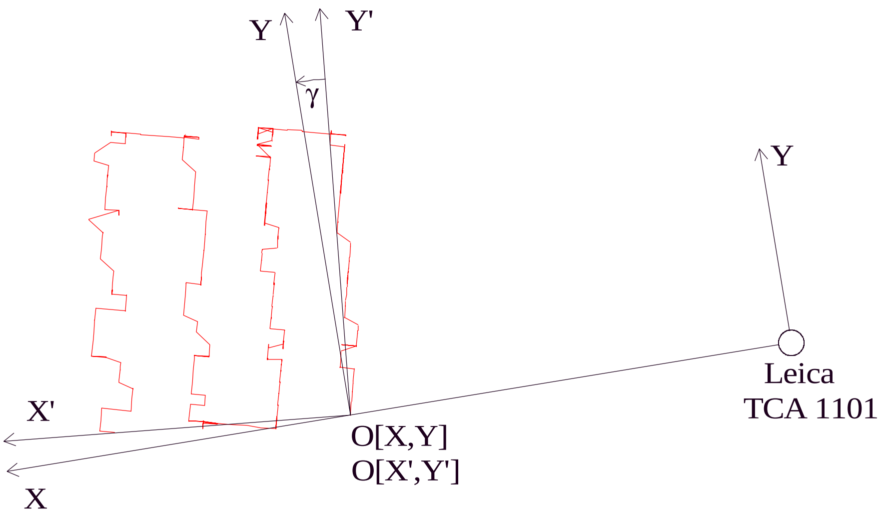

Figure 3: Turning of measured trajectory according to coordinate system O[X,Y]

Coordinate system of measured trajectory O[X,Y]:

- axis X is identical with flow line equipment and first point on trajectory (in direction of measured length),
- axis Y is vertical to it,

Coordinate system of given trajectory O[X´,Y´]:

- axis X´ is identical with axis of shifting screws preparation in longitudinal direction (quasi in direction of measured length),
- axis Y´ in transverse direction.

Origin of both coordinates systems is inserted into point, which is identical with first point of measured trajectory.

3.1 Calculation of Measured Trajectory Coordinates Points

Every point position of measured trajectory is possible to figure with rectangular coordinates X and Y in coordinate system of measured trajectory O[X,Y]. Coordinates are calculated with polar method according to relation:

$$X = s.\sin(z).\cos(\alpha)\,, \tag{1}$$

$$Y = s.\sin(z).\sin(\alpha)\,, \tag{2}$$

where *s* is measured straight slope distance,
z is zenit angle,
α is measured horizontal direction.

Reflecting prism is moving in axis X´ direction or Y´. Measured trajectory is not parallel with coordinate system O[X,Y]. Value of trajectory swinging out according to axis X or Y is expressed in angle γ (Figure 3).

3.2 Comparison of Measured and Given Trajectory

The accuracy of determination of moving target trajectory is made by comparison of measured and given trajectory in universal total station Leica. It's predicted that both trajectories lie down in plains, which are horizontal parallel to each other. Because reflection prism was moved in direction of given trajectory, for judgment of relative point position accuracy will be enough to compare coordinate differences between measured and given trajectory.

For expression of determination points position trajectory accuracy (in direction of measured length and in transverse direction on measured length) will be transformed coordinates of measured and given points into coordinate system O[X,Y]. In case of measured trajectory is going about transformation inside of own coordinate system. Whole trajectory will be slew on angle γ.

Transformations are made on ground of three main transformations elements – one rotation (angle distortion γ) and two translations (movement Δx and Δy) in five steps:

- calculation of distortion angle γ of measured trajectory according to coordinate system O[X,Y],
- transformation of measured trajectory (measured trajectory slew about angle γ),
- given trajectory transformation from coordinate system O[X´,Y´] into coordinate system O[X,Y],
- coordinate centers calculation of measured and given trajectory,
- center identifications of both trajectories (given trajectory movement about value Δx and Δy).

3.2.1 Angle Distortion Calculation of Measured Trajectory

Measured trajectory could be graphically resolve on longitudinal part (in direction of measured length) and transverse part (in transverse direction on measured length). Transverse part could be divided then to four parts. Four independent regression straight lines *a*, *c*, *e* and *g* are moved by using regression analysis method through individual transverse trajectory parts and their slopes A_a, A_c, A_e a A_g are calculated (Figure 4). Slope of regression straight line A_r is calculated with weighted arithmetic mean from straight line slopes A_a, A_c, A_e a A_g according to relation (3), which defines distortion angle whole trajectory transverse part.

$$A_r = \frac{A_a.n_a + A_c.n_c + A_e.n_e + A_g.n_g}{n_a + n_c + n_e + n_g}, \qquad (3)$$

where A_a, A_c, A_e, A_g are slopes of straight lines a, c, e, g,
n_a, n_c, n_e, n_g are amounts of points, which were used for regression straight line calculation.

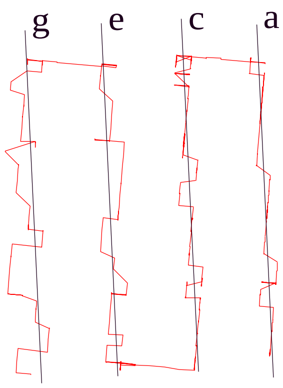

Figure 4: Measured trajectory slopes

Regression straight line consequential distortion angle A_r could be expressed from relation

$$\gamma = \operatorname{atan}|A_r| \qquad (4)$$

and its value is 2.5151 gon.

If there is prediction that parallel and transverse trajectory part are perpendicular to each other, angle γ conveys whole measured trajectory swing according to measured trajectory coordinate system O[X,Y]. Measured trajectory coordinate points, which regress straight line A_r, will be parallel with axis Y from coordinate system O[X,Y], and could be calculated from relations

$$X^M = s.\sin(z).\cos(\alpha - \gamma), \qquad (5)$$

$$Y^M = s.\sin(z).\sin(\alpha - \gamma). \qquad (6)$$

Following angle γ will be transformed (slewed) by given trajectory from coordinate system O[X´,Y´] into coordinate system O[X,Y].

3.2.2 Movement trajectory calculation

Given trajectory have to be moved on value movement Δx and Δy, which are defined by coordinate system O[X,Y], after given trajectory is swung. Movement Δx and Δy is calculated from relations

$$\Delta x = X_S^M - X_S^D , \tag{7}$$

or

$$\Delta y = Y_S^M - Y_S^D , \tag{8}$$

where X_S^M a Y_S^M are center coordinates of measured slew trajectory,
X_S^D a Y_S^D are center coordinates of given slew trajectory.

From parts A, C, E and G measured slew trajectory are calculated average coordinates $\overline{X}_A$, $\overline{X}_C, \overline{X}_E$ a $\overline{X}_G$. Distance in axis X direction between parts A and G will be convey as coordinates difference

$$\Delta x_{A,G} = \overline{X}_A - \overline{X}_G . \tag{9}$$

Calculated distance in part A and G is 16,0 mm and actual distance of given trajectory is 15,0 mm. Error in axis X direction is calculated from relation

$$\varepsilon_{\Delta xAG} = 15{,}0 - \Delta x_{A,G} \,[\mathrm{mm}]. \tag{10}$$

Distance of given trajectory between parts C and E is 5,0 mm. Coordinate difference between parts C and E is $\Delta x_{C,E}$ = 6,2 mm and error $\varepsilon_{\Delta xCE}$ = 1,2 mm.

Errors $\varepsilon_{\Delta xAG}$ and $\varepsilon_{\Delta xCE}$ are isolated pro rate according to points amount of individual parts between coordinates $\overline{X}_A$ a $\overline{X}_G$ and coordinates $\overline{X}_C$ a $\overline{X}_E$. Error appertaining coordinates $\overline{X}_A$ and $\overline{X}_G$, or $\overline{X}_C$ a $\overline{X}_E$ is calculated from relation

$$\varepsilon_{XA} = \frac{\varepsilon_{\Delta xAG} . n_A^{-1}}{n_A^{-1} + n_G^{-1}}, \qquad \varepsilon_{XG} = \frac{\varepsilon_{\Delta xAG} . n_G^{-1}}{n_A^{-1} + n_G^{-1}}, \tag{11}$$

or

$$\varepsilon_{XC} = \frac{\varepsilon_{\Delta xCE} . n_C^{-1}}{n_C^{-1} + n_E^{-1}}, \qquad \varepsilon_{XE} = \frac{\varepsilon_{\Delta xCE} . n_E^{-1}}{n_C^{-1} + n_E^{-1}}. \tag{12}$$

where n_A, n_C , n_E and n_G are point amounts of measured trajectory parts A, C, E and G.

Centre coordinate measured trajectory X_S^M is got from formula

$$X_S^M = \frac{(\overline{X}_A + \varepsilon_{XA}) \cdot n_A + (\overline{X}_C + \varepsilon_{XC}) \cdot n_C + (\overline{X}_E + \varepsilon_{XE}) \cdot n_E + (\overline{X}_G + \varepsilon_{XG}) \cdot n_G}{4 \cdot (n_A + n_C + n_E + n_G)} . \tag{13}$$

Centre coordinate of measured trajectory Y_S^M is calculated from parts B, D and F of measured trajectory. Calculation could be started from coordinate differences $\Delta y_{B,D}$ a $\Delta y_{D,F}$ and directions of given parts trajectory B-D a D-F, which value is 20 mm. For coordinate Y_S^M is

$$Y_S^M = \frac{(\overline{Y}_B + \varepsilon_{YB}) \cdot n_B + (\overline{Y}_D + \varepsilon_{YD}) \cdot n_D + (\overline{Y}_F + \varepsilon_{YF}) \cdot n_F}{3 \cdot (n_B + n_D + n_F)} . \tag{14}$$

Center coordinates of given trajectory X_S^D a Y_S^D, in coordinate system O[X,Y], are calculated according to relation

$$X_S^D = X_1^D + 7{,}5\text{mm} , \tag{15}$$

$$Y_S^D = Y_1^D + 10{,}0\text{mm} , \tag{16}$$

where X_1^D and Y_1^D are rectangular coordinates of given trajectory first point.

4. ACCURACY ANALYSIS

Specification of point position mean error in axis X direction (dominant direction in measured length) and in axis Y direction (dominant direction in measured angle) is calculated according to relation

$$\sigma_X = \sqrt{\frac{\sum_{i=1}^{n} \varepsilon_{X_i}{}^2}{n}} \quad \text{and} \quad \sigma_Y = \sqrt{\frac{\sum_{i=1}^{n} \varepsilon_{Y_i}{}^2}{n}} , \tag{17}$$

where ε_{Xi} and $\varepsilon_{Y'i}$ are really error – point deviation (distance) of measured trajectory from given trajectory in axis *X'* or *Y'* direction.

Mean errors σ_X for parts A, C, E and G and mean errors σ_Y for parts B, D and F are presented in Table 2.

Table 2

Part of trajectory	Length trajectory [mm]	Amount of trajectory points	Mean error m_X [mm]	m_Y [mm]
A	20	126	1,06	-
C	20	121	0.45	-
E	20	192	0.45	-
G	20	160	0.41	-
A+C+E+G	**80**	**599**	**0.62**	**-**
B	5	34	-	0.23
D	5	56	-	0.31
F	5	31	-	0.36
B+D+F	**15**	**121**	**-**	**0.31**

In parts A, C, E and G of trajectory (dominant direction in measured length) is the biggest mean error in point position specification in axis X direction 1,06 mm in part A. In the other parts is value of mean error 0.41, resp. 0.45 mm. In trajectory parts B, D and F (dominant direction in measured angle) is the smallest mean error in point position specification in axis Y 0.23 mm (part B).

5. CONCLUSION

Aim of experiment was determination of trajectory moving reflection prism in horizontal direction by universal total station Leica TCA 1101, comparison of measured trajectory and given trajectory and characterization accuracy trajectory determination. Reflection prism was moving by means of appliance, which defined given trajectory with accuracy of 0.05 mm.

Measured trajectory was divided into seven sectors (from A to G), which enable figure out of actual errors in dominant direction of angle measurements (sectors B, D and F) and in dominant direction of length measurements (sectors A, C, E and G). Realized experiment make possible calculation of accuracy characteristics σ_X and σ_Y of particular trajectory sectors.

Mean error of coordinate σ_X of measured points in sectors A, C, E and G is 0.62 mm. Mean error of coordinate σ_X in sectors B, D and F is 0.31 mm. Mean error of coordinate σ_Y responds an angle value 1,3 mgon (when distance between UMS and reflection prism 15,63 m). Accuracy of coordinate points determination of trajectory is twice advanced in axis Y direction (dominant direction of angle measurements) than in axis X direction (dominant direction of lengths measurements).

Reflection prism shifting was ensured by mechanical rotation shifting screw of appliance. Speed of reflection prism (0.01 až 0.02 mm/s) could be consider as constant within all trajectory in as much as way of movement and accuracy of shifting determination 0.05 mm.

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