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Measurement of Flatness of a Portal Crane Collar

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Abstract. *The paper presents the application of the geodetic metrology methods to measurement of flatness of front surface of the portal crane collar. The collar has a diameter of 4.550 m and is welded to the front surface of a 8.985 m high column. A raised accuracy trigonometric method was applied to measure the flatness. The vertical and horizontal directions as well as the distance values for points located on the collar front surface were measured from one measuring position. Total Station TC 2002 (Leica Company) and especially designed sight shield (notification to the Polish Patent Office) were used in the tests. The obtained measurement accuracy (0.07 mm) allowed to evaluate the accuracy of tested collar workmanship, which should be contained within the interval of tolerance of 0.2 mm. Almost all of the points were contained within. The applied measurement method with the aiding equipment is fully applicable in this type of measurements characterized by very high accuracy.*

Key words: *geodetic metrology*, *portal crane collar, high accuracy*

1 Introduction

Large structures and mechanical devices consist of many elements (see for example the portal crane presented in Figure 1). The accuracy of making component elements this crane is determined by correct working of the whole device (Gocał 1993). The steel portal crane collar is presented in Figures 2 and 3. The tested column can be compared to an inside-empty cylinder with the following geometrical parameters: 8.985 m of height and the outside diameter equalling 4.550 m (Figure 4). From one side the column ends with the collar, the surface of which should be flat with tolerance of 0.2 mm. During tests, the crane column was situated horizontally. Relatively large geometrical parameters and high requirements for accuracy made the authors use geodetic metrology methods for the measurements (Anigacz 1998; 1999; 2001; Anigacz and Cmielewski 2001; 2004).

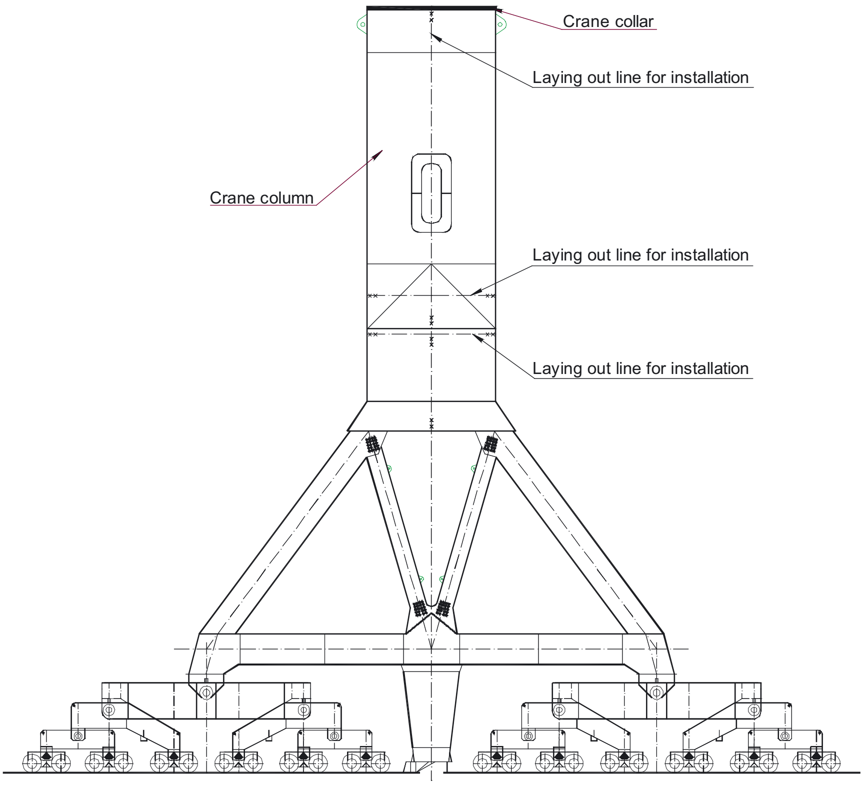

Figure 1. *Side view on the crane column on a carriageable set.*

The factors which influence the measurement accuracy are only the magnifying telescope and distance. The main aim of our paper was not to measure the shape of circular element, but only its flatness.

The difficulty in keeping these conditions results from large sizes and weight of a portal crane column amounting to 40 tones (Anigacz 1998). An additional factor, which hinders keeping the set accuracy parameters is installation technology of the crane (KE Kranbau-Eberswalde AG 2005).

The column consists of five rings that are assembled separately and then connected with each other by welding. During welding one can take into account minor assembly deviations of individual rings, however, in most cases some difficulties to predict welding stresses cause the deformations to the column jacket. The tested collar is made (turned and milled) separately and then

connected with the column by welding. Moreover the column is moved and turned. During installation the column was located horizontally and it was supported by four rolls (Anigacz 1998). Deviations resulting from production, assembly and transport within the factory may cause permissible values to be exceeded. Therefore control measurements should be undertaken and confirmed with a suitable certificate during the whole manufacturing and assembling process, and also during normal service.

Figure 2a. *A front view of the crane column in the assembly hall.*

Figure 2b. *A side view of the crane column in the assembly hall.*

From geometric point of view the column should fulfil the following conditions (Figure 5):

- the bases of the cylinder should be parallel to each other,
- the cross sections of the cylinder should be circular,
- the cylinder axis should go through the bases centre and should be perpendicular to them.

All measurements with optical instruments are subject to pointing error due to such factors as: target design, prevailing atmospheric conditions, operator bias, and focusing. The approximate magnitude of a single-direction pointing error (i.e. standard deviation) is directly related to the magnification of the instrument telescope (US corps 2002) (1):

$$\sigma_p = 45''/M, \tag{1}$$

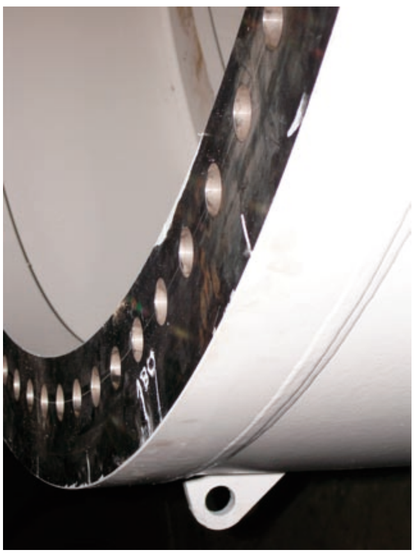

Figure 3. *A fragment of the front surface collar.*

where:

σ_p – instrument pointing error (arcseconds),

M – objective lens magnifications.

For our case (M = 10 m), the approximate magnitude of a single-direction pointing error amounted to 0.00007 m, so it is not much.

2 Measurements methodology

High requirements for measurements accuracy resulted in execution in real conditions of an acceptance test measurement, which was aimed to define the accuracy of equipment and of the applied measurement technology. Taking above mentioned into consideration, the trigonometric method with raised (the highest) accuracy was applied with use of the Total Station TC 2002 instrument (the Leica company) with measurement accuracy of direction 0.6”. The specially constructed target was also used during measurements (being in the process of submission to the Polish Patent Office) – Figure 4. Correctness of the target realization (working) was proved through test measurement after turn of target about 180º. The site of instrument was located within the distance of about 10 m from the reservoir axis so that the sight line axis was approximately parallel to the frontal area of the collar (Figure 5). The measurement was executed from two locations of the telescope for 30 evenly located points (every 12 degrees) and additionally for points on the axes of 90 and 270 degrees (which as a result gave the total of 32 measurement points). It allowed elimination of possible errors of collimation and inclination.

Figure 4. *The specially constructed target which was used during measurements.*

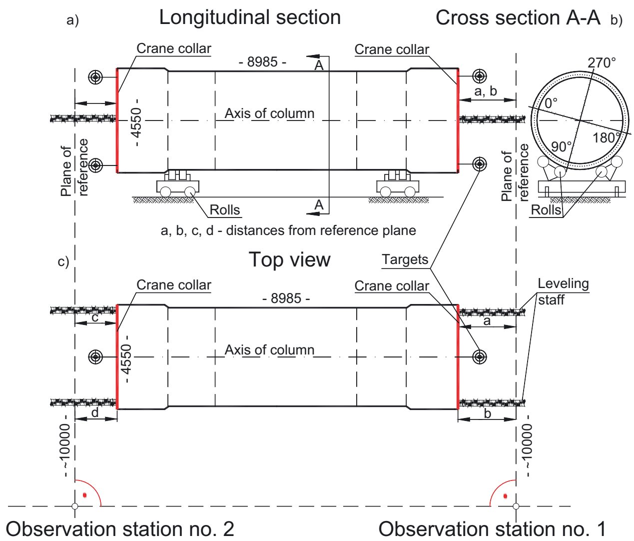

Figure 5. *Scheme of measurement control: a) longitudinal section, b) cross section A-A, and c) top view. Dimensions are given in [mm].*

On the basis of such double measurement, accuracy of 0.07 mm was determined. Such a high accuracy allowed to estimate correctness of execution of the tested collar (Anigacz and Beben 2007).

The measurements were conducted in the following conditions:

- good lighting (artificial),
- constant temperature (10°C),
- constant humidity and atmospheric pressure,
- lack of vibrations (no production in the factory at the time of the measurements).

3 Calculations and analysis

The spatial coordinates (X, Y, Z) of 32 measured points evenly placed on the frontal area of collar were obtained with use of trigonometric method of raised accuracy. The plane, which was accepted as a reference plane to determine the deviations from flatness, was introduced to a set of points with application of the least squares method. Then using a special calculation program developed by one of authors (Anigacz W.), the distance of all points from the computed plane was determined. The real range of frontal area deviations of tested collar of analysed portal crane from flatness was also obtained.

Generally, the equation of plane introduces in form (2):

$$Ax + By + Cz + D = 0 \tag{2}$$

where: A, B and C – they are the axial coefficients describing plane, D – constant, x, y and z – coordinates axes.

The angle between the planes given as the equation system (3):

$$\begin{cases} A_1x + B_1y + C_1z + D_1 = 0 \\ A_2x + B_2y + C_2z + D_2 = 0 \end{cases} \tag{3}$$

it was calculated according to formula (4):

$$\cos\phi = \frac{A_1A_2 + B_1B_2 + C_1C_2}{\sqrt{(A_1^2 + B_1^2 + C_1^2)(A_2^2 + B_2^2 + C_2^2)}} \tag{4}$$

where the special cases of the plane situation in relation to the coordinate orthocartesian system are showed below:

1. $D = 0; Ax + By + Cz = 0$ the plane crosses by coordinate origin,
2. $C = 0; Ax + By + D = 0$ the plane is parallel to the axis Oz,
3. $C = 0; D = 0; Ax + By = 0$ the plane lies in the axis Oz,
4. $B = 0; C = 0; Ax + D = 0$ the plane is perpendicular to the axis Ox,
5. $B = 0; C = 0; D = 0; x = 0$ the plane cover oneself from the Oyz.

Whereas distance d_0 of point (x_0, y_0, z_0) from the plane $Ax + By + Cz + D = 0$ can be counted from formula (5):

$$d_0 = \frac{|Ax_0 + By_0 + Cz_0 + D|}{(A^2 + B^2 + C^2)^{1/2}}. \tag{5}$$

The four-time measurement of the chosen points demonstrated almost the ideal compatibility. Angular resolution of instrument (0.6”), which is nearly three times higher from the calculated accuracy, it causes, that trust level of the measurement direction amounts $P = 1 - \alpha = 0.95$.

Whereas, distribution of portal collar crane deviations from flatness is shown in Table 1. The measurement and calculation results concerning the flatness column of portal crane are presented in Figures 6 and 7.

Table 1. *The composition of collar deviations values from flatness.*

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Distance of point from average plane in [mm]</th><th rowspan="2">Number of points</th><th colspan="3">Number of points in range</th></tr>
<tr><th>0.2 mm</th><th>0.4 mm</th><th>0.6 mm</th></tr>
<tr><td>1.</td><td>–0.3</td><td>2</td><td></td><td></td><td rowspan="7">32</td></tr>
<tr><td>2.</td><td>–0.2</td><td>7</td><td></td><td rowspan="5">27</td></tr>
<tr><td>3.</td><td>–0.1</td><td>6</td><td rowspan="3">12</td></tr>
<tr><td>4.</td><td>0.0</td><td>3</td></tr>
<tr><td>5.</td><td>0.1</td><td>3</td></tr>
<tr><td>6.</td><td>0.2</td><td>8</td><td></td></tr>
<tr><td>7.</td><td>0.3</td><td>3</td><td></td><td></td></tr>
<tr><td colspan="2">Total points</td><td>32</td><td></td><td></td><td></td></tr>
</table>

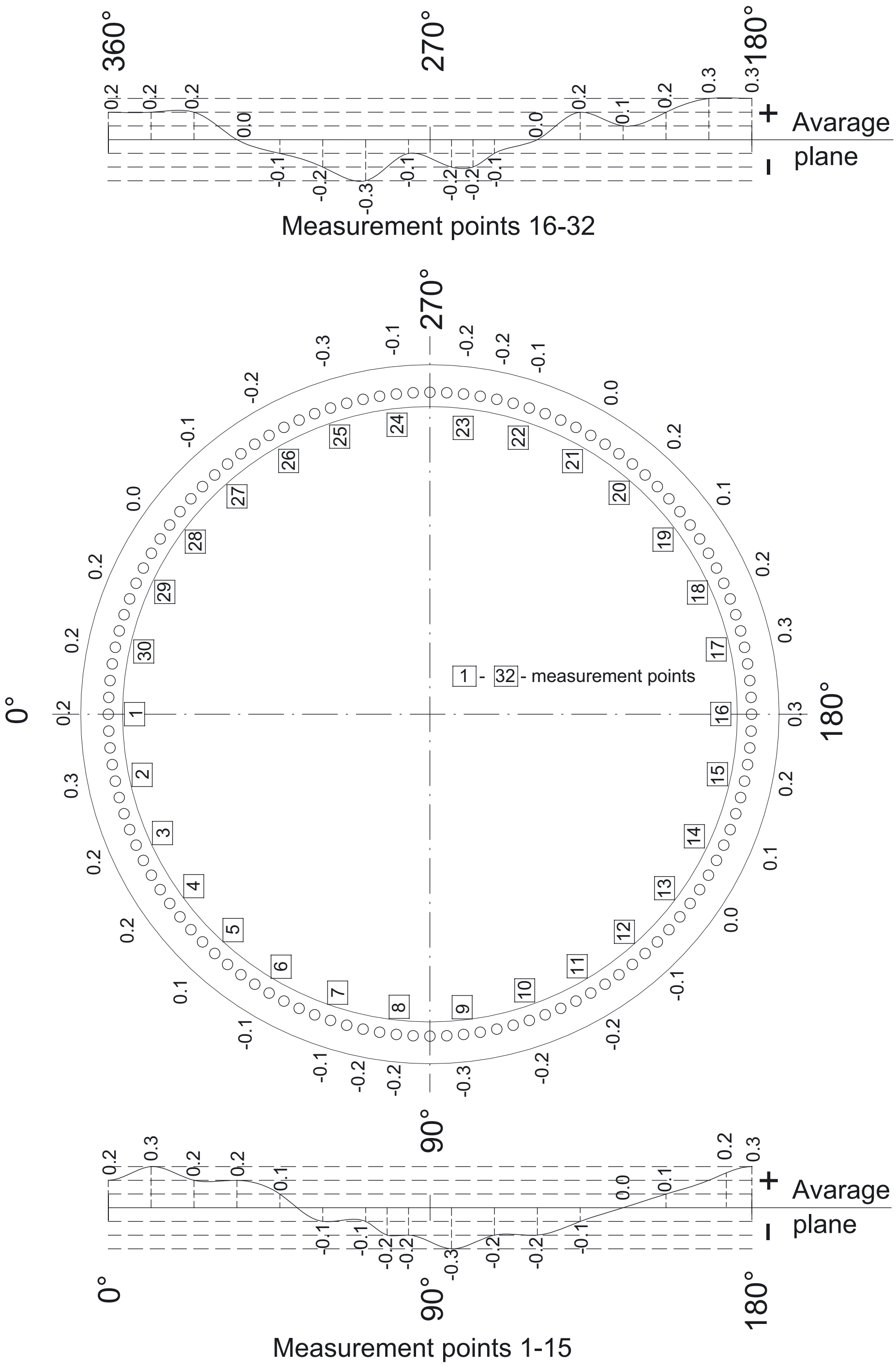

Figure 6. *Scheme of measurement points location with deviations from flatness.*

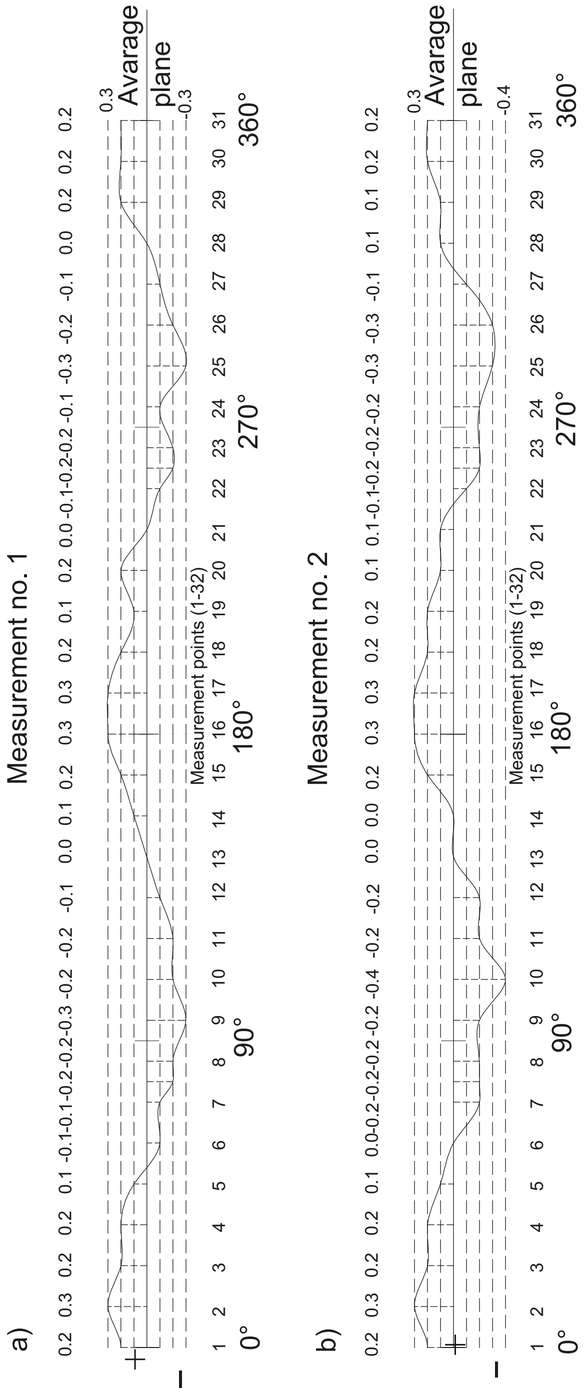

Figure 7. *Deviations of the frontal collar surface from flatness during measurements no.: a) 1 and b) 2.*

Maximum values of deviations from flatness (from average plane) were obtained in the following measurement points: 2, 9, 16, 17 and 25 (during the first test) as well as 2, 10, 16, 17, 25 and 26 (during the second test) and amounted at ±0.3 mm. In other points, smaller values of deviations were received (Figure 6).

4 Conclusions

1. The high measurement accuracy of 0.07 mm was obtained with use of the raised accuracy trigonometric measurement method together with the aiding equipment. It allowed to get correct estimation of frontal surface flatness of the portal crane collar column.
2. The raised accuracy trigonometric measurement method together with aiding equipment is fully applicable to precise measurement of other machines and mechanical devices, e.g. rolling mill, machine engine to the production of the wrap, papers machine engine, overhead cranes and crane runway (Anigacz 2001, Anigacz and Cmielewski 2001, 2004).
3. As a result of tests of portal crane collar flatness, it has been observed that the range of deviations from flatness is contained within the design assumed interval of tolerance from –0.3 to +0.3 mm (Figures 6 and 7).
4. The applied method seems to be optimal for measurements of this kind, due to the following criteria: time and measurement accuracy.
5. The applied method does not require fulfilment of initial conditions in relation to location in space of the tested element in contrast to the geometrical levelling method (a precise method). It is from that reason, that the trigonometric method allows to obtain results of the space coordinates of tested points, hence the situation of the plane in space does not matter, because in the result of approximation the average plane is calculated. Whereas the leveling method operates only vertical co-ordinates and could not be used to determination of collar flatness of column that is positioned freely in space (fig. 5).

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