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Rafał Gawałkiewicz

THE INVENTORY OF HIGH OBJECTS APPLYING LASER SCANNING, FOCUS ON THE CATALOGUING A REINFORCED CONCRETE INDUSTRIAL CHIMNEY

AGH University of Science and Technology in Krakow,
Faculty of Mining Surveying and Environmental Engineering
rgawal@wp.pl

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Abstract

There are many surveying methods to measure the inclination of a chimney with the use of classical protractor instruments (Theo 010A/B, T2 Wild), electronic theodolites (TC2002 Wild-Leica), electronic total stations, including mirrorless ones, allowing to define indirectly the course of the construction's axis on the selected observation levels. The methods are the following: indentations, direct projection, double-edged method, polar method with the option of mirrorless measurement. At the moment a very practical and quick measurement technology, significantly eliminating the influence of human errors on the observation results, is laser scanning. The article presents the results of the scanning of 120-metres high reinforced concrete industrial chimney of the Cement Plant „Ożarów", with the application of modern scanning total station VX Spatial Station by Trimble, as an alternative to the methods applied so far. The advantage of scanning is the possibility to obtain a point cloud, which, apart from the information on the course of the chimney axis in the space, provides detail information on the real shape and deformations of the coating of the object's core.

INWENTARYZACJA OBIEKTÓW WYSOKICH Z WYKORZYSTANIEM SKANINGU LASEROWEGO

Słowa kluczowe: skaning laserowy, inwentaryzacja kominów przemysłowych

Abstrakt

Istnieje szereg geodezyjnych metod pomiaru wychylenia komina przy wykorzystaniu klasycznych instrumentów kątomierczych (Theo 010A/B, T2 Wild), teodolitów elektronicznych (TC2002 Wild-Leica), tachimetrów elektronicznych, w tym bezzwierciadlanych, które pozwalają zdefiniować w sposób pośredni przebieg osi budowli na wybranych poziomach obserwacyjnych. Należą do nich metody: wcięć, bezpośredniego rzutowania, dwusiecznych kierunków stycznych, biegunowa z opcją pomiaru bezzwierciadlanego. W chwili obecnej bardzo praktyczną i szybką technologią pomiarową, eliminującą w sposób znaczący wpływ błędów ludzkich na wyniki obserwacji jest skanowanie laserowe. W artykule przedstawiono wyniki skanowania 120 metrowego żelbetowego komina przemysłowego Cementowni „Ożarów" przy wykorzystaniu nowoczesnego tachimetru skanującego VX Spatial Station firmy Trimble, jako przykład alternatywy dla metod dotychczas stosowanych. Zaletą skanowania jest uzyskiwanie chmury punktów, która poza informacjami o przebiegu osi komina w przestrzeni, dostarcza także szczegółowych informacji o rzczywistym kształcie i deformacji płaszcza trzonu budowli.

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1. INTRODUCTION

The purpose of the surveying measurements of slim constructions such as industrial chimneys, is obtaining information on their technical state (Puniach E., Oruba R., 2013). The indicator of the proper functioning of chimneys is the state of its individual components (Puniach E., Oruba R., 2014), i.e. the degree of surface damage of the inner lining and outer coating of the core as well as the parameterization of their shape, aiming at the definition of the size of local values of shape deformation and the deflection of the chimney axis (inclination).

Full cataloguing of high (slender) industrial constructions requires, by the means of appropriate regulations, the description of changes in geometry and structure of the coating and lining, the application of many measurement methods: surveying, photogrammetric (Bernasik J., 2001) and thermal vision methods. Proper combination of the data from individual methods allow the definition of the full picture of changes in the geometry and structure of the coating, both at the stage of erecting the object (construction control), as well as during its exploitation (Muszyński Z., 2013). Thus the proper interpretation of the data allows the valuation of security works and planning all types of renovations providing full security for the object and its users.

A particularly changeable parameter of a slender construction is the deflection of its vertical axis. The characteristic of the axis shape (the scale of deformations, maximal inclination), depends on the intensity of outer (Koten H. van, Pritchard B.N., 1986; Koten H. van, 1986) and inner factors into the surface and structure of the coating and lining. The definition of the percentage of the participation of individual factors influencing the value and direction of the deflection of the coating is difficult, while the applied surveying and photogrammetric methods allow precise spatial description of this phenomenon (Radulescu C., Radulescu G., 2012). To define the real shape of the chimney core it is necessary to know either points defining the course of the vertical axis of the construction, marked in an indirect way, observing side parts of the core of selected levels, or, based on the set of points physically projected on the reinforced concrete surface, properly signalled or randomly distributed, but making a dense grid on the surface of the building.

In the process of the cataloguing and monitoring of slender objects, the main role in the process of obtaining data has been played so far by predominantly classical surveying methods. Apart from the method of laser scanning, other surveying methods, photogrammetric methods and thermal vision methods have been applied. They were described in details in: Gawałkiewicz R., i inni. (2011), Gocał J., (1999), Gocał J., (2005) i Gocał J., (2010), thus they will not be discussed in this article.

The article illustrates the results of the laser scanning of 120 m high industrial chimney of the Cement Works „Ożarów", as a practical alternative for the already applied methods. Such an alternative would, in a relatively short time, provide large amount of precise data obtained from the available observation of the construction's coating or its selected fragments. The article also presents the results of the modelling of the process of the core deflection, applying the least squares method (LSM) in two versions of the measurement system and the number of data sets.

2. LASER SCANNING METHOD – CHARACTERISTICS

The alternative for the classical measurements can, already nowadays be made by modern remote sensing scanning total stations, which, apart from the standard option of precise angular-linear measurements in control lines, provide huge sets of point data, defining the shape of the studied industrial object. The excess of data makes a great advantage. This allows full control of data, because a definite point in the cloud makes reference to the situation of neighbouring points. The points are defined based on the „diluted" return signal (deformed with the reflection of the impulse from more than one detail). They are relatively easy to identify, because in the set of points they make so-called peaks. The view of the point model in 3D, allows easy recognition and removal in the case of such geometrically simple objects as chimneys.

The number of point data making the grid of coordinates on the surface of the surveyed construction is defined by the user, who can select the size and density of points by the proper choice of angular or distance resolution (variable depending on the distance). The advantage of the measurements with the application of scanning total stations is a technology taken from typical scanners, allowing the diminishing of the measurement area into the area required by the user (Fig. 1), and this way, the limitation of the size of the data file and – first of all – shortening the measurement time to minimum, which is very important in case of limited measurement speeds.

The main factor influencing the situation error of the cloud points is the accuracy of distance measurement. According to Ziajka M., (2003), Lenda G., (2003) and Gawałkiewicz R., (2005), the accuracy is strongly influenced by the colour and texture of the reflecting surface, the size of the laser spot and the angle of the laser beam on the surface of the object. The construction of the present surveying instruments, guarantees the measurement of very steep surfaces, even if the angular measurement threshold is at the level of 88° Gawałkiewicz R., (2006). The growth of the angular threshold is connected with the increase of the measurement time, and consequently, the decrease of scanning speed, which can be observed during the measurements with the application of scanning total stations.

Moreover, in modern scanning total stations the increase of the accuracy in the distance measurements is obtained by setting the repeatability of measurements as n – repetitions in a given direction straight before starting the scanning and the value of the acceptable error given as standard deviation s_d. During the measurement, the instrument counts the distances from n – repetitions and marks the deviation value then comparable to the value of error s_d defined by the user before the start of the work. Such action makes one of the forms of the data filtration already at the stage of the carried out measurement process.

In the cataloguing process of the industrial reinforced concrete chimney scanning total station VX™ Spatial Station by Trimble was applied – allowing the combination of the possibility of classical total station and laser scanner. High accuracy of the measurement of angles ±3^{cc} and distance in the mirrorless measurement mode ±3mm ±2ppm or scanning mode ±3mm in the range of 2÷150m and maximum scanning speed – up to 15 points/second, guarantee the detection of the situation of any point in space with a mean error not exceeding ±10mm.

The total station has a CCD camera (VISION technology) built up into the refractor and integrated with the aim axis and the protractor system. The camera, apart from the function of the visualization of the measurement area on the colour monitor of the controller Trimble CU and direct declaration on the screen of the scanning range (Fig. 2), allows taking sequence images of the object in the defined area before starting the measurement, and using them on the stage of data in the processing by texturising the coating models. Moreover, during the measurement, the image of the reflection strength of individual signal is visualized on the screen. The colour of the point depends on the distance, angle of swerve of the reflecting plain, regarding the direction of the impulse course (Fig. 2).

Fig. 1. The image from the camera of the total station with the marked fragment of the area where the chimney's base was scanned (interrupted yellow line)

Rys. 1. Obraz z kamery tachimetru z zaznaczonym fragmentem pola skanowania podstawy komina (łamana koloru żółtego)

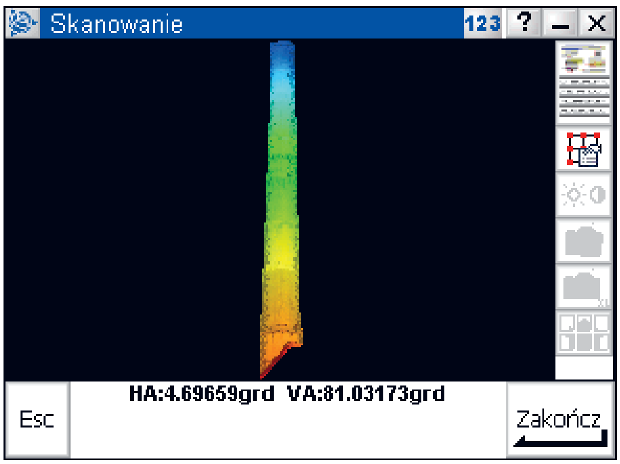

Fig. 2. The image of returning signals – visualization on the monitor screen TCU Trimble'a (view from the side of the check point 1006)

Rys. 2. Obraz sygnałów powracających – wizualizacja na ekranie kontrolera TCU Trimble'a (widok od strony stanowiska pomiarowego 1006)

Fig. 3. Situation – altitude map of the industrial area in the vicinity of the inventoried industrial chimney of the Cement Plant „Ożarów" 1006, 1008, 1111 – measurement points; 1007, 1010, 1028 – situation reference points; 409 – altitude reference point Distanced of measurement points from the measured chimney: 103.5m (point 1006); 43.4m (point 1008); 45.5m (point 1111).
Rys. 3. Mapa sytuacyjno-wysokościowa terenu przemysłowego w otoczeniu inwentaryzowanego komina przemysłowego Cementowni „Ożarów" 1006, 1008, 1111 – stanowiska pomiarowe; 1007, 1010, 1028 – punktów nawiązania sytuacyjnego; 409 – punkt nawiązania wysokościowego. Odległości stanowisk od trzonu mierzonego komina: 103,5m (punkt 1006); 43,4m (punkt 1008); 45,5m (punkt 1111).

The advantage of the total station is the possibility of achieving the high accuracy of the control line points and the (orientation) of polar and scanning measurements in a classical way with the participation of the operator and reference to these points, even with the preservation of the distance in the full measurement of the instrument.

Automation of the measurement process with the application of scanning instruments, allows night measurements, when it is possible to minimize the influence of external factors, i.e. weather (changes in sunshine intensity) affecting the core of the chimney in a dynamic way (Kocierz R., i inni, 2012). Marking real state of chimney geometry, it is also possible to isolate the object from internal factors (temperature of the output gases and the variability of this parameter in time), cataloguing when the technological process is halted (temporary exclusion of the chimney from exploitation), which also influences the final result and shape of the constructed model.

3. THE CHARACTERISTICS OF THE OBJECT

Technologies based on classical measurements of the inclination vector, i.e.: double-edged method, trigonometric two-stands method, or direct projection method, demand open horizon and large area to make optimal conditions of the observation to achieve high accuracy. Many industrial enterprises having the constructions to release the output gases are densely built up, which significantly limits the possibilities of measurements. The catalogued reinforced concrete chimney of the Cement Works „Ożarów" is 120m high (Fig. 3). It was located among tall buildings and technological halls, which significantly makes it more difficult to apply classical measurement methods of the deformation of its core. Due to the application of scanning total station VX Trimble Spatial Station, it was possible to cover the chimney surface with a dense grid of point, having small distance between measurement stands. The situation in the field allowed the choice of the check points of the instrument in the form of a triangular measurement rosette, useful from the point of view of the measurement grid geometry, and this way the accuracy of measurements. Accurate points of the enterprises' control line of determined spatial coordinates XYH, which already at the stage of measurement works, taken for the measurements allowed mathematic transformation of individual point clouds to the superior system of enterprise's control line.

VISION technology built into the refractor camera allowed the overview the chimney into the screen of the monitor without the necessity to apply special deflecting prisms, as well as indicating the range of measurements and selection of the measured areas. The localization of the check points of total station VX, allowed nearly 100% covering of the whole chimney with the grid of points. Only from the stand remote by 103.5m from the base of the chimney, due to its height and limitations in the distance measurement to 150m, only about 5m of the tallest fragment of the head of the construction was not possible to be covered with points. The carried out data analysis suggests that the longest recorded lengths obtained in the mode of laser scanning exceed maximal values defined by the producer by 5.5m (max. 150m).

4. MEASUREMENT CONDITIONS ACCORDING TO THE REGULATIONS

To follow the Requirements [1,2], the measurement of the chimney inclination was carried out in the windless conditions and dense clouds in the temperature range $-4^{o}C \div -1^{o}C$, early morning. The selection of optimal conditions and time of measurement resulted from the limitation of the influence of sun operation disappearing within 9÷10 hours from the moment of the isolation of the construction from the sunshine of the previous day [1]. Fulfilling these conditions can guarantee capturing the course of the axis in a possibly closed resting situation, i.e. when the construction axis is situated, after the complete separation from the influence of external factors or their total balance. In such conditions we can assume that the observation results will be free from the influence of elastic strains and the recorded real shape of the chimney is only a result of the influence of permanent strains.

According to the Requirements [1,2], the measurement of the verticality should be carried out referring to the procedures and methods, so that the accuracy of the determination of the dislocation (given by the mean error m_{dmax}) could be guaranteed on the level less than ±5cm. The test of the usefulness of the scanning total station in the process of the determination of the coating shape, was carried out for the mean-height chimney, for which the influences of external factors were definitely different than those of 2÷3 times higher. Test works including the preparation of the study area and the measurement were carried out in 3^h30min.

5. METHODS OF THE PROCESSING THE RESULTS OF CHIMNEY SCANNING

The determination of inclination vectors of the main (vertical) axis of the chimney into individual levels regarding the base of the core of the construction, was based by the least squares method (LSM). This involved matching circles representing generalised shape of the chimney cross-section on a given height (generalization of the section to circle) into selected bands of points from the cloud. Comparing the coordinates of the centres of adjusted circles on individual heights towards the lowest available level of the measurement, allowed the calculation of the components of vectors of the axis inclination in the main directions and presenting the real shape of the chimney axis – fig. 5. The component values were used to mark total inclination vectors, which was presented in table 1.

Assumptions for the analysis of cross-sections

The analysis of the point data was based on bands defined in the horizontal plains, and not in vertical plains perpendicular to real (local) course of the axis on the definite level. To define the influence of the accepted model on the number of deformations of the obtained results (error of the generalization of the model), the model presented in figure 4 was applied. Crossing the cone deviated from the vertical with the horizontal plain generates elliptic and not circular cross-sections.

This results in the situation that individual radiuses r_1 and r_2 alongside the longer axis of the ellipse of the cross-section is defined by the relations:

$$r_1 = acos\gamma + \frac{asin\gamma - h}{tg(\alpha - \gamma)} \text{ and}$$

$$r_2 = acos\gamma + \frac{asin\gamma + h}{tg(\alpha + \gamma)} \tag{1,2}$$

Thus the formula of the length of the longer axis of ellipse S_p made from the section inclined by the angle g of the frustum with horizontal plain p (cutting on a given observation level) takes the form:

$$S_p = r_1 + r_2 = 2acos\gamma + \frac{asin\gamma - h}{tan(\alpha - \gamma)} - \frac{h + asin\gamma}{tan(\alpha + \gamma)} \tag{3}$$

where:
- α – inclination angle of the chimney making axis in the initial state (of frustum);
- γ – inclination angle of the chimney axis on the studied section;
- a – the radius of the basis of any frustum of the fragment of the chimney core;
- h – height of the examined level referring to the base (height of the horizontal cutting plain p).

The angle of chimney convergence e is defined by the formula:

$$\varepsilon = 2\delta = 2arctg\left(\frac{a-b}{H}\right) \tag{4}$$

where:
- b – the radius of the frustum, e.g. of the chimney's head;
- H – distance between two defined levels of chimney, e.g. total height of the core.

The value of the diameter of the circular cross section (theoretical), resulting from cutting the cone on the height h from the base, with the horizontal plain p (cutting), is defined by the equation:

$$S_t = 2\left(a - h \cdot \frac{sin\delta}{sin\alpha}\right) \tag{5}$$

where:
- δ – half of the convergence angle of the chimney e.

Thus the difference between diameters *DS,* resulting from the inclination of any fragment of the chimney's core in the shape of cone is described by the equation:

$$\Delta S = S_p - S_t \tag{6}$$

This means that for the investigated chimney, for the selected fragment (the cone between levels 44–45) of the greatest inclination g = 0.6384^g, H = 2.5m, h = 1.25m, convergence angle e = 2.2916^g and cone's radiuses a = 2.390m and b = 2.345m, the change in diameter DS, resulting from neglecting the inclination of the chimney and accepting the plain of the cross section as horizontal p, equal **DS = 20.5mm**. From the formulae (3) ÷ (5) it results that the change in the size of the diameter DS and the influence of a wrong definition of the plain describing the plain of the cross section, occurs

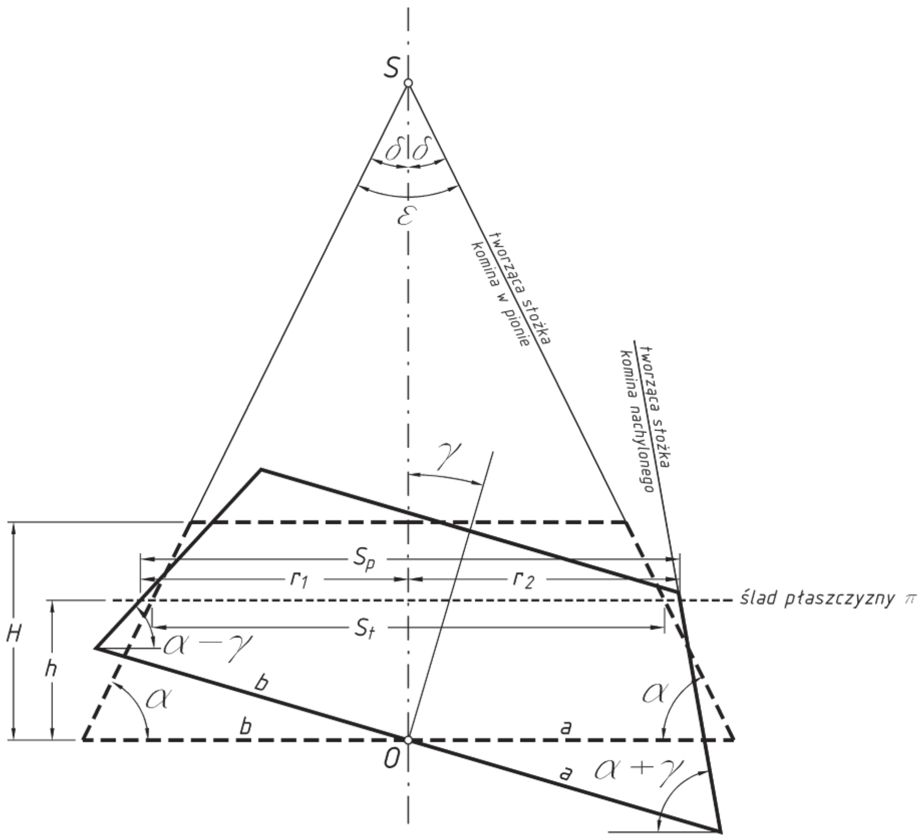

Fig. 4. The scheme of the influence of generalization of the cross-section on determining the size of parameter of radius r
Rys. 4. Schemat wpływu przyjęcia poziomej płaszczyzny przekroju na wyznaczenie wielkości promienia r przekroju

with the increase of the angle of chimney convergence e and the increase of inclination angle of the chimney g.

Crossing of the horizontal cutting plain on the studied level, as the reference level causes interpretation inaccuracies. Thus it is necessary to define mathematically the base plain perpendicular in the point O to the axis of the individual truncated cone (figure 4). Such a procedure reduces the influence of the phenomenon of the ovalization of the chimney cross-section and the need for the application of the smallest squares method in the process of fitting the circle in the band of selected points.

6. RESULTS OF THE CLOUD POINT ANALYSIS

A huge advantage of the method of laser scanning with the application of total station XV, is that physical geometry of the catalogued object is obtained relatively quickly, based on a dense grid of points. The cloud of points obtained from the measurement, can be, if necessary, converted from the carthometric point model into its coating equivalent (final stage of the visualization of the building) in the author's program Trimble'a 3D-RealWorks Survey. Small speed of data recording (max. 15 points/second), compared to present possibilities of scanners, does not allow precise details in the created 3D model of chimney by the elements of its infrastructure (constructions of small galleries, stairs, electric and telecommunication installations).

Based on multi-point combined set of 3D data projected on the surface of the reinforced concrete of the coating (120930 points), defined from three points of precise situation – height control line and accepted height of horizontal cross-sections distributed every 2.5m, in AutoCAD Civil 3D v.2010 program, point bands of the shape of chimney shield were selected on the defined investigated levels. Due to the limited time of measurement and different density of point cloud, depend on the height (distance), to obtain the proper statistic sample selected from general data set, the

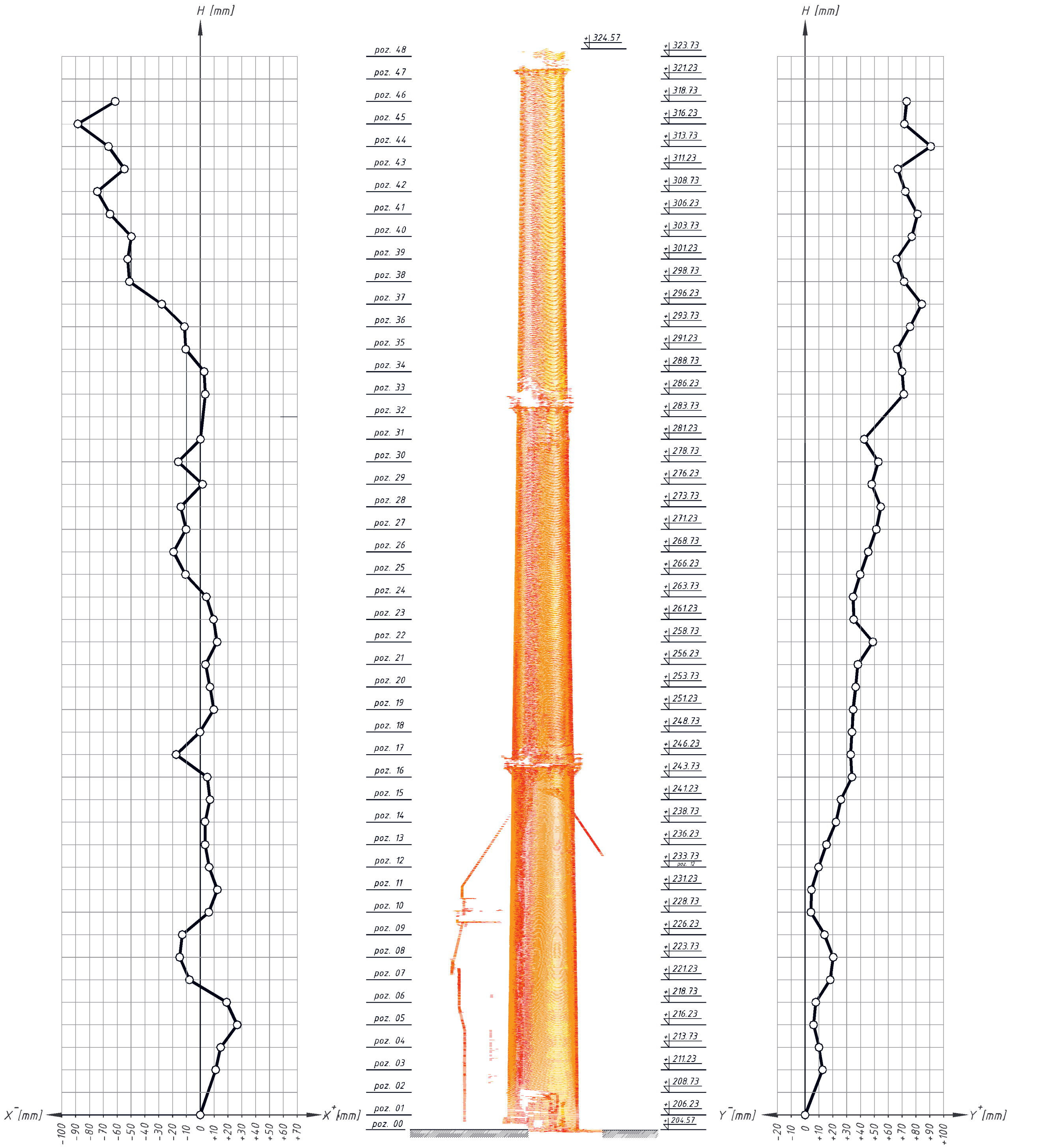

Fig. 5. The image of the point cloud (120930 point), projected on the coating of the reinforced concrete chimney, obtained from the scanning total station measurements VX Spatial Station by Trimble from 3 stands and the graphs of the axis inclination components on the selected levels

Rys. 5. Obraz chmury punktów (120930 punktów), odwzorowanej na powłoce żelbetowego komina uzyskanej z pomiarów tachimetrem skanującym VX Spatial Station firmy Trimble z 3 stanowisk oraz wykresy składowych wychylenia osi komina na wybranych poziomach points localized in the zones of accepted sections on the intensity of the inclination of bands ±5cm, which for 3 combined scans, allowed obtaining the size of samples from the range of 29 ÷146 points. Due to the degree of covering the base of the chimney on its whole circuit on the level 00 (temporary repository of building materials), the reference level was accepted at the height of level 01, i.e. 206.23m (+1.66m) – fig. 5. The analysis of the sections of the chimney's shield on the selected levels, allowed – in the AutoCAD program – filtering from the set (band 0.1m) of the points not situated on the reinforced concrete coating, but belonging to the elements of the chimney's infrastructure , i.e.: ladders of communication tracts, galleries and their supports, power cables, installations and GSM aerials. Determining the parameter of the radius based on selected point data, can be carried out in the branded software of total station 3D-Real Works Survey Trimble'a or in any author's programmes, allowing converting circles into point sets by the least squares method (LSM). In the optimization of the measuring and calculation process to the shape of defined cross-section with the use of

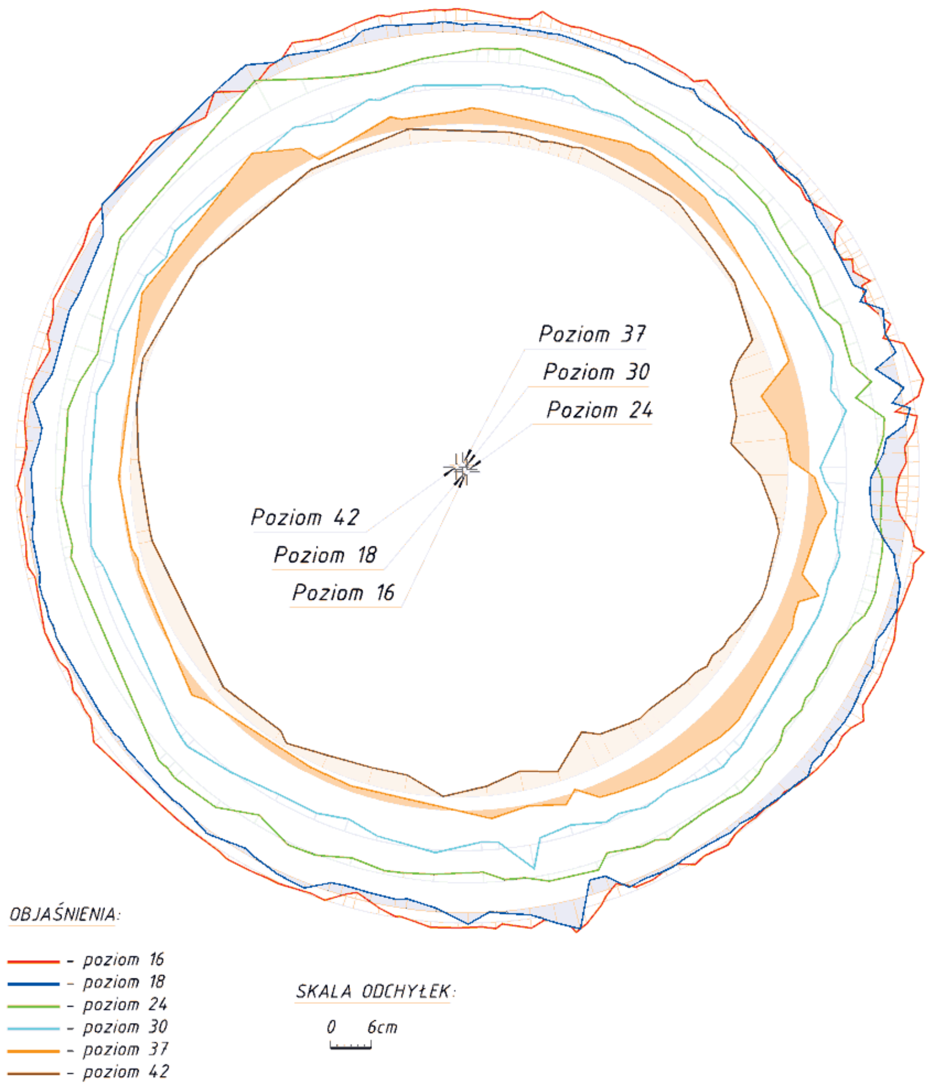

Fig. 6. Visualization of the deviation of the real shape of the cross-section in the relation to the approximated based on point bands of the circles on the selected levels, i.e.: 16, 18, 24, 30, 37, 42

Rys. 6. Wizualizacja odchyłek kształtu rzeczywistego przekroju względem aproksymowanego na podstawie wstęg punktowych okręgów na wybranych poziomach badawczych, tj.: 16, 18, 24, 30, 37, 42

Table. 1. The set of chimney parameters on the selected study levels generated based on 2 and 3 scans
Tabela. 1. Zestawienie parametrów komina na wybranych poziomach badawczych wygenerowanych na podstawie 2 i 3 skanów

LEVEL	3 SCANS (horizon fully covered)							
	Coordinates of the shield centre		The radius of the shield	Error	Components of the vector inclination		Vector inclination	Abundance of the set
	X [m]	Y [m]	R [m]	m_R [cm]	W_x [mm]	W_Y [mm]	W [m]	[szt]
level 16	10285.995	1703.722	3.350	0.8	5.0	33.8	34.2	146
level 17	10285.972	1703.721	3.334	1.8	–17.4	32.9	37.2	60
level 18	10285.989	1703.722	3.274	0.9	–0.2	33.8	33.8	128
level 19	10285.999	1703.723	3.235	1.0	9.8	34.7	36.1	117
level 20	10285.997	1703.725	3.196	0.9	7.0	36.5	37.2	143
level 21	10285.993	1703.726	3.152	1.0	3.8	38.1	38.3	104
level 22	10286.002	1703.737	3.116	1.1	12.2	48.9	50.4	94
level 23	10285.999	1703.723	3.087	1.0	9.6	35.1	36.4	100
level 24	10285.994	1703.723	3.051	1.2	4.4	34.7	35.0	84
level 25	10285.979	1703.728	3.010	1.1	–10.7	39.8	41.2	96
level 26	10285.970	1703.734	2.975	1.2	–19.3	45.6	49.5	73
level 27	10285.979	1703.740	2.929	1.2	–10.2	51.4	52.4	81
level 28	10285.976	1703.743	2.897	1.6	–14.0	54.7	56.5	62
level 29	10285.991	1703.736	2.860	1.6	1.7	48.1	48.1	63
level 30	10285.974	1703.741	2.831	1.6	–15.9	52.9	55.2	60
level 31	10285.990	1703.731	2.754	1.7	0.2	42.6	42.6	59
level 34	10285.992	1703.758	2.637	1.6	2.8	69.8	69.9	50
level 35	10285.979	1703.755	2.604	1.7	–10.5	66.8	67.6	47
level 36	10285.978	1703.764	2.569	1.5	–11.4	75.8	76.7	51
level 37	10285.962	1703.773	2.540	1.8	–27.8	84.3	88.8	45
level 38	10285.939	1703.760	2.502	1.7	–51.1	71.5	87.9	46
level 39	10285.937	1703.754	2.475	1.5	–52.4	66.0	84.3	47
level 40	10285.940	1703.765	2.463	1.4	–49.7	77.1	91.7	56
level 41	10285.924	1703.769	2.431	1.6	–65.2	81.2	104.1	48
level 42	10285.915	1703.761	2.403	1.9	–74.3	72.4	103.7	36
level 43	10285.935	1703.755	2.393	1.7	–54.8	66.9	86.5	48
level 44	10285.923	1703.779	2.390	1.9	–66.3	90.7	112.3	36
level 45	10285.901	1703.760	2.345	1.6	–88.4	71.7	113.8	46
level 46	10285.929	1703.762	2.338	1.8	–61.0	73.3	95.4	47

2 SCANS (horizon partially covered)										
Coordinates of the shield centre		The radius of the shield	Error	Components of the vector inclination		Vector inclination	Abundance of the set	Cover	Difference of the value of vectors	Difference of the value of radius
X [m]	Y [m]	R [m]	m_R [cm]	W_x [mm]	W_Y [mm]	DW [mm]	[szt]	[°]	DW [mm]	DR [mm]
10285.992	1703.724	3.348	1.2	2.4	35.8	35.9	103	269	–1.7	2
10285.962	1703.762	3.298	2.7	–27.6	73.8	78.8	49	240	–41.6	36
10285.988	1703.728	3.272	1.2	–1.6	39.8	39.8	84	237	–6	2
10285.984	1703.741	3.228	1.2	–5.6	52.8	53.1	77	250	–17	7
10285.990	1703.734	3.191	1.2	0.4	45.8	45.8	94	244	–8.6	5
10285.987	1703.735	3.150	1.2	–2.6	46.8	46.9	69	247	–8.6	2
10285.991	1703.738	3.115	1.5	1.4	49.8	49.8	60	240	0.6	1
10285.991	1703.730	3.080	1.5	1.4	41.8	41.8	65	246	–5.4	7
10285.975	1703.736	3.047	1.5	–14.6	47.8	50.0	50	236	–15	4
10285.967	1703.738	3.004	1.5	–22.6	49.8	54.7	62	240	–13.5	6
10285.960	1703.742	2.975	1.8	–29.6	53.8	61.4	48	238	–11.9	0
10285.973	1703.748	2.927	1.8	–16.6	59.8	62.1	50	238	–9.7	2
10285.980	1703.745	2.894	1.8	–9.6	56.8	57.6	40	239	–1.1	3
10285.987	1703.739	2.860	2.1	–2.6	50.8	50.9	36	235	–2.8	0
10285.972	1703.747	2.830	1.8	–17.6	58.8	61.4	48	236	–6.2	1
10285.980	1703.714	2.785	3.0	–9.6	–4.2	10.5	27	238	–20.0	–31
10285.996	1703.771	2.665	2.1	6.4	82.8	83.0	40	232	–13.1	–28
10285.991	1703.767	2.645	1.8	1.4	78.8	78.8	28	240	–11.2	–41
10286.005	1703.746	2.616	3.0	15.4	57.8	59.8	24	211	16.9	–47
10285.969	1703.781	2.560	2.4	–20.6	92.8	95.1	26	228	–6.3	–20
10285.932	1703.805	2.516	2.7	–57.6	116.8	130.2	24	240	–42.3	–14
10285.934	1703.778	2.498	2.4	–55.6	89.8	105.6	19	250	–21.3	–23
10285.937	1703.773	2.472	2.1	–52.6	84.8	99.8	25	250	–8.1	–9
10285.938	1703.778	2.463	2.1	–51.6	89.8	103.6	28	250	0.5	–32
10285.928	1703.770	2.434	1.8	–61.6	81.8	102.4	28	247	1.3	–31
10285.934	1703.755	2.415	3.0	–55.6	66.8	86.9	15	221	–0.4	–22
10285.943	1703.759	2.394	2.1	–46.6	70.8	84.8	23	263	27.5	–4
10285.909	1703.802	2.374	2.7	–80.6	113.8	139.5	18	255	–25.7	–29
10285.898	1703.772	2.342	2.1	–91.6	83.8	124.1	25	265	–28.7	–4

circles, point sets of 0.1m bands were used, while the studies has two stages for:

– two measurement stands located on the opposite sides of the chimney;
– three measurement stands, enabling to cover the surface of the chimney on its whole circuit in nearly 100%.

The optimization process and related minimization of the number of check points, deciding on shortening the measurement time, is related to obtaining the minimal amount of information. Only full covering of the surface of the chimney gives information on the size of structural deformations on its whole circuit. The size of the sought parameter of the radius of the chimney shield *R* on selected study levels for two measurement options, are presented in table 1, while the graph of the components of the inclination of the chimney axis was illustrated in figure 5. Fitting circles into the selected from the combined scans point band, as equivalents of generalized outlines of the cross-sections of chimney on selected levels, allows obtaining detail information on net situation of the situation of the of real cross-section by marking its radius R_i, as well as the centre of approximated circle. Assuming a small value of the interval between individual cross-sections, enables the users to control the modelling of chimney's shape. Sudden and significant from the point view of the direction and value of the deviation from the general trend determined by the range of the neighbouring cross-sections, makes reasonable to remove the definite level from general analysis or, if possible, to control data, by their re-filtration. It can happen that the elements of chimney's infrastructure and elements of temporary securing the coating come to nearly circular shape, but do not represent the surface of the chimney; in this case users can obtain false data. Every instrument equipped in the telemeter of a definite characteristic of emitted light beam, possesses the defined size of the spot for a strictly defined distance. Due to a strictly defined angle of the obtrusion of the beam, its value grows with the distance. Because of that, the measurement of the coating equipped in even small elements adhering to it, can cause the „dilution" of the image in the areas of multiple reflections of the spot from more than one element. A „continuous and smooth" point outline is obtained, but it is often difficult to verify. The example of such deviations is level 32 (fig. 6), defined based on faded and irregular protective mesh attached under the central revision gallery. Thus the parameterized in such a way cross-section was rejected from further analysis. The final effect of the paper can result in the graphs of the deviations of the real shape of the coating from the approximate value of the circle, determined with the least squares method. The deviation is calculated as the distance of the measured point on the coating alongside the normal to the approximated circle. The effect of such a model of analyses was illustrated in figure 6. To make the picture legible, for the do graphic interpretation only selected levels of the chimney were used, i.e.: 16, 18, 24, 30, 37, 42.

7. CONCLUSIONS

The polar method and its automation such as laser scanning, allow defining the shape of the chimney, i.e.: the course of the axis and structural deformations of the surface, provided the proper density of grid points is preserved. Used in the experiment total station VX Spatial Station by Trimble, makes a tool to collect precise data on the geometry of the catalogued objects. The combination of the function of classical measurement, laser scanning and digital photography can guarantee making complete surveyor's documentation, starting from observation diaries, measurement reports, numeric sketches, ending with the photographic documentation, which helps in the analysis of the results. The software flexibility in controller TCU2, enables the user to be able to make choices of the operating mode and the range of the measurement field at any moment. Originally software 3D-Real Works Survey simplifies the process of processing the point clouds, including the determination of investigation of sought geometric parameters, or the change of point models as half-products into metric coating or lump models. Comparing the values of translocation vectors of the vertical axis of the chimney, determined based on 2 or 3 scans, allows the conclusion that it is possible to shorten the measurement time, preserving high point density of the grid, with the limitation of the number of check points to two situated approximately on the opposite side of the construction. The limitation of the number of check points makes sense under the condition that the main parameter marked is the value of the chimney deflection, but not the recording of the phenomenon of local structural deformations, i.e. damage to the reinforced concrete coating.

The condition to obtain high accuracy of the determination of the section radius on a given level is narrowing down the clouds of points from single measurement stations, so that the points, projected in the zones of significant twisting of the surface reflecting in the relation of the direction of impulse run, could be removed. Moreover the carried out analysis of the influence of improperly established cross-section plane (horizontal) towards the real inclination of reinforced concrete structure causes the ovalization of base cross-section and inaccurate interpretation of the deformations. Thus it is important to define the shape of the chimney axis (even approximate) on the selected study levels and mathematic definition of cross-section planes perpendicular to the chimney axis in the point for the correct interpretation of circular cross-section. In case of relatively „young" constructions or neat enterprise archive, possessing in its resources technical documentation of older chimneys, there is a possibility to construct a theoretical model, which can make perfect base for the current cataloguing measurements in the framework of the carried out surveying monitoring. Particularly useful can be the documents containing field sketches, observation diaries from the after-work measurements (especially construction deviations in the cross-sections), continuously developed with the investment and collected during the object construction. Then the information on the construction deviations, including the ovalization of the shape of the shield chimney or irregular, local surface deformations resulting from the errors and construction neglects in the studied cross-section, can significantly simplify and make more accurate results of the description of the core deformation phenomenon while using the object. Thus such a type of information allows the construction of theoretical reference model, more accurate than the model based on the project data. Then it is important that while erecting new chimneys, take care about the storing of surveyed measurement and cartographic materials, made during the construction works and preserve them after the end of the investment. Making a real 3D model based on this, in the combination of the data of project documentation, creates the possibility of full control of the geometry of the building in time. It results from the fact that knowing spatial geometry of the chimney solid, it is possible to apply the shape of the section of the given level; it is possible to fit a theoretical cross-section in a dense cloud of points obtained only one-sided from a single measurement point.

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