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DEFORMATION INVESTIGATION OF THE SHELL OF ROTARY KILN USING TERRESTRIAL LASER SCANNING (TLS) MEASUREMENT

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For the correct operation of the rotary kiln it is necessary to ensure that basic geometric conditions are fulfilled. For regular check the geodetic measurements are used. Based on the developments in survey technology, the geodetic total stations (TS) and terrestrial laser scanning method (TLS) are used. TLS method was used for an investigation of the longitudinal axis of the rotary kiln (RK), axes of the carrier tires, and mainly the kiln shell deformation during its shutdown. The results of the experimental use of the TLS method to obtain ovality ratio of the shell of the rotary kiln are presented in this article.

Key words: rotary kiln, geodetic measurement, geometric parameters, shell deformation, corrections

INTRODUCTION

Deformations of the RK shell can be caused mainly by mechanical factors (incorrect manufacturing, assembly, external and self-weight) and thermal factors (unequal temperature distribution). In general, the upper area of the kiln in cross section is flattened under the influence of self-weight and weight of inner refractory lining. The value of curvature radius increases in this area. The resulting effect is a degradation of refractory brick lining with the need of repair with forced kiln shutdown. The refractory bricks can fall out, and this causes, in consequence, local overheating, which is the main cause of shell deformations [1].

A very useful parameter for geometry assessment of RK shell is the ovality ratio. For the ovality ratio comparison, it is suitable to establish the quotient ω_0, which allows a comparison of objects with different dimensions.

$$\omega_0 = \frac{\left(r_{\max} - r_{\min}\right)}{r} \cdot 100 \ \% \qquad (1)$$

where r_{max} and r_{min} are maximal and minimal radiuses of the shell r is the known nominal radius of RK shell.

Advantages of the TLS method are mainly in big amount of the measured points with a high speed of measurement and high level of detail of the resulted model [2]. TLS also allows measurements from a network reference system with irregular shape and from safe and comfortable standpoints on the ground. Data collection of several geometrical features of the whole object within a single measurement is an additional benefit by the proposed method, which minimizes the time of RK shutdown.

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Site description and scope of the study

The measurement was taken at the rotary kiln in cement factory CRH Turňa nad Bodvou in eastern Slovakia (Figure 1). Length of the RK is 80 meters; the nominal slope is 3,500 %, the nominal inner diameter of the shell is 5 000 mm. The kiln is placed on three carrier tires and on three pairs of radial rollers on separate foundations approximately 10 meters above the ground. The rotary kiln was in shut down mode (stationary position and cold) during the entire period of measurement.

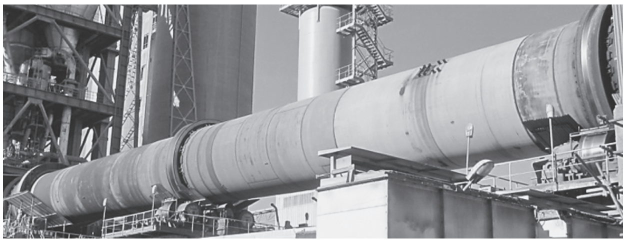

Figure 1 Rotary kiln - overall view.

Methodology of the measurement generally consists of the design and realization of the reference system (local horizontal and vertical coordinate system) and of following measurement and investigation of spatial relationships of the longitudinal axis of the kiln, axes of carrier tires and shell of the RK [3-5].

The first assumption for the data processing is that the real axis of RK is identical to the axis of the carrier tires. Carrier tires with radial rollers are the only carrier feature of the whole RK. They have a determining influence on the geometry of all other parts of the RK including its shell. The second assumption is that all points localized on the whole shell of RK should be in a constant distance from the longitudinal axis of the RK. These geometrical conditions were derived and assessed from point cloud obtained by TLS [6, 7]. The spatial 3D model in Trimble Realworks® software was used. Values of the radiuses of RK for ovality ratio calculation of the shell of RK in several cross-sections were intended.

Surveying equipment and data collection

For terrestrial laser scanning 6-inch circular planar HDS targets with tilt and turn options placed on a tripod were used as Ground Control Points (GCP). Four stations of the laser scanner Leica ScanStation C10 were used to survey the whole rotary kiln and related objects. The mean position error of separate point is $m_p = \pm 6$ mm, the precision of modelled surface is ± 2 mm. Other parameters of the used instrument are shown in its datasheet. All scans were mutually registered in the selected local coordinate system through GCP [8-10]. The accuracy of scan registration derived from resection residuals was less than 2 mm. As the most important parameter, the scan resolution for each scan was set to 10 mm for longest scanned distance 40 m. In data pre-processing phase the merged point cloud with overlapped scans was unified by spatial filtering to 10 mm resolution.

Longitudinal axis investigation

Centres of the carrier tires should be identical to the points on the nominal longitudinal axis of the kiln and the axis of the shell. As the selected RK undergoes regular inspections and rectification, it is assumed that the carrier tires are most reliable for the longitudinal axis of RK spatial determining. Points from the entire point cloud located on each of three carrier tires have been manually selected and saved to the partial point clouds. Approximated cylindrical solids were fitted through these points. Value of the fit root-mean-square deviation (RMSD) was 2 mm at each tire. Taking into account the configuration of instrument's station and the visibility of the measured object, tire A was approximated by 16 084 points, tire B by 76 542 points and tire C by 3 573 points (Figure 2). Parameters of fitting of the cylinders are shown in Table 1.

The longitudinal axis of the kiln was placed through the centres of outer tires A and C. Based on a comparison of the centre of the tire B and a corresponding point on investigated longitudinal axis a 2 mm deflection was detected. Longitudinal partial slope angle between A and B tires was found to be 3,529 % and between B and C tires 3,523 %. The linear regression was subsequently used to approximate the real longitudinal axis of the kiln with minimal corrections. The resulting value of

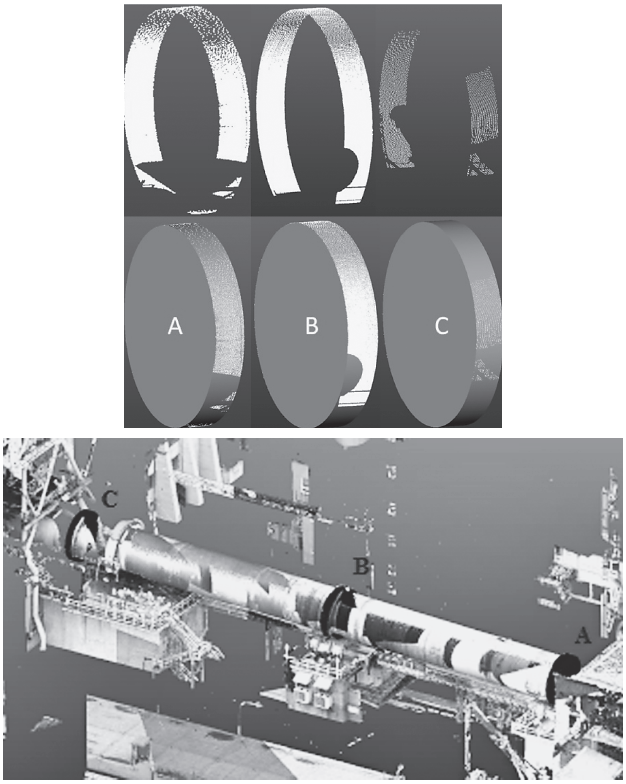

Figure 2 Carrier tires of the rotary kiln

the slope of the real longitudinal axis of the RK derived from the measurement is 3,526 % which shows the difference 0,026 % against nominal value 3,500 % and 0,016 % against previously realized measurements with axis slope value 3,510 %. Control parameter for the approximation accuracy of the point clouds by cylindrical solids was the verification of the slope of the cylinder against the resulting axis of the kiln. Slope values of this check are 3,53 %, 3,55 % and 3,56 % on the tires A, B and C. All these values provide a good confirmation of the initial assumption about the geometry of the longitudinal axis and the kiln slope.

Table 1 **Fitting of the cylinder - parameters**

Tire	Parameter	Value
A	Number of points	16 084
	Radius of tire	3,0315 m
	Cylinder fit RMSD	mm
	Direction of axis	0,999; - 0,001; 0,035
B	Number of points	76 542
	Radius of tire	3,0965 m
	Cylinder fit RMSD	2 mm
	Direction of axis	0,999; - 0,001; 0,036
C	Number of points	3 573
	Radius of tire	3,0525 m
	Cylinder fit RMSD	2 mm
	Direction of axis	0,999; 0,000; 0,036

Rotary kiln shell analysis of ovality ratio

Before further processing, the point cloud has been manually modified. Points except the points on the shell of RK were removed. This final point cloud was further assessed in Trimble Realworks® software. As part of a brief check, the cylinder was fitted through the final point cloud created by the previously performed manual selection. Its main geometric parameters were derived. They are shown in Table 2.

Based on the previous findings the nominal value of the outer radius for the entire RK was set to 2 540 mm. The reference cylinder with given radius was constructed (Figure 3). The longitudinal axis of the cylinder was identical with the examined longitudinal axis of the RK.

Table 2 **Comparison of final point clouds including only points on the shell of RK characteristics**

Parameter	Value
Number of points	2 963 072
Radius of RK	2,5395 m
Cylinder fit RMSD	mm
Direction of axis	0,999; - 0,001; 0,035

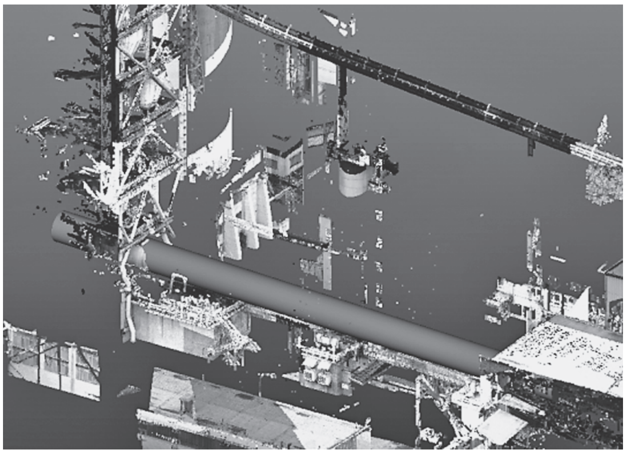

Figure 3 Cylinder with the nominal value of the radius

For this study the eleven centre graphs where the differences between radiuses of the nominal cylinder and real surface of the RK shell were shown graphically. Example of this graph is shown on Figure 4.

The red circle represents nominal cylinder; the green curve represents the real surface of the RK shell in this cross-section. Differences are triply amplified. The nominal and real centre of the RK shell are also showed. By combining of multiple cuts, the real longitudinal axis of whole RK can be investigated in longitudinal section form.

In the next procedure, the separate manually selected point clouds were compared with the nominal cylinder. The Realworks® software was used for this purpose.

Results are shown in comparative colored mesh on Figure 5, and projections onto a plane are shown on Figure 6.

The differences range of calculated radiuses of the RK shell in point cloud comparison with the nominal cylinder was in a range from - 40 mm to + 40 mm for the whole RK. Radiuses and ovality calculation was performed in 11 cross-sections. The maximum detected values of differences to the nominal cylinder in single crosscut were in the range from - 32 mm to + 30 mm. For these values, according to formula (1) the ovality ratio parameter was calculated as $\omega_0 = 2,44$ %. Average value of the ovality ratio detected in eleven created cross-sections is 1,868 %.

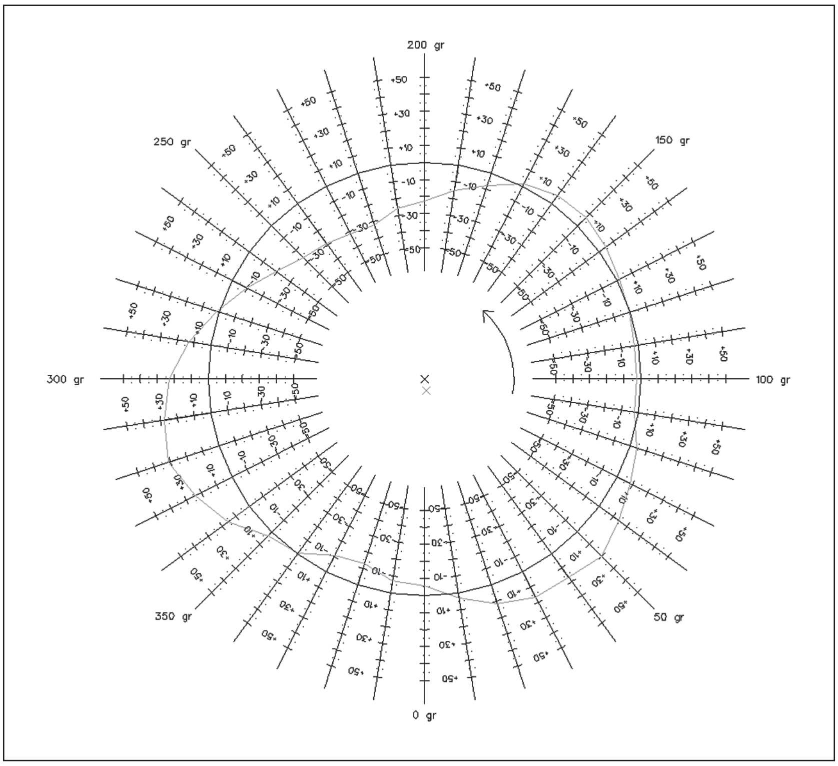

Figure 4 Center graphs - differences between radiuses of the nominal cylinder and real surface of the RK shell

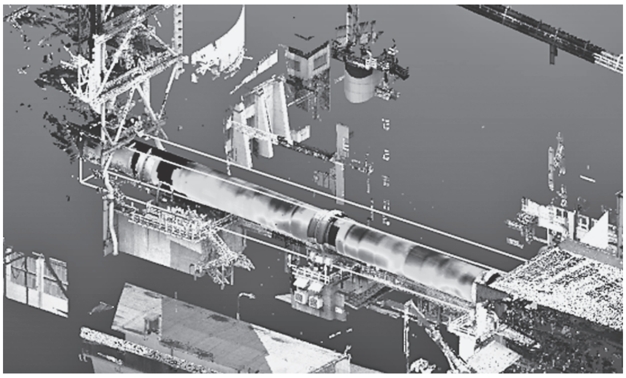

Figure 5 Comparative colored mesh

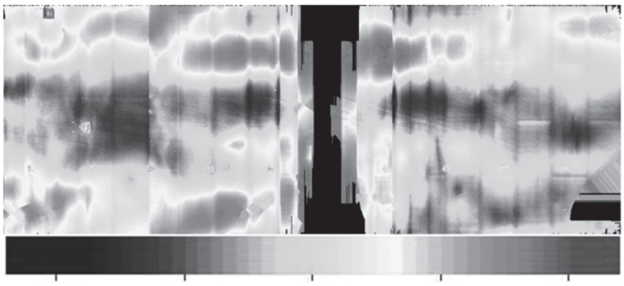

Figure 6 Shell of RK in flat mode

CONCLUSION

Determination of geometric parameters of the rotary kiln and their correction is a prerequisite for its correct, efficient and safe operation. The size and shape of the rotary kiln together with the spatial configuration and the possibility of deployment of the surveying instruments in the area are an important factor for the choice of methods of measurement and instrumentation. This article deals with the possibility and reliability of terrestrial laser scanning method for surveying of similar objects and indirect derivation of required parameters. TLS method is a fast, accurate and reliable method to acquire big amount of spatial data about the surveyed object. All in-situ TLS measurements of the selected RK were made within 5 hours. About 22 millions of points from 4 stations have been measured. It is also preferred, that the measurement can be performed safely from the station on the ground and also several mutually registered stations of scanners can be applied. Whole measurement was taken during a service shutdown of the RK in cold status. The advantage of this method in comparison with the traditional method of measurement is that there is no necessity of the sequential rotation of the RK. As a disadvantage of the TLS method, we consider especially the fact, that in most cases it is impossible to survey the entire body of RK (for example axes of radial rollers or the whole shell of the kiln) because of the complex shape of the RK and permanent obstacles.

TLS measurement is fast, but the data processing is significantly slower. The most time-consuming part in the data processing phase is the effort to remove the maximum number of unnecessary points and keep the maximum of the important ones for next processing. We were focused mainly on the investigation of carrier tires and their centres, the spatial position of the longitudinal axis of the RK, shell shape and its deformation difference values against the nominal status. The results obtained by the proposed work can be used for practical tasks related to the maintenance and reconstruction of the RK. The great advantage is the possibility to create sections perpendicular to the longitudinal axis of the kiln at any stationing. From these cross sections, kiln shell ovality can be derived, which is documented in the form of circular diagrams and eccentricity of the longitudinal axis of the furnace in the form of the longitudinal profile along the length of the RK.

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Note: The responsible translator for English language is RNDr. Ladislav Pivka, CSc., Institute of Computer technics, Technical University of Košice, Slovakia