CHECKING OF CRANE RAILS BY TERRESTRIAL LASER SCANNING TECHNOLOGY

Tomáš KŘEMEN[1], Bronislav KOSKA[1] and Jiří POSPÍŠIL[1]
Peter KYRINOVIČ[2], Jana HALIČKOVÁ and Alojz KOPÁČIK[2]

[1] *Department of Special Geodesy, Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic*
[2] *Department of Surveying, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovak Republic*

Abstract: Measuring crane rails is one of important applications in the engineering geodesy. At present, crane rails are most frequently measured with using theodolites, levelling instruments and total stations. Another possibility for measuring crane rails is using terrestrial laser scanning. Technology of the terrestrial laser scanning offers several advantages in comparison with commonly used processes. One of the most significant advantages is fast data collection and high density of the detailed points measured on the crane rails. Although this technology does not achieve such accuracy for the individual points as when using the exact classical procedures, the final accuracy of this method can be fully compared with the other methods thanks to the point density and knowledge of shape of the measured crane rails. The paper presents experimental using of the laser scanning technology for the static check of the crane rail placed in the engine room of the water power plant in Gabčíkovo (the Slovak Republic) with the Leica HDS 3000. The measured data are processed in the Cyclone software and in the PointClouder software by means of fitting geometric primitives. Accuracy of the final data is judged by the accuracy analysis and also by comparison with the results of the classical method. The results are compared with the allowable deviation stated in the ISO 12488-1 norm and the STN 73 5130 state norm.

1. GENERAL

Crane rails are big machine units. Safety of their operation is conditioned by keeping technical demands on their geometric parameters. Changes of geometric parameters stated in the project documentation arise not only during installation, but especially during operation of the crane rail. These changes are caused by various influences as forces affecting the crane when the crane is moving, crane weight, material depreciation, heat influences etc. To keep technical demands on operation of the crane rail it is necessary to carry out check of its geometric shape by geodetic means. Geometric shape of the crane rail is defined by tolerances for production, installation and operation of the crane rails stated in the ISO 12488-1 norm and the STN 73 5130 state norm.

These are the following geometric parameters of the crane rails:

- Span of the crane rails related to rail centre at each point of travelling track
- Horizontal straightness of rail head, in ground plan, at each point of travelling track
- Horizontal straightness related to test length of 2 metres in ground plan (sample value) at each point of rail head
- Straightness related to of height of crane rail centre at each point of travelling track
- Straightness related to test length of 2 metres at each point of height of crane rail

Geometric parameters of the crane rails have to fulfil tolerances stated in the above-mentioned norms. These are the following values of construction tolerance for the overhead travelling crane we measure; the projected span is 17,7 m and the overhead travelling crane belongs between travelling track of tolerance class 2 (ISO 12488-1):

- Tolerance of span S (valid for spans S >16 m) of the crane rails related to rail centre at each point of travelling track is:

$$\pm\left[5+0,25*\left(S-16\right)\right] \quad [\text{m}] \qquad (1)$$

For our crane rails is tolerance of span 5,5 mm.

- Tolerance of horizontal straightness of rail head is ± 10 mm
- Tolerance of horizontal straightness related to test length of 2 metres is 1 mm
- Tolerance of straightness related to of height of crane rail centre is ± 10 mm
- Tolerance of straightness related to test length of 2 metres of height is 2 mm

1.1. Characteristic of checked crane rails

Overhead travelling crane (fig. 1) is placed in the hall of the engine room of the Gabčíkovo water power plant. The steel hall consists of four independent dilated blocks with sizes of 60,5 m x 20,2 m. Each block is created by two turbines with a generator. The total size of the hall is 242,0 m x 20,2 m. The horizontal girders of the crane rail with rails are fixed on vertical columns situated in the distance of 14,6 m. The total length of the crane rail is 241,0 m and the projected span of the track is 17,7 m. Height of the top of the rail above the level of the hall floor is 6,5 m. Width of the rail is 85 mm.

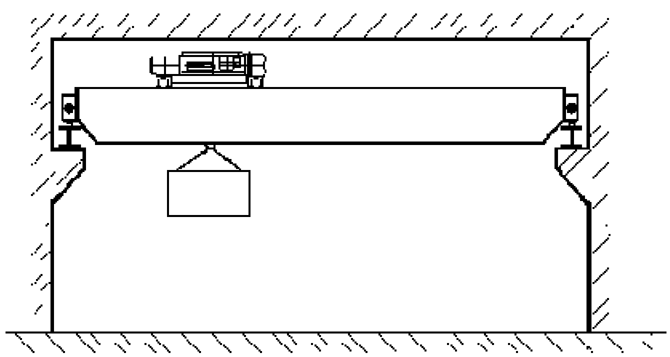

Figure 1- Overhead travelling crane

1.2. Experimental checking of overhead travelling crane

This article deals with possibilities of using the terrestrial scanning for measuring crane rails. As it was an experimental measuring that was supposed to verify whether and how exactly it is possible to measure rails of the crane rails with a terrestrial laser scanner, all rules valid for check of the geometric parameters of the crane rails were not followed during this measurement. The crane was not placed into the terminal position of the crane rails during measuring (the crane deck was used for placing the standpoints of the scanner). The line of sight parallel to the join of the endpoints of the longitudinal central line of the first rail and the secondary line of sight of the second rail were not signalized. For this reason, only coordinates of the points lying on the inner edges of the rail of the crane rails were obtained from the scanning and it was not possible to calculate the correct rectifications from them. Measurement by the classical geodetic method was used to determine rectifications of a part of the crane rail and to carry out comparison with results of the scanning.

2. MEASUREMENT WITH CLASSICAL METHOD

2.1. Measurement of direction and height deviations of the crane rail

The object of the check measurement was a part of the crane rail in the section of two blocks of the hall with length of approximately 106 m. The overhead crane was placed at the beginning of the crane rails during measuring, for this reason it was not possible to measure the whole rail.

The observed points were chosen in the stated transverse cuts in the place of the supports, in the middle between the supports and at dilatation of the rail. Position of points was set with a rail and marked in the middle of the rail width by means of the division clamps. The first observed point on the rail tape – point A1, or B1 and the last observed point of the rail tape – point A17, or B17 formed a reference system (fig. 2).

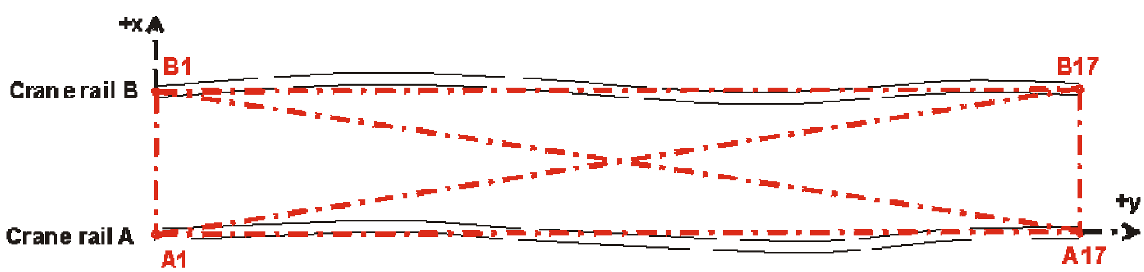

Figure 2 - Referential system of the crane rail

Both lines A1-A17 and B1-B17 are mutually interconnected with angle and length measurement on the endpoints of the line. So as to be able to compare directional and height course of the rails with the values determined by the laser scanning, the reference system was connected with reference points F1 to F6 (with reflection foils) placed on the carrying columns of the steel construction. Position of point B1 on side B was set on the central line of the rail of the side B in the perpendicular direction with respect to line of sight of the side A.

The position measurement was carried out with the Leica TCA 1101 total station ($\sigma_\omega = 3^{cc}$, $\sigma_d = 2+2ppm*d$) from the points of the reference system A1, A17, B1 a B17. The total station was placed directly on the rail and centred by means of the centring plate.

Position of the observed points was determined by the space polar method. The observed points were signalized with the Leica reflection miniprism. All observed points (A2 to A16) on the rail A were measured from standpoint A1 and all observed points (B2 to B16) on the rail B were measured from standpoint B1. Only position of observed points A8 to A16, or B8 to B16 was determined on standpoint A17, or B17. The sight passed closely above the level of the rail, near the supporting structure and walls of the object. The measurement on standpoints A17 a B17 was unfavourably affected by strong solar radiation, for this reason we decided not to measure more distant observed points.

The span was measured only at the beginning and at the end of the measured section of the rail (points A1-B1 and A17-B17) by means of the Leica TCA1101 total station.

Height course of the rails was determined by the geometric levelling with them Zeiss NI007 instrument, whereas the measurement was organized into a closed levelling polygon. Heights of the observed points were also determined by the trigonometric method on the basis of the measured zenith angle and length by means of the Leica TCA1101 total station.

2.2. Processing of measured data

Calculation of the standard deviation consisted of three steps:

- Estimation of coordinates of the reference and observed points,
- Estimation of coefficients of the regression line,
- Calculation of direction deviations

Coordinates of the reference and the observed points as well as of the reference points for the laser scanner (points F1 to F6), were determined by the least squares method. A local system of coordinates with the beginning in point A1 and orientation of axis „y“ into point A17 was chosen for the calculation. Coefficients of one regression line k and q were consequently estimated for both rails by the regression analysis method on the basis of the estimated coordinates. The regression line equation for both rails can be expressed from the following relations:

$$y_A = kx + q - \frac{R_{mean}}{2} \tag{2}$$

$$y_B = kx + q + \frac{R_{mean}}{2} \tag{3}$$

where k is direction of the estimated regression line,

q is shift,

R_{mean} is mean value of the crane rail span, calculated from the estimated coordinates of the points.

Values of rectifications were calculated as transverse deviations of the observed point from the regression line. By the stated procedure we achieved that both rails will fulfil after rectification one of the basic conditions that the axes of the rails have to be parallel to each other.

Only data measured from the levelling were used for determination of height. Heights determined by the trigonometric method were used only for purposes of check. Values of height determinations were calculated with respect to the observed point the height of which is the biggest (point B9) of all points of both rails.

2.3. Results

The calculated coordinates of the measured points of the rails are stated in Table 1. Values of rectifications are not stated, as they are not important for comparison of results obtained by the classical method and by the terrestrial laser scanning method.

Point number	Station [m]	Y [m]	X [m]	H [m]	Point number	Station [m]	Y [m]	X [m]	H [m]
A1	0	100	100	100	B1	0.000	100.000	117.700	100.006
A2	7.292	107.292	99.997	99.998	B2	7.281	107.281	117.700	99.999
A3	14.591	114.591	99.992	99.995	B3	14.577	114.577	117.696	100.001
A4	21.881	121.881	99.994	99.988	B4	21.874	121.874	117.698	99.993
A5	29.173	129.173	99.998	99.994	B5	29.179	129.179	117.695	100.001
A6	36.478	136.478	99.994	99.990	B6	36.477	136.477	117.695	100.004
A7	43.785	143.785	99.988	99.997	B7	43.772	143.772	117.698	100.006
A8	45.861	145.861	99.995	100.006	B8	45.851	145.851	117.696	100.009
A81	46.738	146.738	99.997	100.003	B81	46.677	146.677	117.697	100.007
A9	53.166	153.166	99.995	99.995	B9	53.146	153.146	117.694	100.001
A10	60.471	160.471	100.000	99.999	B10	60.455	160.455	117.693	100.005
A11	67.769	167.769	100.005	99.998	B11	67.753	167.753	117.701	100.001
A12	75.072	175.072	100.004	99.998	B12	75.057	175.057	117.703	100.003
A13	82.377	182.377	100.002	99.996	B13	82.351	182.351	117.702	100.001
A14	89.670	189.670	100.002	99.999	B14	89.662	189.662	117.702	100.002
A15	96.977	196.977	100.004	99.999	B15	96.955	196.955	117.699	99.999
A16	104.288	204.288	99.995	100.001	B16	104.255	204.255	117.699	100.005
A17	106.373	206.373	100.000	100.004	B17	106.387	206.387	117.702	100.003

Table 1- List of coordinates of the observed points of the rails

3. MEASUREMENT WITH LASER SCANNING TECHNOLOGY

3.1. Measurement

The measurement took place in the engine room of the Gabčíkovo water power plant in the working condition. As it was an experimental measurement, only 73 m long section of the crane rail situated in the second quarter of the total length of the rail was measured.

The Leica HDS3000 laser scanning system was used to measure the crane rail. The basic specifications of the Leica HDS3000 are: length standard deviation 4 mm, vertical and horizontal angle standard deviation 60 micro-radians (4 mgon), optimum working range 1 – 100 meters, track diameter 5 mm per 50 meters, measuring speed 4000 points per second.

The crane rail was measured from four standpoints. The first two standpoints were placed on the left (for rail B) and on the right (for rail A) edge of the crane, which was placed at the beginning of the measured section. After measuring the first two standpoints, the crane was moved 30 m forward. New two standpoints repeatedly placed on the left (for rail B) and on the right edge (for rail A) of the crane were measured from this new position of the crane. The standpoints were chosen so that position of the scanner were approximately two meters above the rail (the left rail was measured from the left standpoint, the right rail was measured from the right standpoint) and two meters from the rail axis in the direction of the centre of the crane (fig. 3).

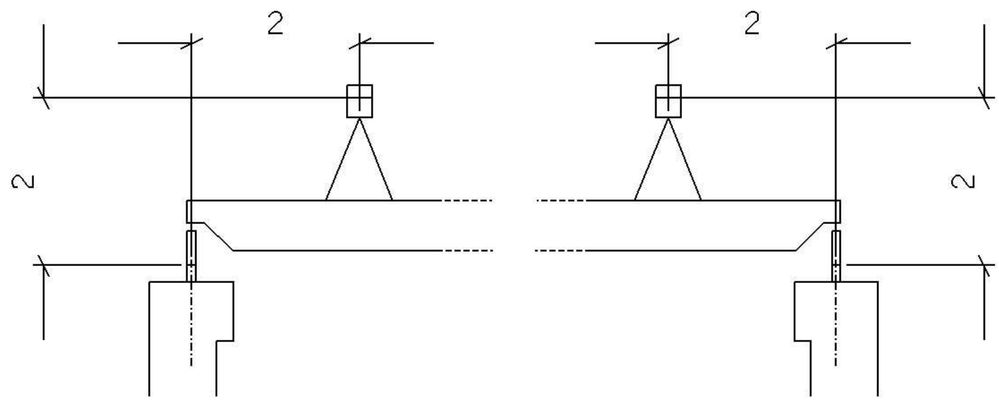

Figure 3 - Placing the standpoints on the crane

Approximately 50 m of the rail were measured from the first and from the second position of the crane. The total measured section of the crane rail was 80 m (30 m from the first position of the crane and 50 m from the second position of the crane, the measurements from both positions of the crane overlapped in the section in stationing 30 – 50 m). The rails were measured with several scans (11; 11; 15; 15 scans) on the individual standpoints. The scans differed from one another in the set scanning density. Scanning density was chosen so that the measured rail were covered with a sufficiently thick network of points even in the most distant place from the scanner.

3.2. Processing of measured data

The basic processing of the measured data took place in the Cyclone program and for check reasons in the PointClouder program. Registration of the individual measurements into one unit was carried out first. Six reference points were measured from each standpoint for these purposes. Absolute error mean of transformation for registration was 0,8 mm.

The next step was clearance of the result point cloud from noise, i.e. from needles points. The result of the clearance was a point cloud containing only points of the left and the right rail. A line passing through the inner edge, which represented the axis of the rail, was inserted into the cleaned cloud of rail B. The cleaned rails were segmented into one-meter sections in the stationing direction. 73 segments on each rail were obtained in total. The transverse cut through the rail is approximately of a square form with side of 85 mm. When evaluating the segment, one plane was fitted with a traverse surface and the other plane was fitted with the inner side wall of the rail. The obtained planes were lengthened to their intersection, through which a line was fitted. This line represented the inner traverse edge of the rail. 73 lines were modelled on each rail. In fig. 4 we can see the point cloud of rail B with the modelled inner edge.

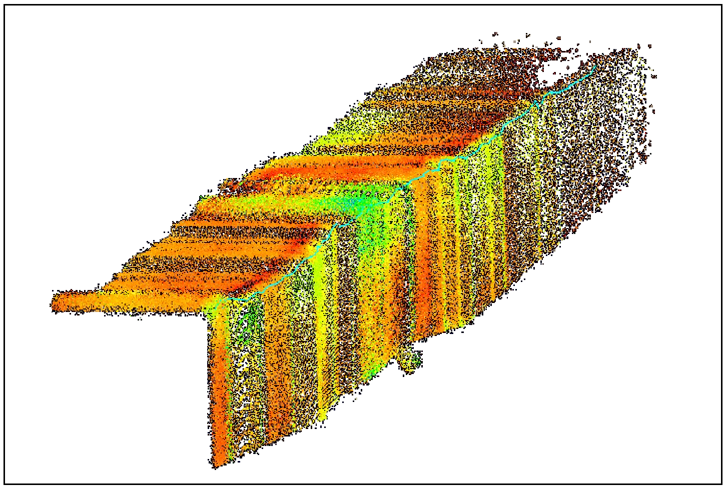

Figure 4 - Point cloud of the left rail with length 80 m with the modelled inner edge

Cuts perpendicular to the stationing direction were lead through the modelled inner edges. The cuts were lead in the stationing:

$$0,5 + (N - 1) \quad [\mathrm{m}] \tag{4}$$

where N is the segment number of the rail.

Points, which were used for the resulting evaluation of measuring the crane rail, were inserted into these cuts of the modelled lines.

3.3. Accuracy analysis

Accuracy analysis of determination of a point in the intersection of two planes was carried out to determine accuracy of evaluation of the crane rail. The third plane, which defines us a point in the intersection of the first two planes, is taken for error free. The library SpatFig was used for accuracy analysis.

Parameters and a covariance matrix of the first two planes were determined from the measured data. The complete law of mean error propagation was applied to these input quantities. Standard deviations of the determined point in directions of the coordinate axes σ_x = 0.07 mm and σ_z = 0.1 mm were calculated.

These standard deviations characterize inner measurement accuracy with the HDS 3000 scanning system. For the total accuracy it is necessary to think even of influence of transformation of the individual standpoints into one model. After including this influence, accuracy of the determined parameters of the crane rail was better than 1 mm.

3.4. Results

The ISO 12488-1 norm was used for evaluation of measured the crane rail. Crane rails span and horizontal and vertical course of rail B were evaluated.

In figure 5 we see a chart illustrating the crane rails span in the individual cuts and the projected span (for the inner edge of the rails).

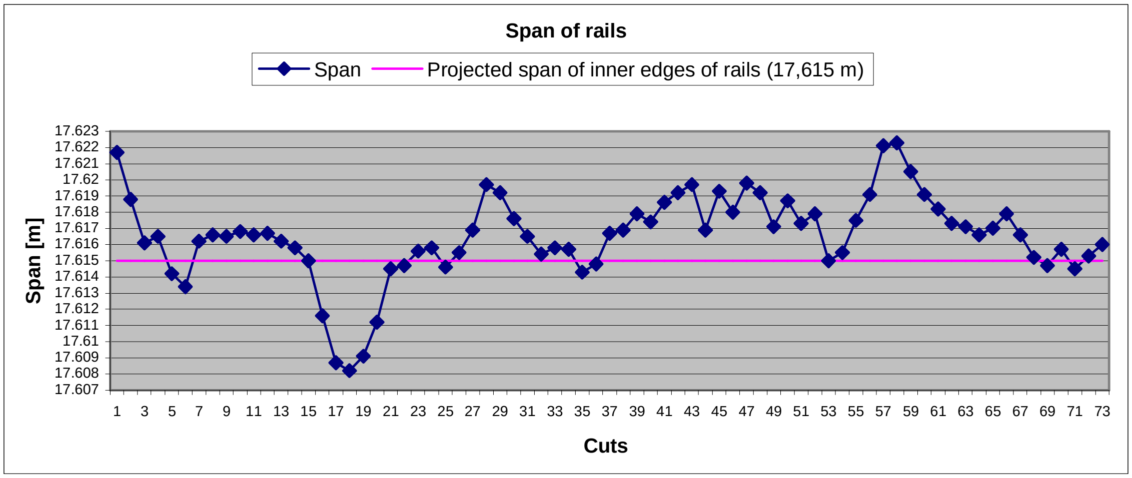

Figure 5 - Span of the crane rails

Figure 6 shows horizontal deviations of rail B in the individual cuts from the rail axis.

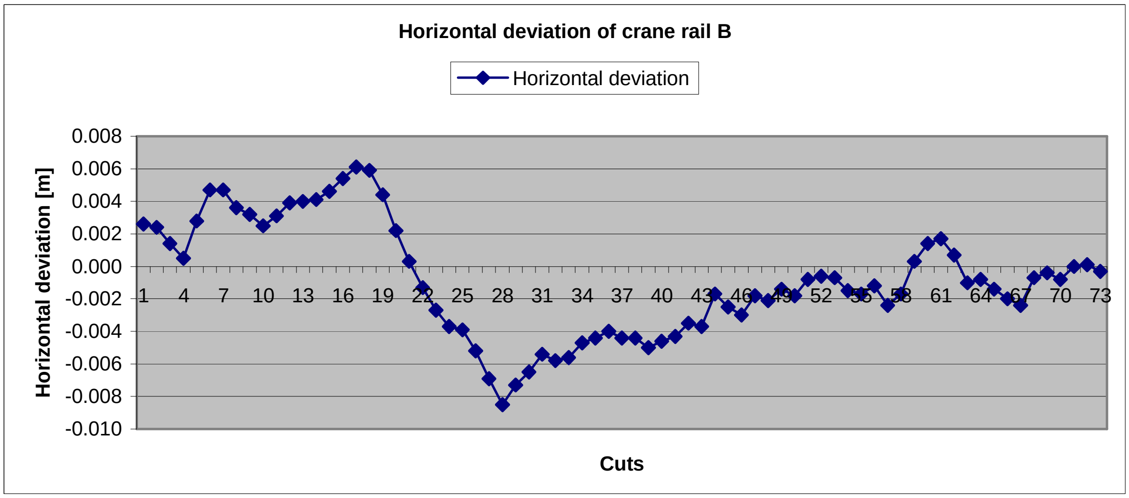

Figure 6 - Horizontal deviations of the crane rail B

Figure 7 shows vertical deviations of rail B in the individual cuts from the rail axis.

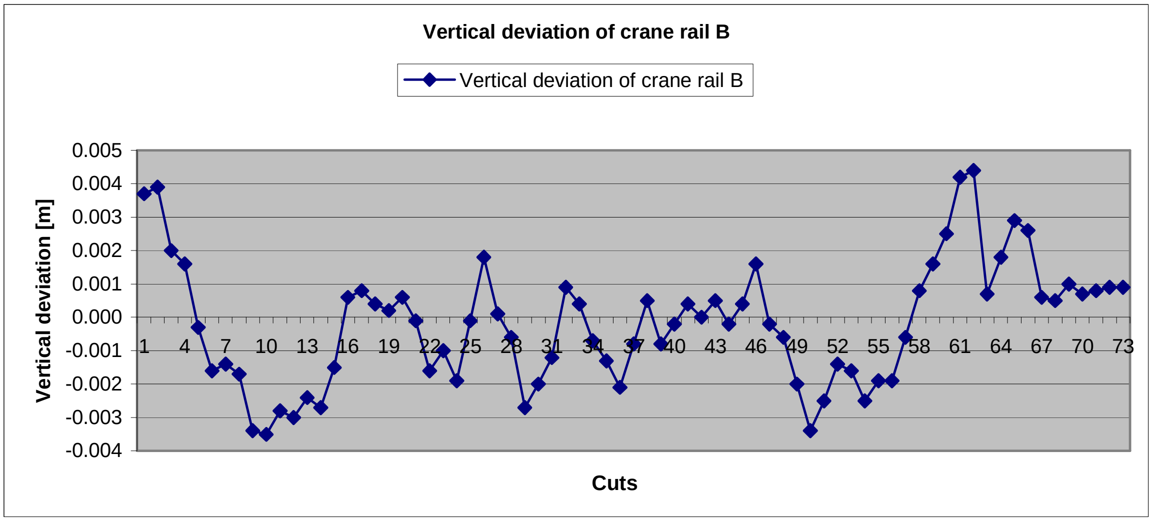

Figure 7 - Vertical deviation of the crane rail B

It implies from the stated charts that three observed parameters were exceeded: tolerance in the crane rail span, tolerance of horizontal straightness related to test length of 2 metres and tolerance of straightness related to test length of 2 metres of height.

4. COMPARISION BETWEEN CLASSICAL METHOD AND LASERSCANNING

In order to verify accuracy of the laser scanning, comparison of its results with results obtained by the classical method was carried out. Point coordinates of the rails determined by the classical method (see Table 1) were being compared with coordinates obtained from evaluation of the scanning system measurement. Table 2 shows results of this comparison.

Station	Span [m]	Δ S [m]	Rail A		Rail B	
			Δ H [m]	Δ X [m]	Δ H [m]	Δ X [m]
45.611	17.704	-0.003	-0.001	0.001	0.002	-0.001
46.611	17.702	-0.001	-0.002	-0.001	0.002	-0.002
52.611	17.702	-0.003	-0.002	-0.001	0.001	-0.003
53.611	17.702	-0.003	-0.001	-0.001	0.001	-0.004
60.612	17.694	-0.001	0.000	-0.002	0.001	-0.003
67.612	17.701	-0.006	0.000	0.000	0.000	-0.005
74.612	17.702	-0.002	-0.001	-0.003	0.001	-0.005
75.612	17.701	-0.001	-0.001	-0.005	-0.001	-0.005
82.612	17.703	-0.004	-0.002	-0.005	0.000	-0.007
89.612	17.703	-0.004	-0.001	-0.003	-0.001	-0.006
96.613	17.700	-0.005	0.001	-0.002	-0.001	-0.007
104.613	17.704	0.000	-0.001	-0.007	-0.001	-0.006
106.613	17.703	0.000	0.000	-0.006	0.001	-0.005
Average difference [m]		-0.003	-0.001	-0.003	0.000	-0.004
Standard deviation of measure differences [m]		0.003	0.001	0.003	0.001	0.005

Table 2 -Difference between classical measurement and laserscanning

Both measurements overlapped on an approximately 60 m section. 11 points determined by the classical method were situated on each rail in this section. Points evaluated from the measurement by the scanning system were assigned to these points so that the difference in stationing of the compared couples of points were as small as possible. 13 points were chosen from measurement with the scanner on each rail. As in the classical measurement the rail axis was placed in the middle of the rail head, whereas in the measurement with the scanner the axis was placed onto the inner edge of the rail, the obtained differences between both measurements were corrected by the difference in placing the axes. Differences in span of the rails Δ S, in height of the rails Δ H and in transverse position of the rails Δ X were determined. Average differences and standard deviations of measure differences were calculated from these results.

5. CONCLUSION

A laser scanning technology for purposes of checking geometric parameters of the crane rails was tested. The measured data were processed in the Cyclone a PointClouder programs. In order to judge accuracy of the obtained results, accuracy analysis with usage SpatFig library and comparison with classical measuring the crane rails with the total station were carried out. They showed comparable accuracy of the laser scanning with classical method. Measuring and procession time were also similar when compared with classical method. The experiment proved that it is possible to measure the rail of the crane rails with the terrestrial scanning system in big distance under a very steep angle of incidence. The main benefit of the tested technology was obtaining much more amount of data to be able to check geometric parameters of the crane rails than it is usually obtained by the classical method. The conducted experiment showed utility and suitability of the laser scanning technology for purpose of checking geometric parameters of the crane rails.

Acknowledgments

This research has been supported by grant GA ČR No. 103/06/0094 and by grant VEGA No. 1/3308/06 (Slovak Republic).

References

STN 73 5130 Crane rails. State norm

ISO 12488-1 Cranes – Tolerances for wheels and travel and traversing tracks.

Koska, B. - Štroner, M. - Pospíšil, J. (2005). *The Result Presentation of the Development of Laser and Optic Rotating Scanner LORS and Introduction of Public Library of Classes and Functions SPATFIG*. In: Optical 3-D Measurement Techniques. Wien: Vienna University of Technology.

Corresponding author contacts

Tomáš KŘEMEN
tomas.kremen@fsv.cvut.cz
Department of Special Geodesy, Faculty of Civil Engineering,
CTU in Prague, Czech Republic