System for Automatic Crane Measurement

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Key words: automated measurement system, crane rails, inductive transducer, robot station, crane rail position and geometry, Kalman filter

SUMMARY

The paper presents results of determination of the bridge crane rails (CR) with automated measurement system. The system consists of geodetic (robot station) and non-geodetic (electronic measurement systems) technologies. The robot station Leica TCA1101 (equipped with function LOCK and ATR), the three standard prisms for orientation and notebook are located on the floor and create the static part of the measurement system. Non-geodetic technologies - amplifier HBM Spider8, inductive transducers HBM WA100, terminal and connecting cables and 360° prism are attached to the moved part of the measurement system, which is drifted by a crane. Position of the 360° prism is determined by the 3D polar method from one or several instrument positions. All measured data from robot station are registered to the notebook. Two electronic (inductive) transducers are fixed to the moved part of the measurement system and determine the relative position of the rail to the prism centre in both vertical and transverse direction. The accuracy of the rail position depends on the accuracy of the prism position, of the system geometry and determination of electronic sensor position changes.

SUMMARY (German)

Im Beitrag sind die Ergebnisse der Messung der Krangleisgeometrie, die mit neuentwickeltem vollautomatischem Messsystem durchgeführt wurde, vorgestellt. Das System ist von geodätisches (Robotstation) und nicht-geodätisches (elektronischen) Messanteil aufgebaut. Das Leica TCA 1101 Robotstation (mit LOCK und ATR Funktionen), drei Prismen und Notebook sind am Boden positioniert und bildet das statisches Teil des Messsystems. Das nicht-geodätische Teil des Systems ist vom Datenregistriereinheit, von mehreren induktive Gebern HBM WA100, ein 360° Prismen, Terminal und Messkabeln zusammengestellt und am Kran lagert. Mit diesem ist das bewegliche Teil des Systems gebildet. Die Lage der 360° Prismen ist bei ein oder mehreren Robotstation und Verwendung der 3D polar Methode bestimmt. Die Messdaten sind am Notebook registriert. Die induktiven Geber sind für relativ Lagenbestimmung der Gleis (Lage zu 360° Reflektoren Zentrum) verwendet. Die Genauigkeit der Gleisposition ist von der Genauigkeit der Lagebestimmung der 360° Prismen und Genauigkeit der Geometrie des Messsystems abhängig.

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1. INTRODUCTION

Rail geometry assurance and performance of CR geometric parameters is an important factor for its reliability and safety. Obligation of regular inspection of CR is given by regulation (ISO 12488 and STN 73 5130), but without verification of parameters it is not possible to put the rail into operation.

Constantly increasing of demands for time measurement from the operation manager and demands for accuracy caused gradual elimination of geodetic instruments, which need surveyor's mechanical activity. Present process established on straight line of sight method and on geometric levelling with help of theodolite, shifted target, levelling instrument and rod are compensated by 3D polar method with instruments, which are based on electronic tachometer of higher precision. This mentioned process of parameter determination also needs personal movement on CR. In case of elevated crane rail (rails of crane are in certain elevation) is very important a question of safety of work in such height. Therefore it is necessary to stop working the crane during measurements.

New way of geometric parameter determination of CR comes out from integration of geodetic (robotic stations) and non-geodetic (electronic measurement systems) technologies into one unit. Automated measurement system working on cinematic methods allows doing measurements during crane operation. Effective time measurement, error elimination caused by surveyor during measurement, movement limitation and therefore increasing of personal safety on a crane rail during a control measurement are the main reasons of a suggestion and realization of automated measurement system for crane rail measuring.

2. MEASUREMENT SYSTEM DESCRIPTION

Automated measurement system (AMS) consists of the geodetic and non geodetic part, which are connected into one unit. The system is based on the kinematics method of measurement and enables to carry out the measurement during the crane operation (Kopáčik 1998 and Kyrinovič 2002). Measurement system consists of:

- robotic measurement station Leica TCA 1101,
- standard prisms,
- 360° prism,
- portable operative personal computer,
- measured amplifier HBM Spider8,
- inductive transducers HBM WA100,
- DC/AC power inverter (DC 12V to AC 230V, 50 Hz), auto battery DC 12V
- power, terminal and connecting cables.

The bearing structure of the measuring system (BSMS) made of dural is suggested to enable various settings of sensor positions concerning a crane rail. The structure consists of two U-shaped frames, which are connected to each other and armed by dural disks (Figure 1). The treatment of structure connections and connection of each structure parts by screws ensure sufficient stiffness of the whole structure. A part of structure is also a tetrad of appliances for positioning of the prism (two from the up and two from the side of structure) (Figure 2).

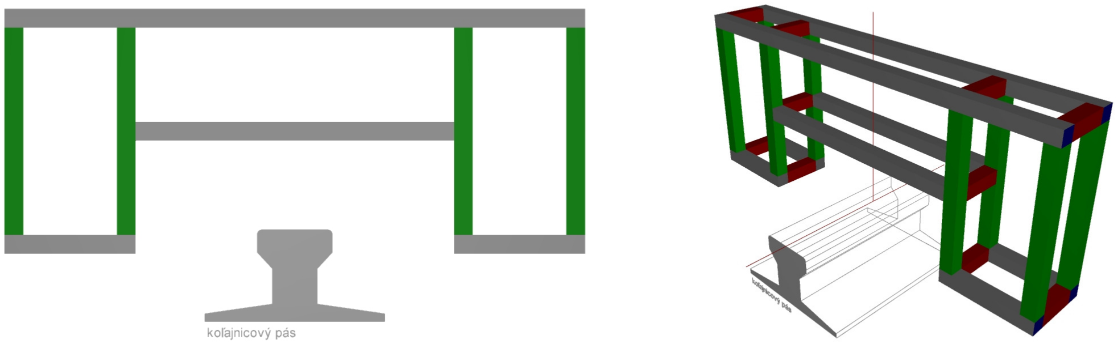


Figure 1 Design of bearing construction

The straight contact of inductive transducers tips with a rail is impossible because the contact area of rail stripes is not smooth and it can lead to the sensor damage. Therefore the sensors have to be attached on axis of press mechanism guide wheels, which enables continual contact of the wheel with a rail. In a frame there are two reference grooves for fixation and setting of the position of two individual structures of the pressure mechanism, of the reference wheel and the inductive sensor. The directional position setting of the vertical wheel (moving on the head of rail stripe) it is possible to change approximately in a range of 100 mm. The vertical setting of side pressure mechanism in a range of 150 mm is ensured by the movement of the structures in grooves as well as by the movement of the wheel axis (Figure 2). The shape of the bearing structures enables to situate the side reference wheel from the left side eventually from the right side. The displacement range of the pressure mechanism is ± 50 mm, this responds to a range of HBM WA100 distance sensor (HBM, 2004).

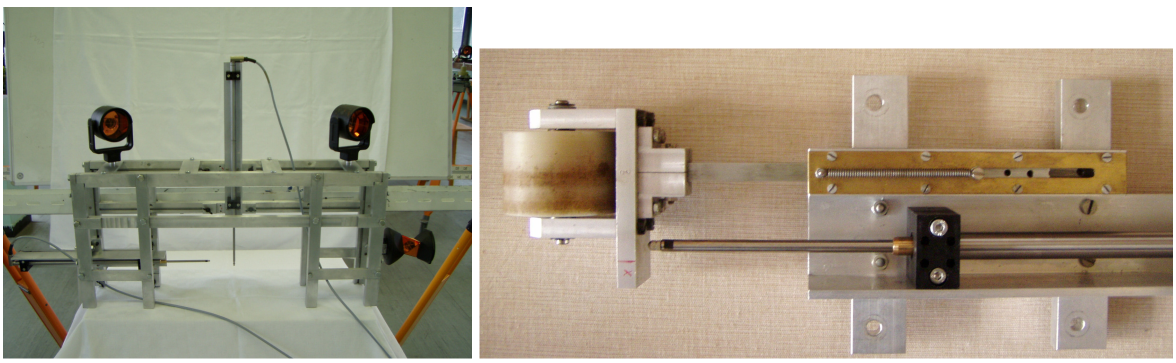


Figure 2 Bearing structure of the system (left)
and mechanism of vertical guide wheels with sensor (right)

The position of the wheel axis and centres of the prisms are suggested to sit in a one vertical plane. Sensors are fixated to the shifting structures with help of L-shaped dural profiles and assembling blocks. Edge of the L-profile ensures definite sensor position and at the same way protects the sensors against mechanical destruction. The spike of the sensor freely touches of the bottom part of the pressure mechanism. The measures of bearing construction are 0.638 m (length) x 0.320 m (height) x 0.129 m (width). Weight of construction inclusive of two guide wheels and 360° prism is 8.4 kg.

3. CALIBRATION OF THE BEARING STRUCTURE OF THE MEASURING SYSTEM

For calculation of 3D position of observed point on the rail stripe it is necessary to know the horizontal and vertical distances between the end points (contact points) of distance sensors (HZ1, HZ4 and V) and reference points (points 1 to 4) of the bearing structure.

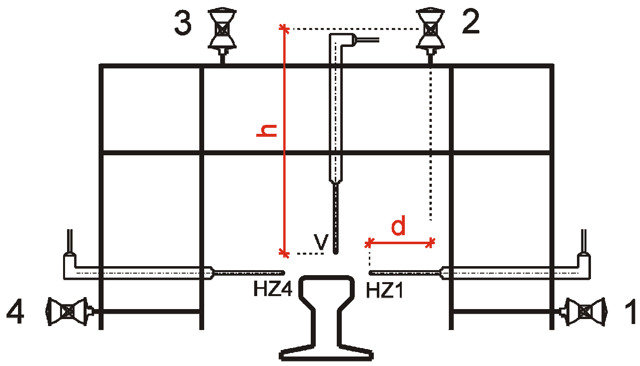


Figure 3 The horizontal and vertical distances of the contact and observed points

Reference points 1 to 4 are defined by the position of the prism. The system calibration consists from the determination of 3D coordinates of the reference points of the bearing structure and the contact points of the distance sensors in their zero position, fixed on the structures.

The position of the reference points was determined by the method of 3D intersection from three standpoints, made by Leica TCA 1101. The instrument standpoints (P4, P6 and P7) created a reference framework of triangular shaped, which centre was situated in the calibrated bearing structure (Figure 4). Distances between the standpoints (baselines) were determined by angle measurement made at the invar rod scale, which was situated against the given baselines. The calibrated structure was placed on the wooden pedestal and its stability was ensured with help of additional steel structure and the pair of tripods.

The coordinates of reference points were calculated by the Least Square Method (LSM) using the second linear processing model (2^{nd} LM) as well as non-covalence network. The accuracy of the 3D position of the observed points and the sensor contact points were from 0,4 mm to 0,5 mm.

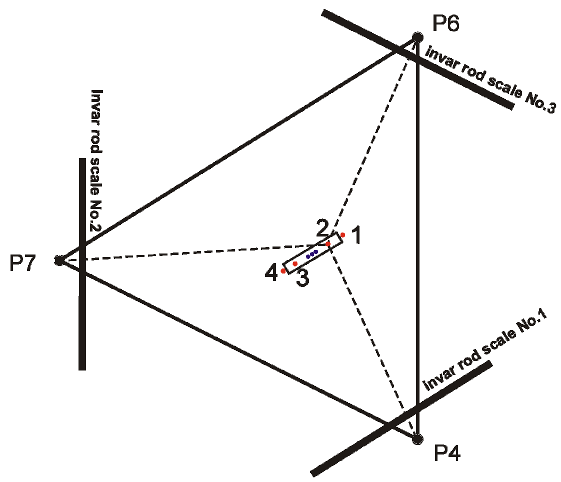


Figure 4 Calibration of the measurement system bearing structure in laboratory

4. THE PRINCIPLE OF THE CRANE RAIL PARAMETER DETERMINATION

The calculation principle of the 3D position determination of observed points on the rail stripe will be defined by following steps:

- determination of the reference framework position (X_{St}, Y_{St}, Z_{St}) – instrument standpoints,
- determination of the bearing structure orientation in space – determination of the position at least three points signed on the bearing structure (points 1 to 4),
- calculation of the angle α_{NK} and β_{NK} (Figure 5),
- determination of the position (X_P, Y_P, Z_P) of 360° prism, fixed on the bearing structure of the measuring system,
- determination of relative distances (changes) Δd and Δh between the observed points of the bearing structure (points 1 to 4) and the contact spike of the distance sensors in the horizontal and vertical direction.

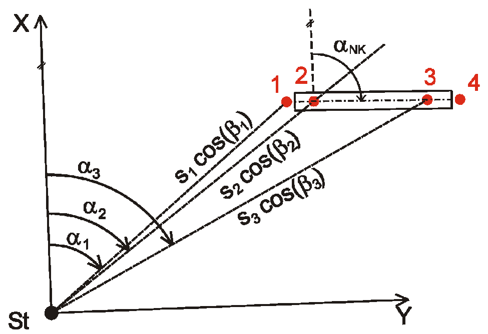


Figure 5 Determination of the bearing structure orientation in space

After the activation (start) of both systems before the crane movement, it has to be carried out the repeated position measurement of the prism (Fig. 6).

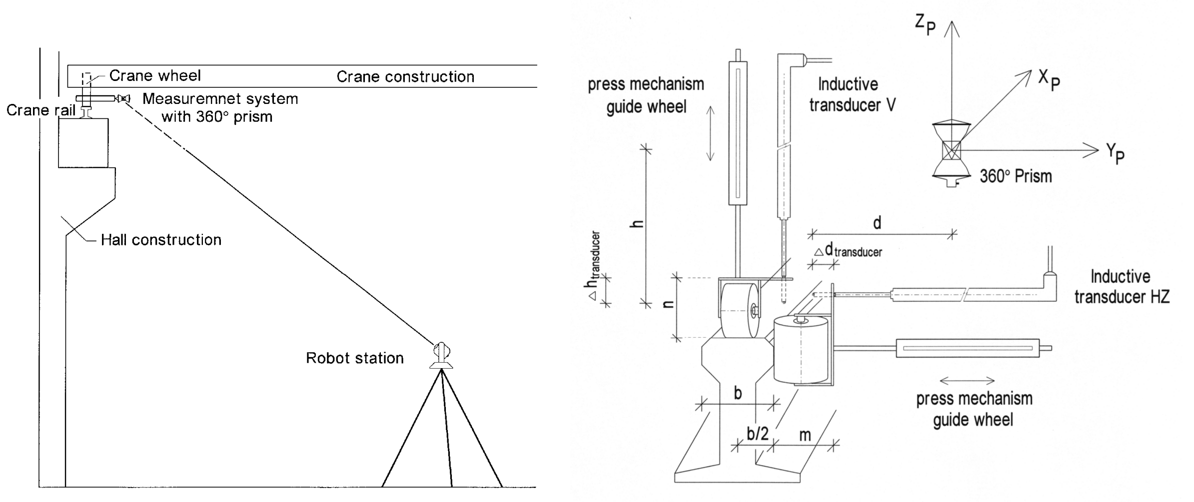


Figure 6 Determination of 3D position of the observed point

After the start of the crane movement a pressure begin to induct at an inductive transducer's output ratio to the position change of a transducer's tip. Measured data (Δd, Δh) are registered into the portable computer located on the moving crane. Data measured to the 360° prism (X_P, Y_P, Z_P) are registered into the portable computer. The data post-processing consists of connection of both files into one unit. Consequential the 3D position of the observed point is given on a base of Figure 6 by the following formulas:

$$X = X_{St} + s\cos(\beta)\cos(\alpha) + \left(d - \Delta d + m + \frac{b}{2}\right)\cos(\beta_{NK})\cos(\alpha_{NK}),$$

$$Y = Y_{St} + s\cos(\beta)\sin(\alpha) + \left(d - \Delta d + m + \frac{b}{2}\right)\cos(\beta_{NK})\sin(\alpha_{NK}), \qquad (2)$$

$$Z = Z_{St} + s\sin(\beta) - (h - \Delta h + n)\cos(\beta_{NK}),$$

where
- X, Y, Z are local 3D co-ordinates of the measured point on a rail,
- X_{St}, Y_{St}, Z_{St} are local 3D co-ordinates of the robot station,
- α, β are the horizontal orientation and the vertical angle,
- s is the slope distance between the observed point and the station,
- d, h are distances between the prism and the definite point of inductive transducer in their zero position in vertical and horizontal direction,
- Δd, Δh are distance changes in a vertical and horizontal direction,
- m is the width of the leading wheel,
- n is the high of the leading wheel,
- b is the width of the rail head (top),
- α_{NK} is the horizontal orientation of longitudinal axis of bearing construction,
- β_{NK} is the vertical angle of longitudinal axis of bearing construction.

5. THE EXAMPLE CRANE RAIL GEOMETRY DETERMINATION

The measured bridge crane rail is situated in the main building of the hydro-electric power plant in Gabčíkovo (Slovakia). It is a part of steel hall, which consist of four independent blocks. The whole dimension of the hall is 242,0 m x 20,2 m. The length of CR is 241,0 m, the designed gauge is 17,700 m and the height of the top of the rail stripe above the floor is 6,0 m. The width of the rail stripe is 85 mm. Lifting capacity of CR is 32 tons. (Figure 7).

Figure 7 Cross section of the hydro-electric power plant (left) and bridge crane rail (right)

Bearing construction of measuring system is fixed in the level of the rail stripe on the crane body through auxiliary steel construction (Figure 8). The aim of measurement was CR of the length of 106,4 m in area of the third and fourth blocks.

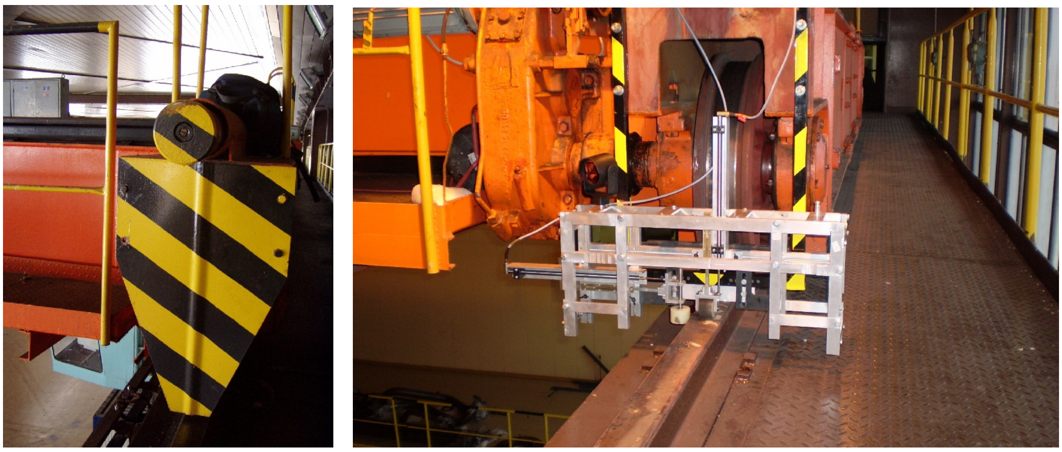


Figure 8 Fixation of BSMS on the crane construction

Standpoints of robot station (S1 to S4) are in the level of the machine hall floor in regard to the CR type, to the position of BSMS on the crane and to the request for visibility of the identical point during the whole measuring time.

Measurement of rail stripe relays has followed after determination of point position of three identical points from the given standpoint. Measuring process and processing of the measured data consist of the following steps:

- time synchronization of the registration equipments (personal computers),
- measured data registration from Leica TCA1101 and from HBM WA100 distance sensors,
- connection of the measured data – binding of the data from the distance sensors to the measured data from robot station on the base of time record,
- calculation of the 3D coordinates of measured points.

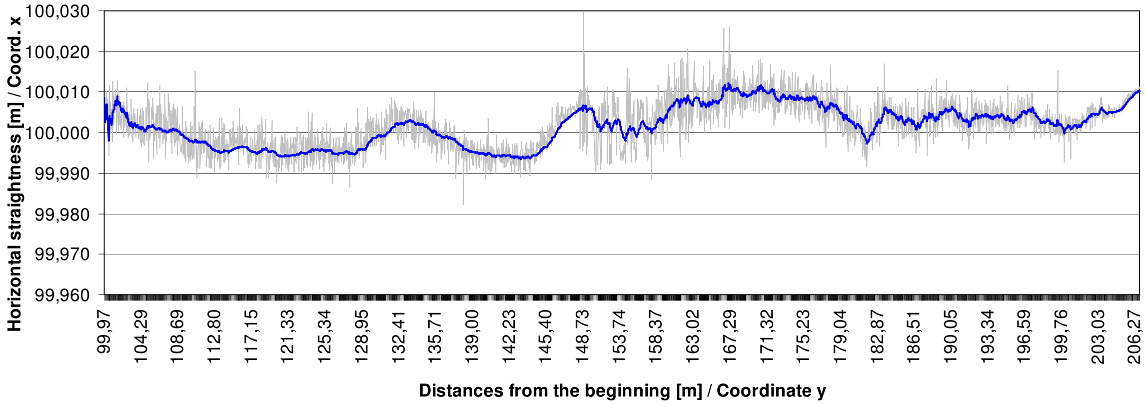
Configuration of the measurement system came out from the suggestion of the data registration only to the one personal computer to ensure time synchronization of measured data. On the base of the non-successful data connection and data transmission into the one personal computer we have decided to register data independently into the two personal computers but before the beginning of the measurement we have to realize time synchronization in the both PCs. Mentioned synchronization was realized with help of Simple Network Time Protocol (SNTP) on the web page of the Microsoft – *www.time.windows.com.*

3D coordinates x, y and z of observed points of the rail stripes are calculated according to the formula (2) and consequently they are connected into the one file for each rail stripe. File with coordinates of the rail stripe A consists of 2813 points and of the rail stripe B of 2672 points. Achieved accuracy of determination of spatial point position on the rail stripe σ_{xyz} is from 2.6 mm to 3.6 mm. The different number of points results at the first from the length inequality of measured relays as well as from the registration frequency of robot station and from the velocity of crane travel. The base characteristics of CR measurement are in the Table 1, where ΔSt_{mean} is average value of differences of distances of observed points from the beginning, Δt_{mean} is average value of the time differences of registration of robot station and v_{mean} is average value of velocity of crane travel. Average values are calculated as arithmetical mean of the all partly values of the distances from the beginning, of the times and of the velocities (Table 1).

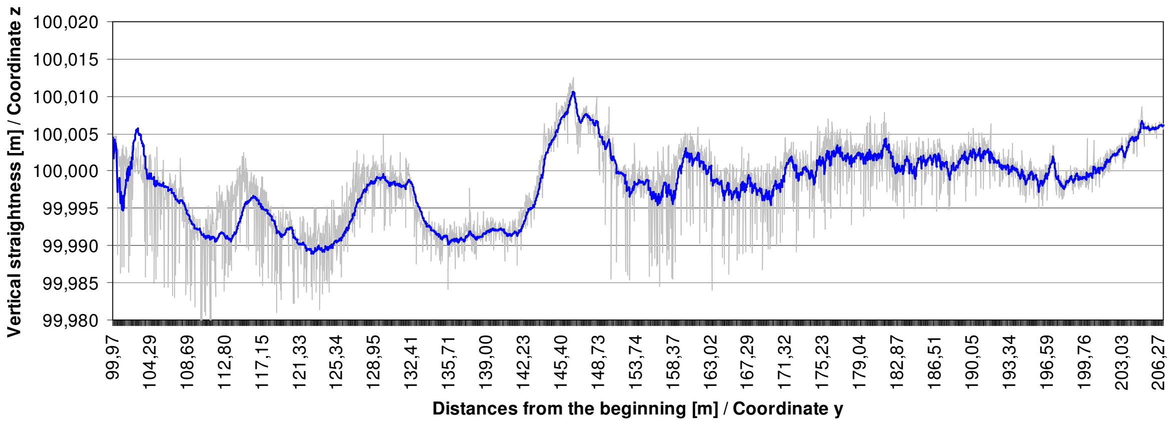
Table 1 Crane rail measuring characteristic

Crane rail	Part of crane rails	Length [m]	No. of points	Time [s]	ΔSt_{mean} [m]	Δt_{mean} [s]	v_{mean} [m/s]
A	A1	53.685	1352	585.0	0.037	0.4	0.084
	A2	58.373	1461	697.7	0.038	0.4	0.085
	A1 + A2	112.058	2813	1282.7	0.037	0.4	0.085
B	B1	51.673	1237	615.0	0.038	0.4	0.085
	B2	58.427	1435	696.4	0.038	0.4	0.085
	B1 + B2	110.100	2672	1311.4	0.038	0.4	0.085

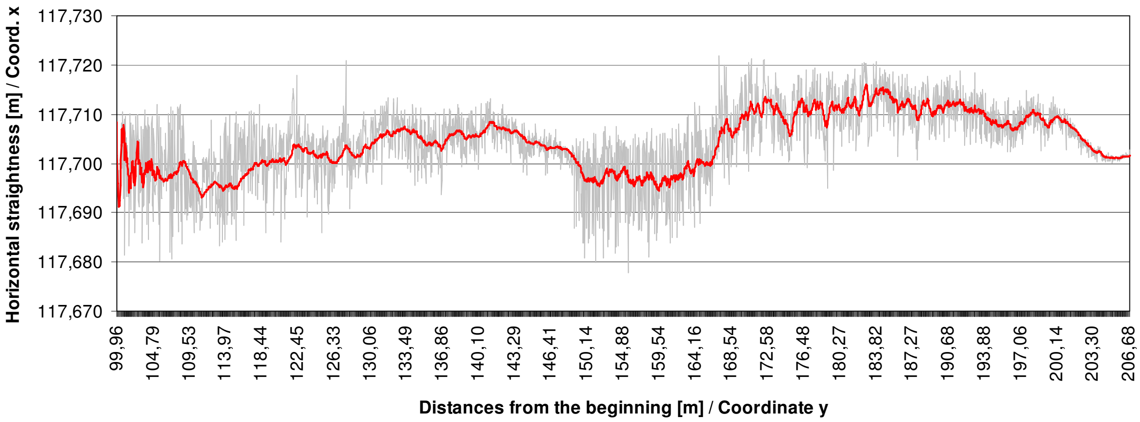
In the next were analysed the coordinates x and z to determine the horizontal and vertical straightness of rail stripes. Were estimated the parameters of trend (coefficient a, b) and cyclic part (coefficient c, d). Because of the huge file of values as well as signal noise in the file of the values were used for data analysis the Kalman filter (KF). The result of KF are the corrected coefficients of the transformation function a, b, c and d for horizontal and vertical straightness of the rail stripes of CR for each epoch and their mean errors. On the base of the coefficients were calculated the corrected coordinates x and z, which have no signal noise part. Presentation of the horizontal and vertical straightness of the rail stripe A and B are in the Graphs 1 to 4.



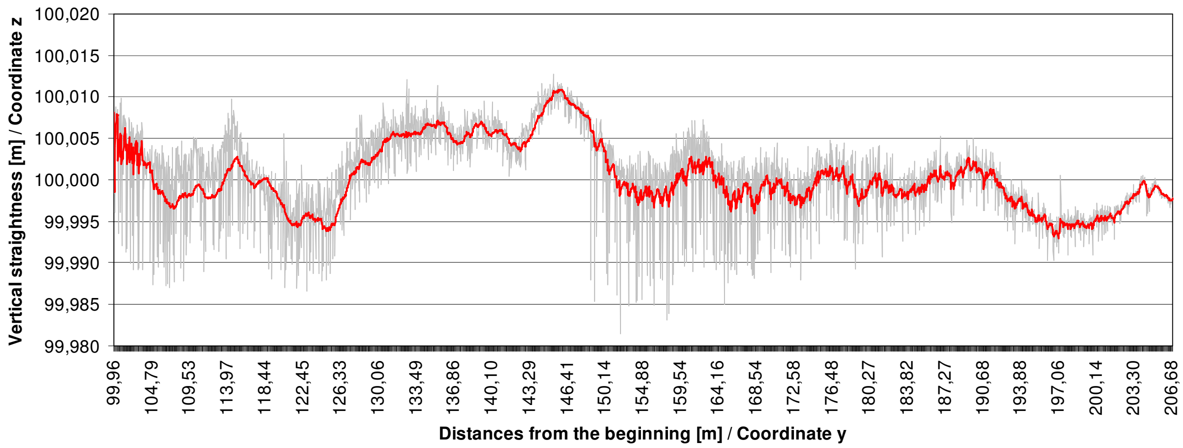
Graph 1 Horizontal straightness of the rail stripe A before (gray colour) and after KF (blue colour)



Graph 2 Vertical straightness of the rail stripe A before (gray colour) and after KF (blue colour)



Graph 3 Horizontal straightness of the rail stripe B before (gray colour) and after KF (red colour)



Graph 4 Vertical straightness of the rail stripe B before (gray colour) and after KF (red colour)

Using interpolation of coordinates x and z of the observed points we can describe the horiznotal and vertical straightness of the rail stripe in the random distance from the beginning of CR. The horizontal and vertical staightness of CR were determined by classical method (polar method and geometric levelling) before AMS testing. With comparison of the results achieved by classical method and by AMS can be appreciate if the suggested AMS is suitable for measurement of geometric parameters of CR. From coordinates and heights of observed points determined by classical method and by AMS were calculated the differences Δx and Δz and present graphically (Graph 5 and 6).

Graph 5 Horizontal straightness of the rail stripe B determined by AMS (blue colour) and by classical method (green colour)

Graph 5 Vertical straightness of the rail stripe B determined by AMS (red colour) and by classical method (green colour)

6. CONCLUSION

The crane rail with longitude of 106.4 m in the machine hall of Gabčíkovo water work is defined by 2700 observed points (rail stripe A) and by 2607 observed points (rail stripe B) with the mean value of relative distances from 37 mm to 38 mm between the points. The huge density of points characterizes the rail stripe also in that places which haven't been mention by classical methods yet. The results of measurements confirm that the horizontal and vertical straghtness of the stripe between two observed points determined by classical method is non-linear and cannot be approximated by line. The stripes show the local deformations which have to be taken into account by installation and rectification of crane rail.

AMS is able to determine the position and elevation of the stripe by the dynamic loading with help of the alone crane weight which is in the motion during the measurement. The valid standards and technologies haven't allowed this described situation before. The usage of developed system enables to eliminate motion of the measuring staff on the rail stripes. It means the strong step forwards in area of safety of measuring personal.

The achieved accuracy of determination of spatial point position on the crane stripe σ_{xyz} is from 2.6 mm to 3.6 mm. The parameters of used robot station, the type of reflected prism and their relative distance influence the accuracy of determination of point position. Distance sensors HBM WA100 give data with uncertainty of 0.1 mm.

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BIOGRAPHICAL NOTES

Peter Kyrinovič is Lecturer at the Slovak University of Technology Bratislava, Department of Surveying. Lectures from Engineering Geodesy, Underground Measurement and Field Courses on Engineering Surveying. Study Geodesy and Cartography SUT Bratislava 1993-1998. Publications in various journals and conference proceedings. Vice Chair of FIG C6 WG6.2 Engineering Surveys.

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Study Geodesy and Cartography SUT Bratislava 1977-82. Doctor studies at the Department of Surveying the SUT Bratislava in 1982-85. Senior lecturer 1985-1998, 1998-2004 Assoc. Professor, since 2004 Professor at the Department of Surveying. Lecture from Geodesy for CE, the Underground and Mine Surveying and Engineering Surveying, Measurement systems in engineering surveying and Surveying for Civil Engineering (in English).
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