AUTOMATED MEASUREMENT SYSTEM FOR CRANE RAIL GEOMETRY DETERMINATION

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Abstract

The paper presents results of the bridge crane rail (CR) geometry determination 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. The paper included the development of the system and the results of first application at 240 m long bridge crane which is situated in Power Station Gabčíkovo (Slovakia)

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

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.

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.

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 (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.

Connection scheme and reciprocal structure component arrangement of the system is illustrated on the Figure 1.

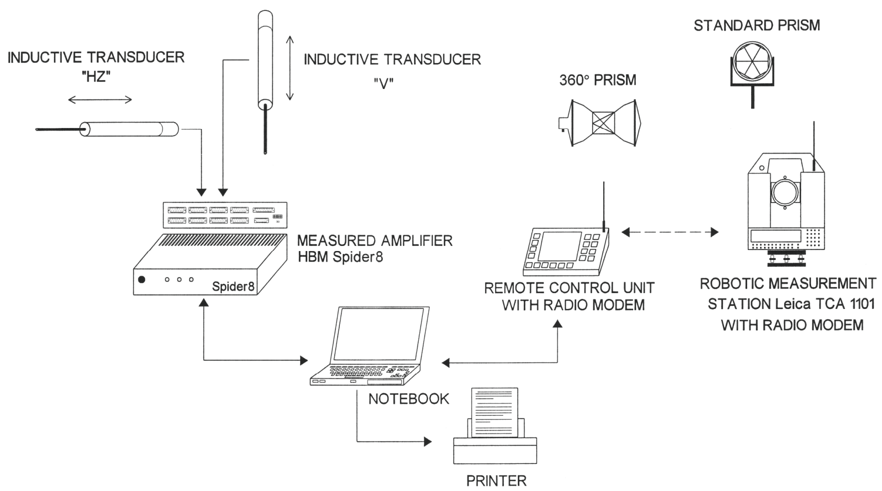


Figure 1: Connection scheme of the AMS

Inductive displacement transducer

Two HBM WA100 inductive transducers with 100 millimeters range and 80mV/V sensitivity determine the relative position or position changes (in vertical and transverse direction) of the top and the portable rail edge considering the middle of the prism (HBM 2004). The accuracy of position changes is given in order of 0,01 mm.

The sensor construction enables to determine a position changes only in one direction, which is defined by the longitudinal sensor axis. The sensors measure a distance change of the bearing structure and the crane stripe in a vertical direction (transducer “V”) and horizontal direction (transducer “HZ”). Output signal of inductive distance sensors is analogue voltage signal, which has to be enforced for the next data processing, digitalized through HBM Spider8 booster and consequently to redirect into PC for registration and next processing (Kopačik 1998).

Bearing structure of the measurement system

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 2). 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 4).

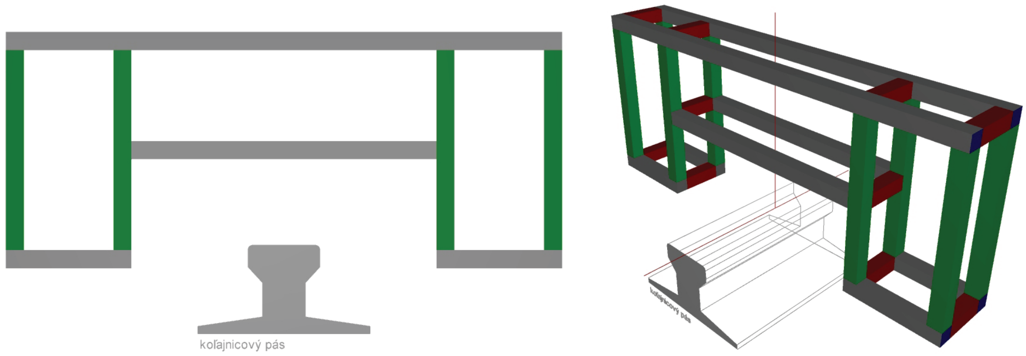


Figure 2 Design of bearing construction

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 (Figure 3). 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.

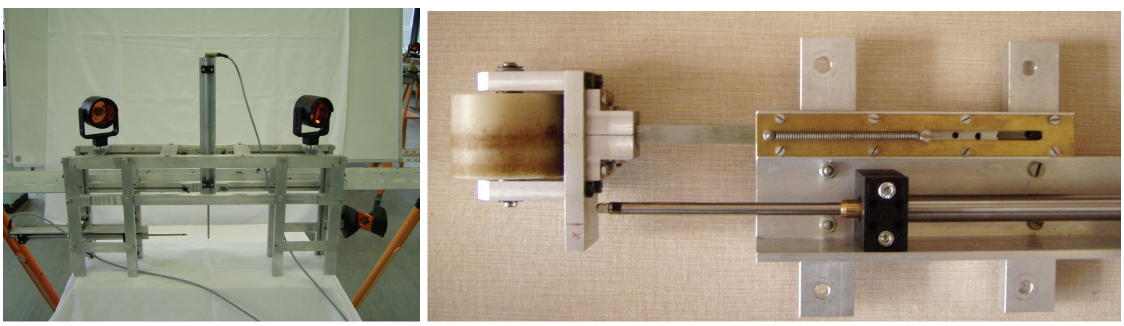


Figure 3 The bearing structure of the system (left)
and mechanism of vertical guide wheels with sensor (right)

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.

CALIBRATION OF THE MEASURING SYSTEM BEARING STRUCTURE

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 (contact) points of distance sensors (HZ1, HZ4 and V) and reference points of the bearing structure - points 1 to 4(Figure 4).

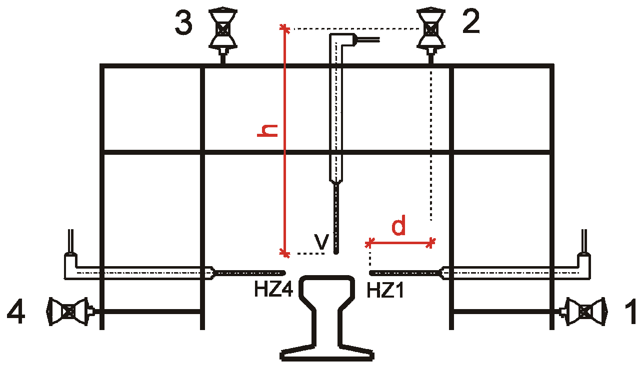


Figure 4 The horizontal and vertical distances of the contact and observed points

The system calibration consists from the determination of 3D coordinates of the reference points on 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.

The Cartesian coordinates of reference points were calculated by the Least Square Method (LSM) using the second linear processing model (2nd LM) as well as non-covalence network. The accuracy of the 3D position of the bearing structure reference points and the sensor contact points were from 0.4 to 0.5 mm.

Horizontal eventually vertical distances between the points 1 to 4 and the sensor contact points were calculated from the 3D coordinates of these points. Because there was not possible to rectify a bearing structure perfectly into the ideal horizontal position and to turn it parallel with one of the baseline before the measurement, it was necessary to carry out a transformation of 3D coordinates respecting the rotation angles ω, φ and κ. The 3D coordinates of the reference points were at first reduced to have an origin of coordinate system in the point 2 and consequently were transformed with help of the following formula

$$\boldsymbol{XYZ} = \boldsymbol{R}_{\omega}\boldsymbol{R}_{\varphi}\boldsymbol{R}_{\kappa}\ \boldsymbol{xyz}\,. \tag{1}$$

The rotation angles ω, φ and κ were calculated from the coordinates of points 1 to 4 of the bearing structure.

From transformed coordinates was calculated the horizontal and vertical displacement between points 1 to 4 as well as between the standpoints and the end (contact) points of distance sensors.

PRINCIPLE OF CRANE RAIL PARAMETER DETERMINATION

The calculation principle of the 3D position 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 points of the bearing structure (points 1 to 4) and the contact spike of the distance sensors in the horizontal and vertical direction.

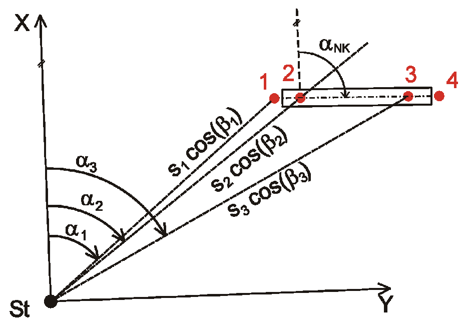


Figure 5 Determination of the bearing structure orientation in space

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).

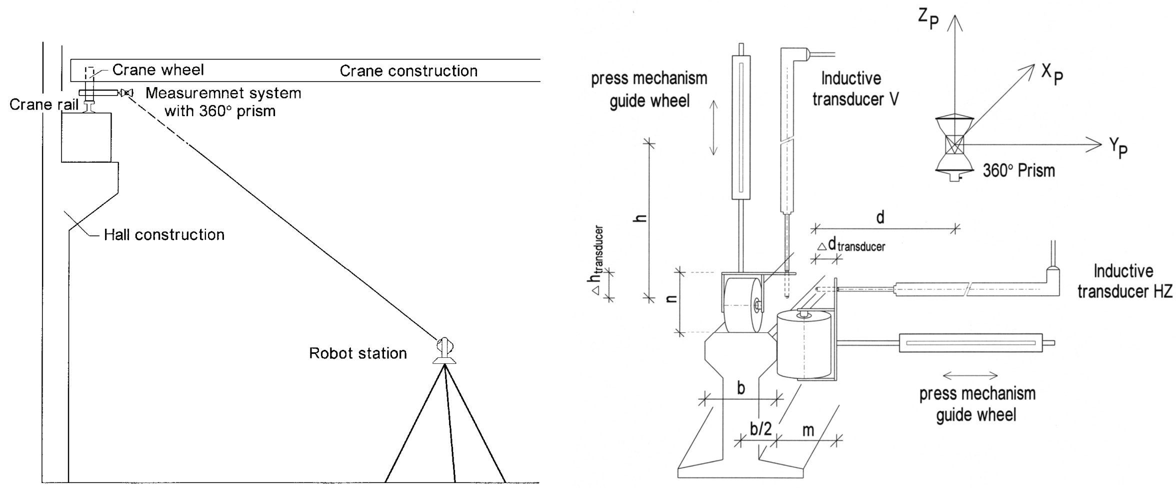


Figure 6 Determination of 3D position of the observed point

Because the crane is static, transducers of the trajectory don't show any change in a horizontal and vertical direction. 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_T, Y_T, H_T) 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:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_{St} \\ Y_{St} \\ Z_{St} \end{pmatrix} + s \begin{pmatrix} \cos(\beta)\cos(\alpha) \\ \cos(\beta)\sin(\alpha) \\ \sin(\beta) \end{pmatrix} + \cos(\beta_{NK}) \begin{pmatrix} \left(d - \Delta d + m + \frac{b}{2} \right) \cos(\alpha_{NK}) \\ \left(d - \Delta d + m + \frac{b}{2} \right) \sin(\alpha_{NK}) \\ h - \Delta h + n \end{pmatrix}, \tag{2}$$

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.

DETERMINATION OF BRIDGE CRANE RAILS

The 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. The height of the top of the rail stripe is above the floor is 6.0 m (Figure 7).

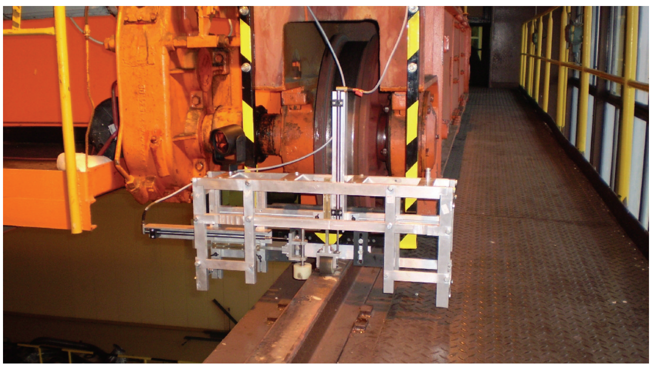


Figure 7 Bridge crane rail (left) and fixation of BSMS on the crane construction (right)

The width of the rail stripe is 85 mm. Lifting capacity of CR is 32 tons. Bearing construction of measuring system is fixed in the level of the rail stripe on the crane body through auxiliary steel construction. The aim of measurement was CR of the length of 106.4 m in area of the third and fourth blocks.

Point position of the base system is selected according to the parameters of the bridge CR. Standpoints of robot station (S1 to S4) are in the level of the floor in machine hall 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 (Figure 8).

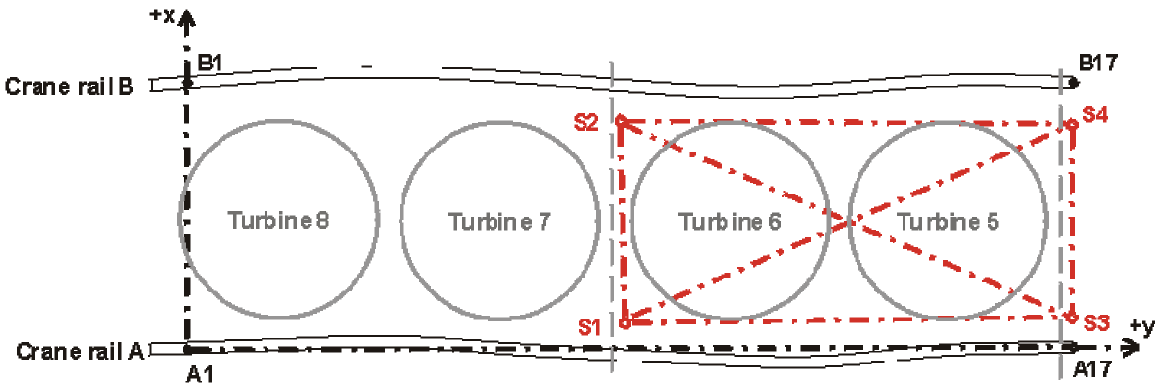


Figure 8 Base system configurations in the machine hall

From the points of the base system we determine the 3D position of the identical points No.1 to No.4. Measuring process of the identical points as well as observed points on the rail stripes is in the Table 1. The origin of the measurement was selected approximately 5 metres before the level of the observed point A1 eventually B1. Distance of the relay ending from the beginning is conditioned by the position of standpoints S1 to S4 of the base network.

Table 1 Measuring process and distance of measured relays of CR from the beginning

No. of measurement	Crane rail	Robot station	Observed points	Part of crane rails	Distance of observed points from the beginning [m]
1	A	S2	1, 2, 3	A1	-5.4 to 48.3
2		S4	1, 2, 3	A2	48.3 to 106.7
3	B	S1	2, 3, 4	B1	-4.4 to 48.3
4		S3	2, 3, 4	B2	48.3 to 106.7

Identical points of BSMS were signalized by Leica GPR121 prism as well as by 360° prism. Horizontal directions, zenith angles and slope distances were measured in the two ranks and all measured data were registered on robot station storage card. Inspection of the determination of the spatial orientation of the bearing construction of the measured system (inspection of the relative distance of the identical points) at the beginning of the each measuring series after fixation of the construction on the crane, we have realized as post-process by processing of measured data. From the coordinates and elevations of the identical points 2 and 3 we calculate the oriented angles α_{NK} and elevation angles β_{NK} of BSMS, which are used for calculation of 3D coordinates of the observed points on the rail stripes.

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 robot station 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 the time record,
- calculation of 3D coordinates of the points.

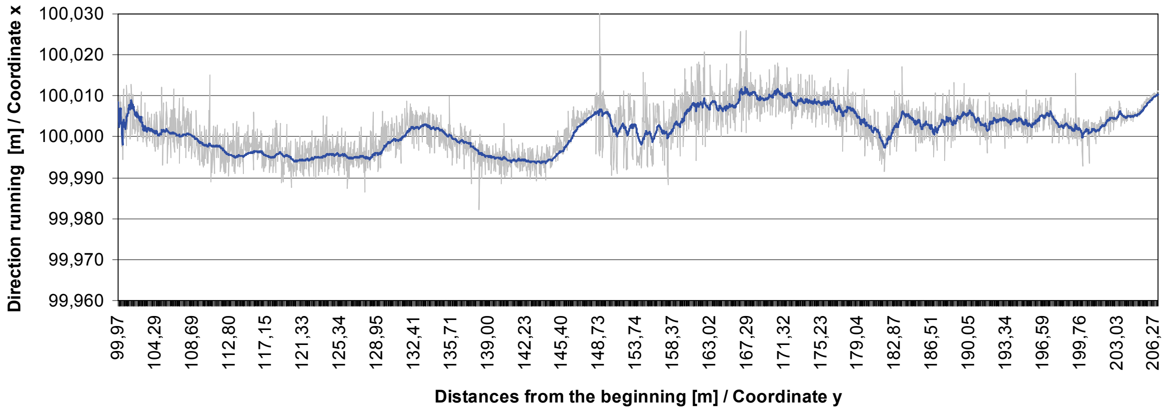
Configuration of the measurement system came out from the suggestion of the data registration only to the one personal computer to ensure time synchronization of measured data. On the base of the non-successful data connection and data transmission into the one personal computer we have decided to register 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). Coordinates are calculated independently for each measured relay (Table 1) 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 3D 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 relay measuring of CR are in the Table 2, 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 2).

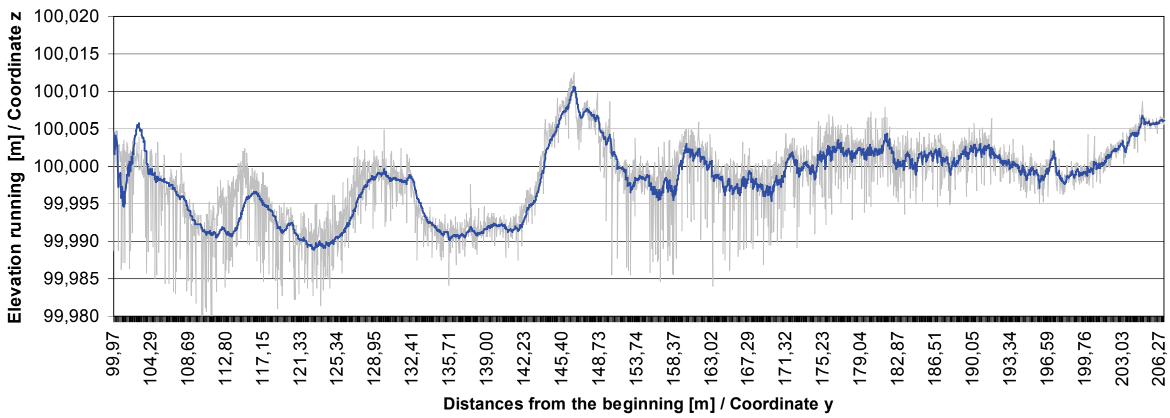
Table 2 Crane rail measuring characteristic

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

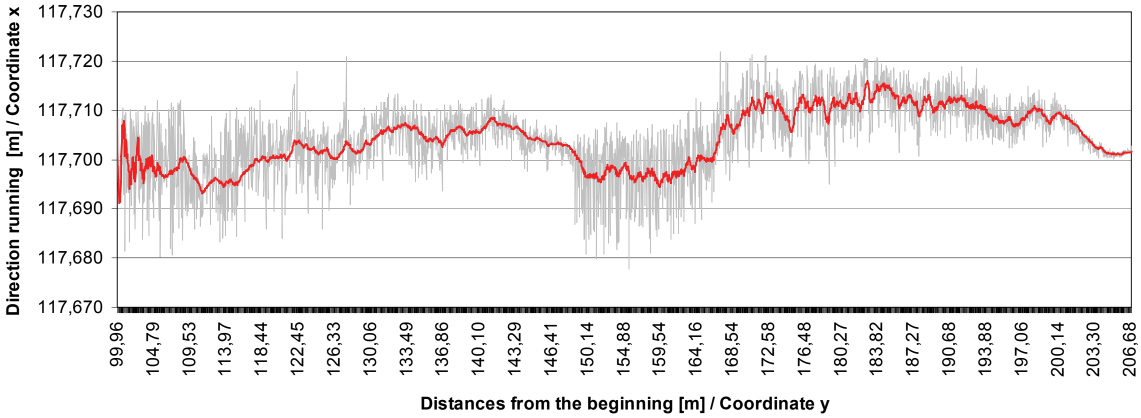
Next was made the analysis of coordinates of the direction running (coordinate *x*) and elevation running (coordinate *z*) of rail stripes. Were estimated the parameters of trend (coefficient *a*, *b*) and cyclic part (coefficient *c*, *d*). Because of the huge file of values as well as signal noise 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* of the direction and elevation running 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. Graphical presentation of direction and elevation running of the rail stripe A and B are in the Graphs 1 to 4.



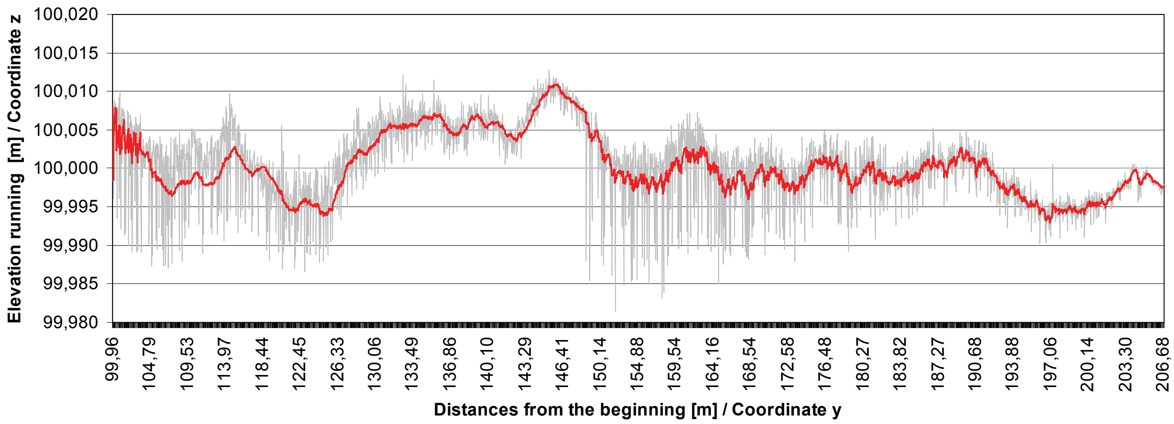
Graph 1 Direction running of the rail stripe A before (gray colour) and after Kalman filter (blue colour)



Graph 2 Elevation running of the rail stripe A before (gray colour) and after Kalman filter (blue colour)



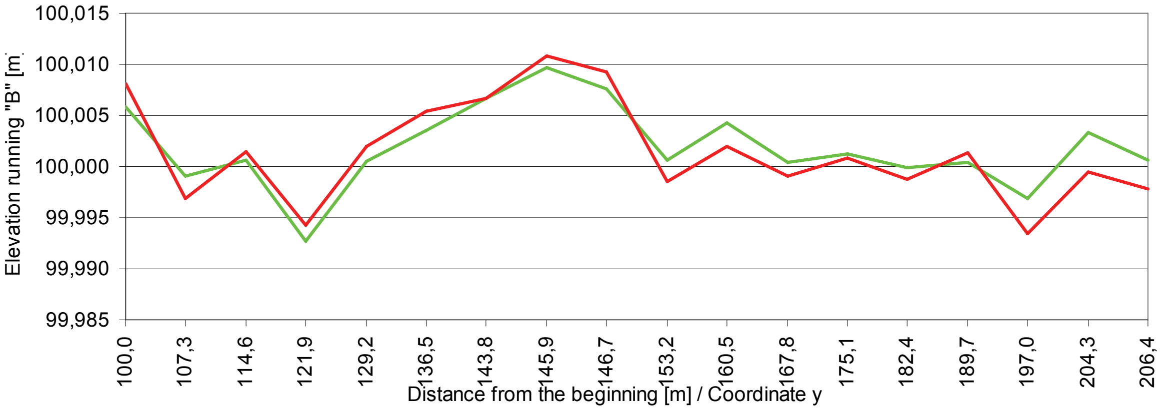
Graph 3 Direction running of the rail stripe B before (gray colour) and after Kalman filter (red colour)



Graph 4 Elevation running of the rail stripe B before (gray colour) and after Kalman filter (red colour)

Using interpolation of coordinates x and z of the observed points we can describe position and elevation of the rail stripe in the random distance from the beginning of CR. The direction and elevation running 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 could be appreciated if the suggested AMS is suitable for measurement of geometric parameters of CR. From coordinates and elevations of observed points determined by classical method and by AMS were calculated the differences Δx and Δz and are presented graphically the direction and elevation running of the rail stripes (Graph 5 and 6).

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



Graph 6 Elevation running of the rail stripe B determined by AMS (red colour) and by classical method (green colour)

CONCLUSIONS

The crane rail with distance 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 directional or elevation running of 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.

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.

Determination of geometric parameters of CR with help of AMS is despite of the huge number of observed points more effective from the time point of view in comparison to the classical measuring method. Practical knowledge from AMS testing shows that measurement of CR with length of 106.4 m takes maximum two or three hours. Into this time is involved also the time for preparation – localization of base point network, installation of BSMS, connection of components, registration setting from robot station and distance sensors, measurement of base point network and determination of 3D position of points and orientation of BSMS. Raw time which is necessary for measurement of one crane stripe is only from 20 to 25 minutes.

Also 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.

Last but not at least is important to mention that AMS enables to eliminate motion of measuring staff on the rail stripes. It means the strong step forwards in area of safety of measuring personals.

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