AUTOMATIC MEASUREMENT SYSTEM FOR CRANE MEASUREMENT

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Abstract: New way of geometric parameter determination of crane rails comes out from integration of geodetic (robot station) and non-geodetic (electronic measurement systems) technologies into one unit. The measuring system consists of robot station and remote control unit with the radio modem, standard and 360° reflecting prism, notebook, amplifier, inductive transducers, terminal and connecting cables. The robot station with the radio modem and the prism for orientation are located on the floor and create a static part of the measurement system. The 360° prism is attached to the moved part of the measurement system, which is drifted by a crane. The robot station is equipped with Automatic Target Tracking (LOCK) and Automatic Target Recognition (ATR). Position of the 360° prism is determined by the 3D polar method, dependent on the railway length from one or several instrument positions. The measured data (a horizontal direction, a vertical angle and a slope distance) are registered to the notebook. Electronic transducers are fixed to the moved part of the measurement system. Two inductive sensors with 100 mm range and 80mV/V sensitivity determine the relative position of the rail to the prism centre in both vertical and transverse direction. The analogue output signal is send to the measuring amplifier (Spider8 from Hottinger Baldwin Messtechnik (HBM) is used), filtered and transformed to digital data sets stored by the notebook. The data processing consists of the connection of both files into one and the rail position calculation. 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 relative position of the reflecting prism and the transducers (their definition points) are determined in laboratory with accuracy of 0,5 mm.

1. Measurement system description

Measurement system consists of the geodetic and non geodetic part, which are connected into one unit. The system based on kinematics method of measurement and enables to carry out the measurement during the crane operation [1].

Measurement system consists of:

- robotic measurement station Leica TCA 1101 with a radio modem and remote control unit,
- standard prism,
- 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.

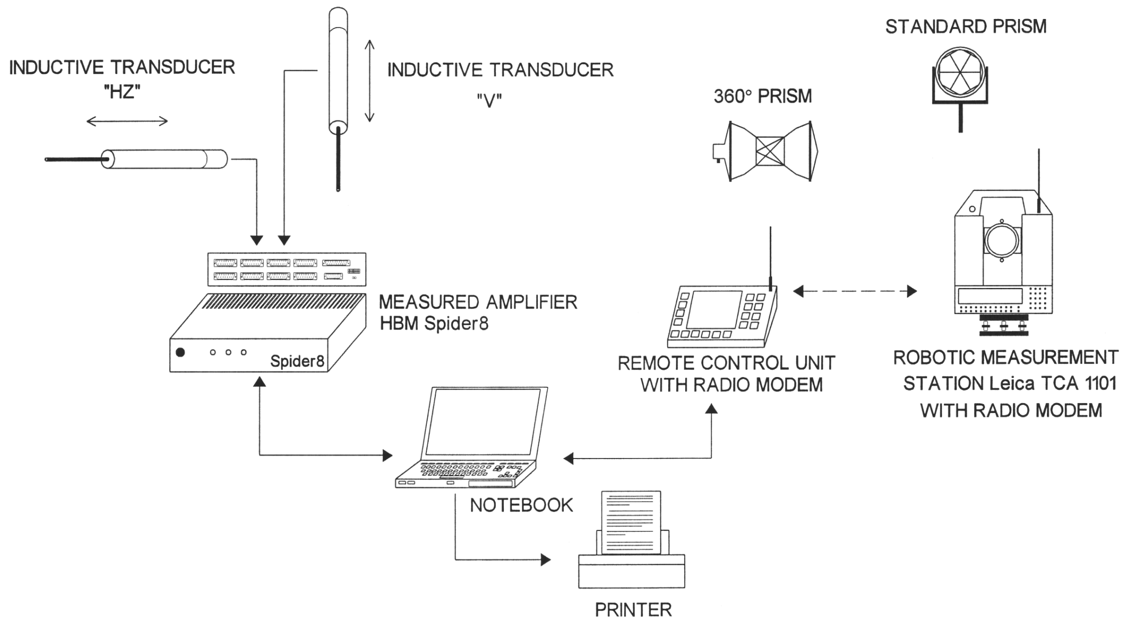

Figure 1. Connection scheme of the measurement system

2. 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 [2]. The accuracy of position changes is given in order of 0,01 mm (Fig. 2).

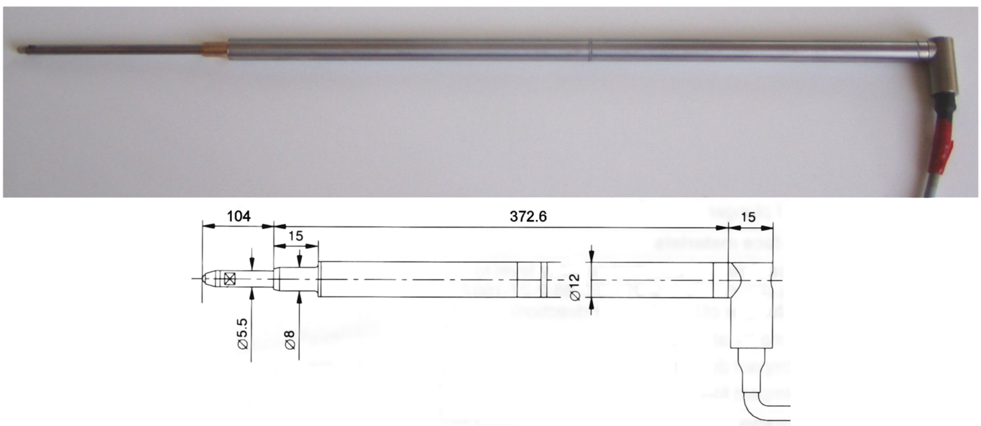

Figure 2. HBM WA100 inductive transducers

The sensor construction enables to determine a position changes only in one direction, which is defined by the longitudinal sensor axis. For determination of positional, eventually spatial changes of the position, is necessary to use two or three independent sensors, which are situated perpendicular to each other. 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 [3].

3. Measurement system structure

The bearing structure of the measuring system 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 connecting to each other and armed by dural disks. 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).

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 continued 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 elevation 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 (Fig. 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.

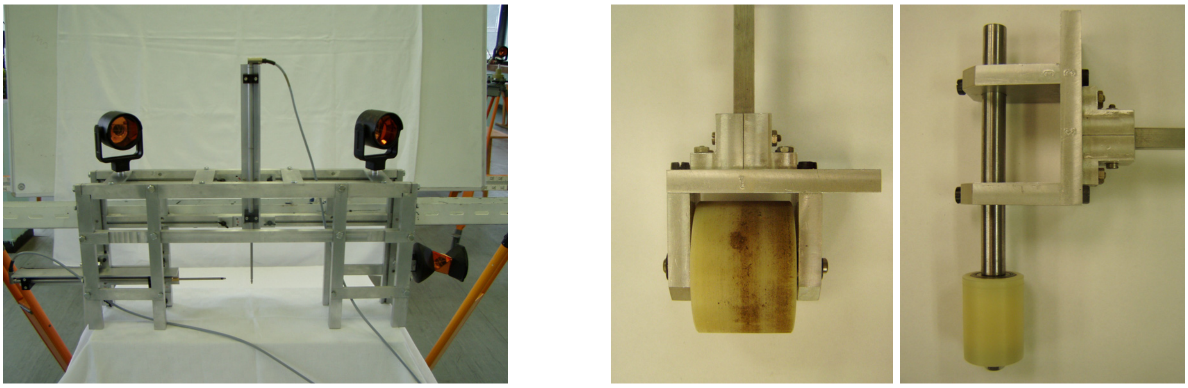

Figure 3. The bearing structure of the system (left) and mechanism of vertical guide wheels (middle) and horizontal guide wheels (right)

The position of the wheel axis and centres of the prisms is 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 the same way protect the sensors against mechanical destruction. The spike of the sensor freely touches of the bottom part of the pressure mechanism (Fig. 4).


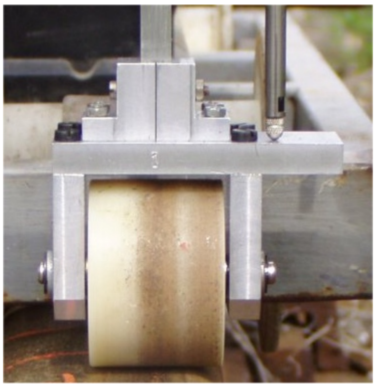

Figure 4. The WA100 sensor protection

4. Calibration of the bearing structure of the measuring system

For calculation of spatial 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 and observed points of the bearing structure (points 1 to 4). Observed points 1 to 4 are defined by the position of the prism. The system calibration consists from the determination of spatial coordinates of the observed points on the bearing structure and the contact points of the distance sensors in their zero position, fixed on the structures.

Measurement was carried out in a laboratory of the Department of Surveying of the SUT in Bratislava. The position of observed points was determined by the method of spatial intersection from four standpoints, made by Leica TCA 1101. The instrument standpoints (1001 to 1004) created a reference framework of quadrilateral shaped, which centre was situated the calibrated bearing structure (Fig. 5). Distances between the reference points (baselines) were determined by angle measurement made at the invar rod scale, which was situated against a 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.

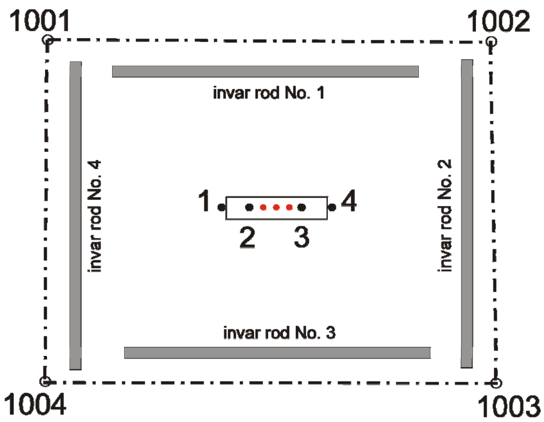

Figure 5. Calibration of bearing structure of measurement system in laboratory (reference points 1001 to 1004, observed points 1 to 4 – black circles, contact points of sensors in a zero position – red circles)

The instrument standpoints 1001 to 1003 (reference points) were stabilized by pillars with the forced centring. The last standpoint (1004) was stabilized by the heavy tripod because of the missing pillar in the given schema. Selection of a reference framework enables the relative visibility of all reference points as well as observed points from the standpoints. Position of the reference and the observed points was signalised by Leica prisms. The position of sensors contact points was presented by the extension with steel spikes of conical shape. Measured data were processed as two stage network. In the first stage were determined the accuracy characteristics of the first and second order of the reference points and consequently in the second stage the accuracy characteristics of observed points of the bearing structure and the distance sensors.

The Cartesian 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 spatial position of the observed points and the sensor contact points were from 0,4 to 0,5 mm.

Horizontal eventually vertical distances between the observed points 1 to 4 and the sensor contact points were calculated from the spatial coordinates of the observed points. Because there was not possible to rectify a bearing structure perfectly into the an 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 spatial coordinates respecting the rotation angles ω, φ and κ. The spatial coordinates of the observed 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 observed points 1 to 4 of the bearing structure.

5. Crane rail parameter determination

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

- determination of the reference framework position (X_S, Y_S, Z_S) – instrument standpoints),
- determination of the bearing structure orientation in space – determination of the position at least three observed points signed on the bearing structure (points 1 to 4),
- calculation of the twist angle ω,
- 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.

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). 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 with help of remote control unit and the radio modem into the portable computer.

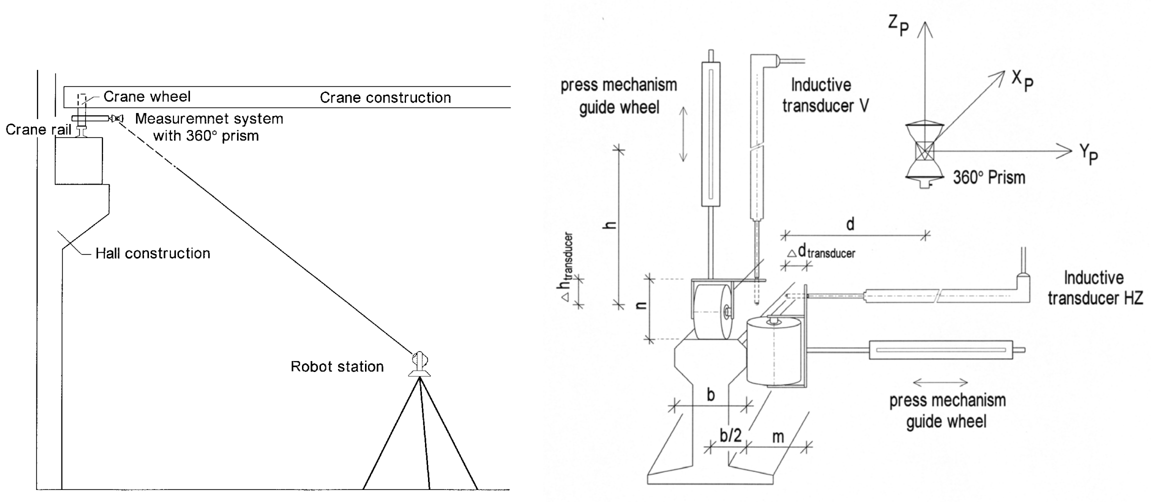

Figure 6. Determination of 3D position of the observed point

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 (Fig. 7):

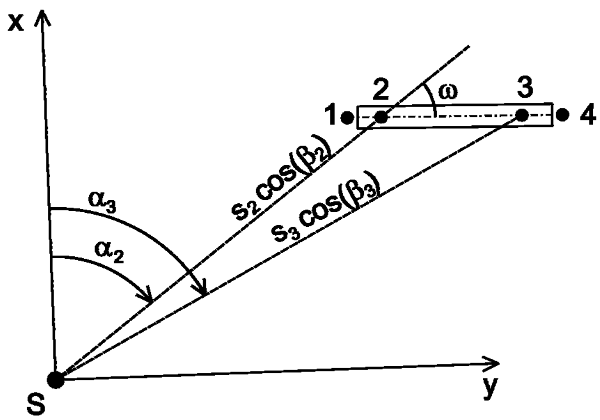

Figure 7. Determination of the 3D position of observed point

$$X = X_{St} + s\cos(\beta)\cos(\alpha) + (d - \Delta d + m + \frac{b}{2})\cos(\alpha + \omega),$$

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

$$H = H_{St} + s\sin(\beta) - h - \Delta h + n,$$

where
- X, Y, Z are local 3D co-ordinates of the measured point on a rail,
- X_{St}, Y_{St}, H_{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,
- $\Delta d, \Delta h$ 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).

The unstable motion of the crane leads to the abrasion of the rail, mainly their inside edge. To add the value of b/2 in a formula (2) we obtain the point position on the rail head, which doesn't represent a rail axis in the case of their abrasion. To have the possibility to determine the correct rail position in the case the worn rail, it should be to fill up the measuring system with third guide wheel and the inductive sensor placed to the both side of the rail edge.

6. Inspection of system function and test measurements

Inspection of mechanical function of the individual parts of measuring system as well as the transmission and registration of measured data into notebook, was carried out on the rail way in Bratislava (Fig. 8). The bearing structure was fixated on the special truck, which enables a movement of the structure on (over) the rail. Because of necessary time for fixation and setting of measuring system we suggested to carry out the first testing measurement on the rail way with out operation. Furthermore it was not easy to find crane, which could be set with out operation and to ensure handling of the crane during the whole testing time.

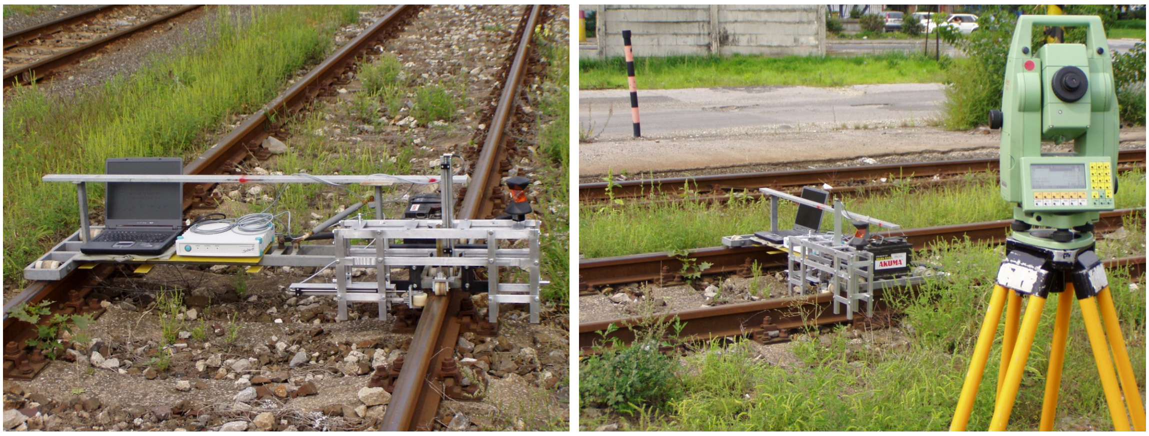

Figure 8. Testing of the measuring system on the rail way

Test measurements showed at small construction negatives of the bearing structure and the leading wheels. On a base of obtained knowledge and skills the structure of the horizontal leading wheel for sensing of rail position in horizontal direction was corrected. The next discovered negative was that the pressure mechanism of leading wheels didn't ensure the continuous transition on dilatation of the two rail stripes. The wheel wobbled after transition through the dilatation and the distance sensor registered a big distance changes in horizontal and also in vertical direction (Fig. 9). This negative was solved by the change of distance and the stiffness of the pressure spring.

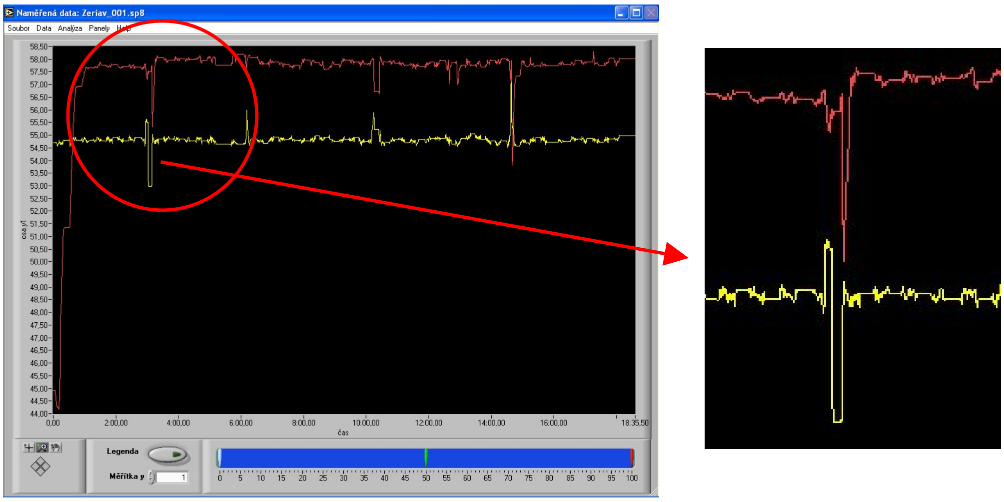

Figure 9. Changes in distances measured by sensor after transition of the rail dilatation

7. Conclusion

The suggested measuring system is in the preliminary stadium of their development, testing and trimming of detected negatives. Results of the first test measurements carried out at the ca 100 m long rail way show reliability and functionality of individual parts as well as the whole system. Data obtained with the measuring system correspond to the data obtained from the measurements carried out by the classical ways (straight line method and levelling).

References:

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