MEASURING SYSTEM FOR MONITORING OF CONCRETE DAM DEFORMATIONS

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1. INTRODUCTION

Dam disasters and failures are very dangerous for settlements and property located in river valleys below the dam' level, therefore their safety always had and still has the highest priority. Although number of disasters in last decades decreased, constantly growing quantity of dams causes the risk that accompanies their exploitation and is a concern for more and more areas and their populations. Thus, geodetic monitoring of dam deformations is constantly expanded with new methods and measuring systems that provide data which - together with their interpretations - are a base for assessment of dam safety (Bryś H., Przewłocki S., 1998).

2. THE IDEA AND STRUCTURE OF PROPOSED MEASURING SYSTEM

Deformations of dam section in the vertical XH plane as well as YH plane can be defined by observation of value of displacements between shaft's wall and a plumb line on multiple levels.

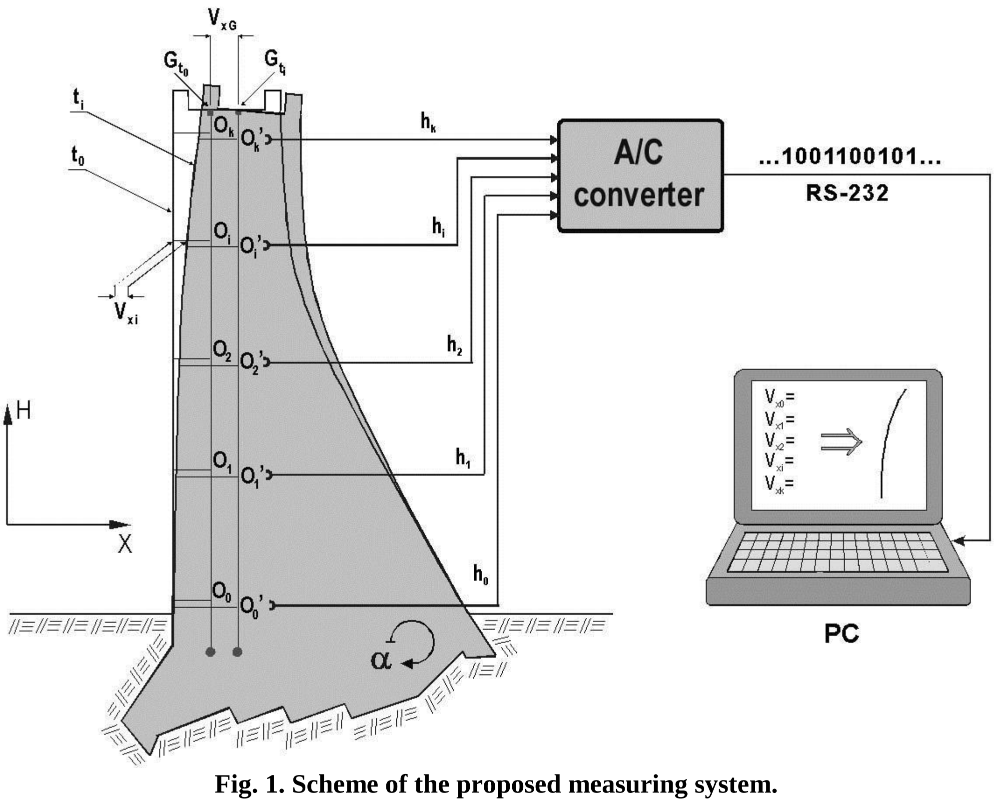

Fig. 1. Scheme of the proposed measuring system.

The primary components of the measuring system are Hall-effect based plumb line displacement detectors fixed to shaft's wall on respective observation levels (h_0, h_1, h_2, ... h_k). Analog signals from detectors are converted to their digital form by analog/digital converter and transmitted to the computer with proposed system software installed. Linear values of horizontal displacements are calculated on the basis of the following formula (Bryś H., 2002):

$$V_{X_i} = (\Delta O_0 - \Delta O_i) - h_i \cdot \tan(\pm \alpha) \quad (1)$$

where:

$\Delta O_0 = O'_0 - O_0$ **– increase/decrease of readouts on the 0-level (reference level)**

$\Delta O_i = O'_i - O_i$ **– increase/decrease of readouts on the following i-levels**

$O_0, O_1, O_2, \ldots O_k$ **– detectors' readouts in the t_0 moment**

$O'_0, O'_1, O'_2, \ldots O'_k$ **– detectors' readouts in the t_i moment**

h_i **– relative heights of the observation levels**

α **– rotation angle of the dam section defined on the basis of data from clinometers**

Deformation of the dam section is represented by a curve (spline function) that interpolates several points with pair of coordinates: value of horizontal displacement on the i-level and relative height of the i-level (Bryś H., Mirek G., 2005).

3. HALL-EFFECT DISPLACEMENT DETECTOR, ITS CALIBRATION AND TECHNICAL DATA

Displacements detector designed and built especially for the proposed measuring system works on the basis of Hall effect. In this effect magnetic field affects current flowing through semiconductor plate causing concentration of particles with positive and negative charges at the edges of the plate according to Lorentz's force law. The concentration of charges causes difference in electrical potential and is equivalent of voltage (so called Hall-voltage). With constant current and plate dimensions as constants the voltage depends strictly on magnetic flux density (Popovic R., 2004).

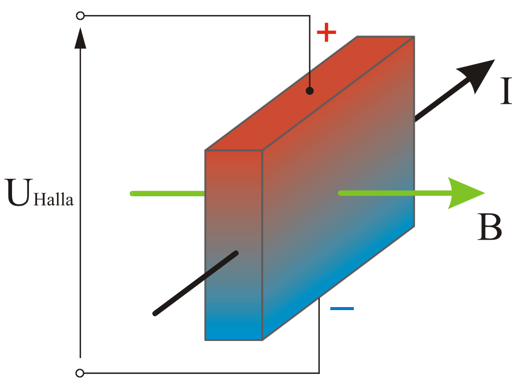

Fig. 2. Hall effect. U_{Halla} – Hall's voltage, *B* – magnetic flux, *I* – current.

The designed displacement detector contains linear Hall-effect sensor (A3515-Allegro Microsystems chip) fixed on stable magnetic field of the magnet. A magnet moves together with the object of which displacement is being measured. This way a value of

linear displacement is transformed to a value of voltage. The principal assumption is the invariability of magnetic field parameters in time. The source of a stable magnetic field is neodymium magnet. Its high value of magnetic flux density and coercion coefficient make it invulnerable for demagnetization and disturbing magnetic fields. The value of linear displacement can be calculated from:

$$\Delta X = F_H(\Delta U) \tag{2}$$

where:

U – output voltage [V], F_H – function that describes dependence between displacement and output voltage. This function depends mainly on arrangement of A3515 chip in relation to the magnet and its mathematical representation is calculated during calibration of displacement detector. Detector's frame and its other mechanic parts are made of paramagnetic materials like aluminum and plastics for elimination of unnecessary and harmful magnetization (Mirek G., 2003).

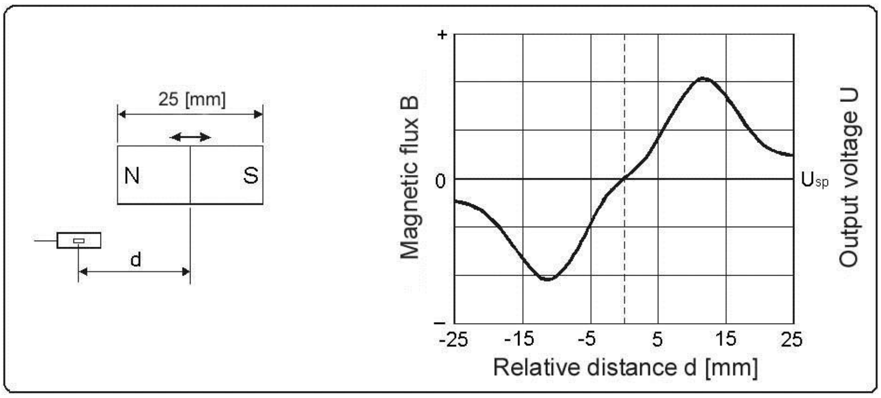

Fig. 3. Chosen magnet configuration and approximated shape of corresponded F_H function.

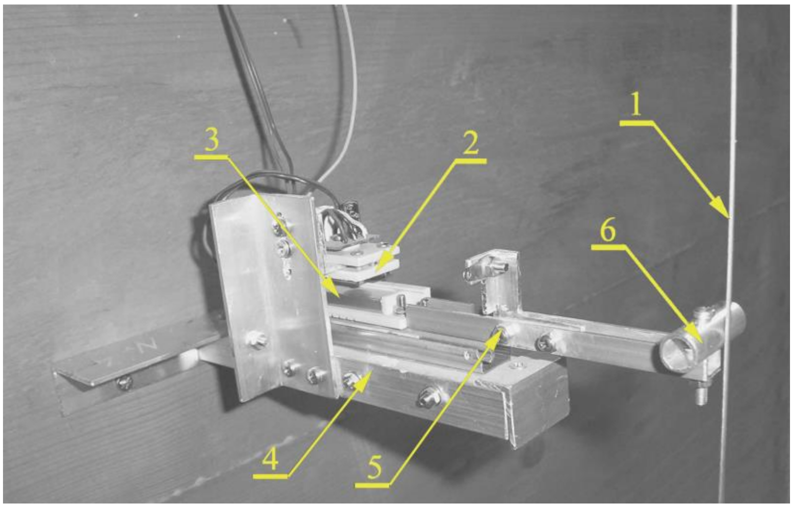

Fig. 4. The prototype of the plumb line displacement detector for the proposed measuring system. 1) a plumb line, 2) Hall-effect sensor, 3) neodymium magnet, 4) aluminum frame, 5) movable rod in guide rail, 6) magnetic contact.

Highly precise measuring of displacements by proposed detectors requires their proper calibration before use. During calibration an accurate mathematical representation of a non-linear F_H function is calculated separately for each detector. Necessary discrete data needed for calibration is obtained with a micrometer caliper while for approximation of the F_H cubic spline functions are applied. Mathematical formulas specified during calibration process are used for recalculation of voltage values (detector's output signal) into linear values of measured displacements.

Calibrated detectors were subject to laboratory testing in order to specify their technical parameters such as: standard deviation error of a single readout, temperature influence on accuracy and long-term drift. The results are presented in table 1. During testing increased errors of a single readout in the middle of measuring range were observed which can be explained by residual magnetization of detector's mechanical parts. Nevertheless, value of single readout error did not exceed ±0.025mm for the entire measuring range. Temperature has a slight influence on sensitivity of the proposed displacement detector and much lower influence on its zero-drift (fig. 5). The long term drift observed during the six-month observation period was below 0.25mm. However, it is recommended to carry out observations for much longer period (one year or more) in order to determine time intervals between necessary calibrations of the proposed displacement detectors.

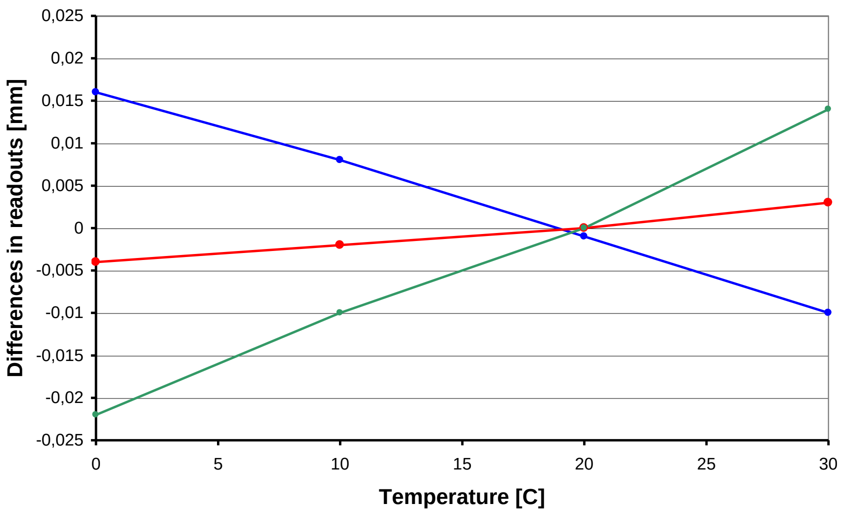

Fig. 5. Temperature influence on: detector sensitivity: blue and green lines (beginning and end of measuring range), zero-drift: red line.

Table 1. Technical parameters of the displacement detectors.

Standard deviation error of single readout	**0.025 mm**
Temperature influence	**0.035 mm / 30 °C**
Long term drift	**<0.025 mm / 6 months**
Size	**10 x 20 x 8 cm**
Mass	**0.2 kg**
Supply voltage	**5 V**

4. LABORATORY SURVEY OF DISPLACEMENTS OF CONTROLLED POINTS WITH PROPOSED MEASURING SYSTEM

To simulate deformations similar to ones that a section of a dam is subject to, a special stand was constructed at Geotechnics Institute of Politechnika Krakowska. It consisted of three meters long vertical aluminum bar with its lower end fixed to the wall and a plumb line hanged on its upper end. Displacements detectors were set along a bar at four observation levels. Several marks serving as controlled points were fixed to the side of a bar both at observation levels and between them. Displacements of controlled points were achieved simply with bending a bar by applying a force to its upper end. In order to regulate this force, simple mechanism was used that enabled both smooth and gradual regulation in N, A, B and C positions. The values of displacements of controlled points for each position were measured using two independent methods in order to compare them with values obtained from installed measuring system.

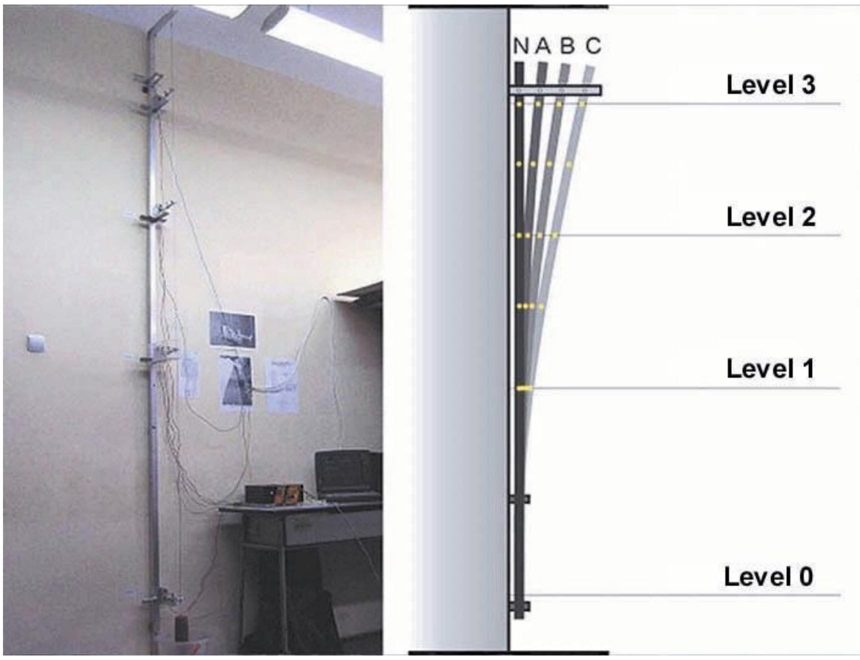

Fig. 6. Laboratory stand with the proposed measuring system installed.

The results are showed in tables 2,3 and 4. The average values of V_{X_i} are comparable with values of displacement of controlled points within range of its standard deviation errors. Although values of σ_{V_X} errors on average are twice as big as errors specified in the preliminary analysis of accuracy, they do not exceed ±0.2mm, hence accuracy of the proposed measuring system is satisfactory. It should also be noted that the cost of Hall-effect displacement detector and thus overall cost of the system is very low compared to similar systems already on the market (Mirek. G., 2007).

Table 2. Results of measures for position A.

		mark nr 1 obs. level nr 1	mark nr 2	mark nr 3 obs. level nr 2	mark nr 4	mark nr 5 obs. level nr 3
position A	Displacements values of controlled points obtained from other methods [mm]:					
	micrometer	0.30	1.10	2.10	3.20	4.20
	GPT-8201A	0.48	1.02	2.05	2.94	4.04
	Values of displacements obtained from the installed proposed measuring system:					
	medium values [mm]	**0.51**	**1.17**	**2.14**	**3.05**	**4.16**
	Δ_{tach} [mm]	0.03	0.15	0.09	0.11	0.12
	Δ_{suw} [mm]	0.21	0.07	0.04	0.15	0.04
	σ_{V_x} [mm]	**±0.10**	–	**±0.11**	–	**±0.15**

Table 3. Results of measures for position B.

		mark nr 1 obs. level nr 1	mark nr 2	mark nr 3 obs. level nr 2	mark nr 4	mark nr 5 obs. level nr 3
position B	Displacements values of controlled points obtained from other methods [mm]:					
	micrometer	0.8	2.1	4.2	6.3	8.3
	GPT-8201A	0.97	2.02	4.27	6.07	8.21
	Values of displacements obtained from the installed proposed measuring system:					
	medium values [mm]	**0.88**	**2.29**	**4.32**	**6.27**	**8.40**
	Δ_{tach} [mm]	0.09	0.27	0.05	0.2	0.19
	Δ_{suw} [mm]	0.08	0.19	0.12	0.03	0.10
	σ_{V_x} [mm]	**±0.08**	–	**±0.10**	–	**±0.13**

Table 4. Results of measures for position C.

		mark nr 1 obs. level nr 1	mark nr 2	mark nr 3 obs. level nr 2	mark nr 4	mark nr 5 obs. level nr 3
position C	Displacements values of controlled points obtained from other methods [mm]:					
	micrometer	1.3	3.2	6.4	9.2	12.7
	GPT-8201A	1.53	3.31	6.54	9.16	12.52
	Values of displacements obtained from the installed proposed measuring system:					
	medium values [mm]	**1.32**	**3.46**	**6.62**	**9.37**	**12.74**
	Δ_{tach} [mm]	0.21	0.15	0.08	0.21	0.22
	Δ_{suw} [mm]	0.02	0.26	0.22	0.17	0.04
	σ_{V_x} [mm]	**±0.09**	–	**±0.12**	–	**±0.14**

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