DEVELOPMENT OF PRECISE WATER LEVEL SENSOR FOR LABORATORY MEASUREMENTS

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Summary:*For the purpose of work on hydraulic models at the laboratory of the "Jaroslav Černi" Institute for Development of Water Resources, a water level meter based on a buoyant force has been developed. This paper presents the specifications and characteristics of level meter, with particular focus on its linearity, dynamic characteristics and usage on hydraulic models. Its relatively simple construction and flexibility allow the user to perform the measurements with high precision.*

Keywords:*Water level meter, hydraulic model, measurement, buoyant force*

1. INTRODUCTION

Water level measurement is the basis of hydrotechnical research. Physical hydraulic models are often made in a 1:40 scale which makes precision measuring a challenge. Hydraulic model level measurements are usually done with a vernier depth gauge with a needle or a hook at its tip. However, this method of measuring requires an operator that manually adjusts the needle up to the surface of the water and as such, represents a discontinuous measurement of the level. If a continuous monitoring of the water levels is preferred, a different method should be considered.
In this paper, a continuous level meter based on buoyant force is presented. Device was developed at the Hydraulic laboratory of the Institute for Development of Water Resources "Jaroslav Černi", for the needs of hydraulic models and is verified on several physical hydraulic models of dams „BENI SLIMANE" [1], „BOČAC 2" [2], „RIGA" [3], „TARZOUT" [4] and „TABEGGART"[5]. With the intensive development of the scale industry, measuring the mass is done with various types of relatively cheap, high precision measuring cells. Archimedes (287–212 BC),the greatest mathematician and physicist of the Classical Ages, revealed the force of thrust and determined its properties. Archimedes' law states: "Each solid body immersed in a fluid experiences an upward

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force equals to the weight of fluid extruded by that solid body". If we combine the Archimedes' law (Figure 1) to measure the buoyant force and a cheap force measuring cell, we come to the presented principle used in this paper.

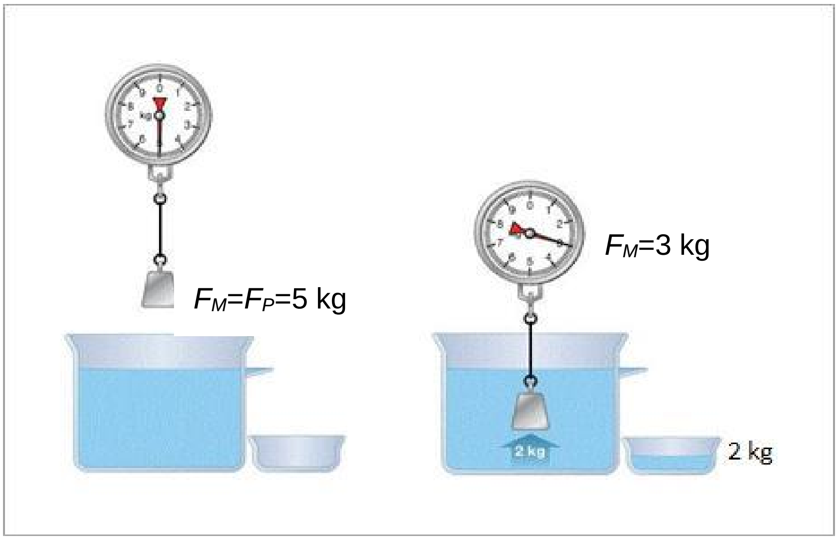

Figure 1. Archimedes' law [6]

In case of solid body partially submerged into the water, the total weight of the body F_P, made of material with density ρ_{sol} and having total volume V, will be reduced by buoyant upward force F_A which depends on the volume of submerged body part V_i and water density ρ_{sol} (Figure 2 and equations (1) and (2)).

$$F_M = F_P - F_A \qquad (1)$$

$$F_M = \rho_{sol} \cdot g \cdot V - \rho_{flu} \cdot g \cdot V_i = F_P - \rho_{flu} \cdot g \cdot V_i \qquad (2)$$

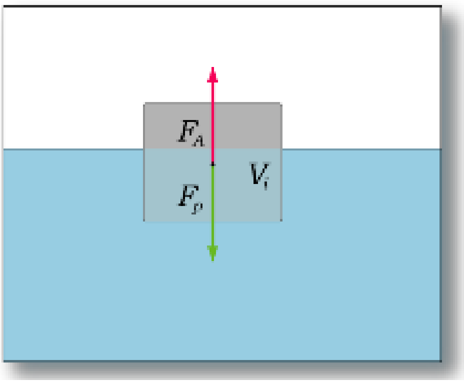

Figure 2. Force equilibrium in a floating solid body [7]

If we measure the weight of the submerged body F_M, using equation (2) and knowing the weight of non-submerged body F_P and density of the water, we can compute the unknown volume V_i. From known body's geometry, it is easy to compute the depth of submerged part of the body, i.e. the level of the water.

2. CONSTRUCTION DESCRIPTION

The level measuring system (Figure 3) consists of a cylindrical float (1) (specific weight similar to the weight of water is recommended, approximately 1000 kg/m^3), structural bars for the support of the float (2), part for transferring force on the load cell (3) , load cells (4) and data processing electronics (5).

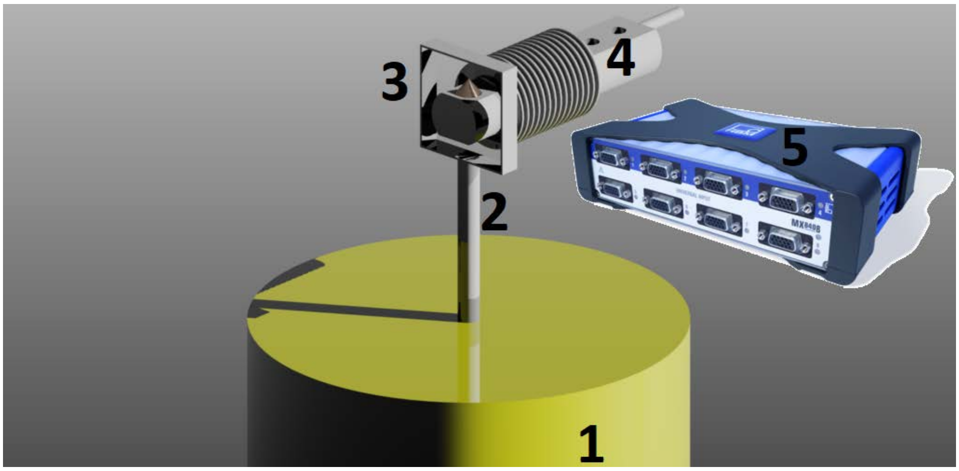

Figure 3. Measuring system

To measure the force using load cells, it is necessary to apply the force without the influence of moment and lateral force components. To accomplish this, the force F_M is transferred from the float through a spike (Figure 3, (3)). This type of construction for force transfer limits the measurements to conditions when there is no water flow around the float, so standard measuring wells are to be used. Measuring well will also improve the reduction of water level fluctuation and will consequently increases measuring accuracy.

Load cells HBM Z6 10kg [8] in C3 class and HBM SP4M 10kg [9] in C6 class have been used for tests. The selection of these two load cells was preferred due to the fact that the first one can be used for measurements over a long period of time, as the cell has a welded steel coat but reduced measurement accuracy, while the later has a silicone insulation and hence higher measurement accuracy. The float (i.e. weight, or body) is cylindrical so the level-mass equation remains linear. The solid body must also be non-hygroscopic with a specific weight and expansion coefficient similar to the fluid parameters (Figure 4) thus any change in water density in the desired temperature range is being compensated.

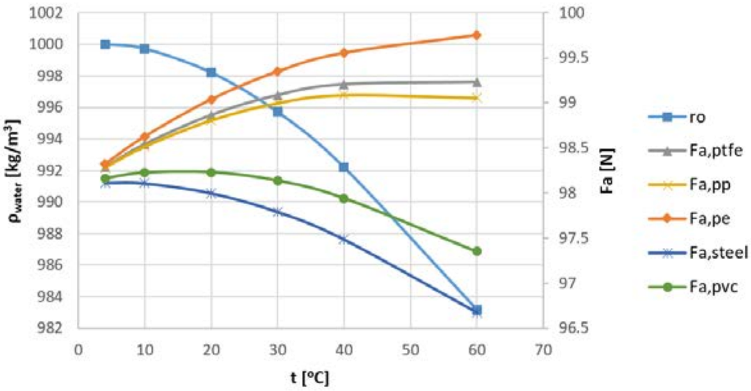

Figure 4. Temperature influence on the float material

The selection of measuring range can be determined in two ways: by fixing the float dimensions and changing the measuring range of the load cell (Figure 5) or by changing the diameter of the float and fixing the measuring range of the load cell (this is the preferred option in this paper). Float height must be higher than the maximum expected measuring range. The data processing electronics used for reading measurements from the load cell consist of HBM MX840 [10] or HBM AED9401 [11], first one has an accuracy class of 0.05%, while the second one has 0.01%. If the usual range of level meters for hydraulic models (500mm) was taken, according to available electronics, the classes are, respectively, 0.25mm and 0.05mm. Apart from this uncertainty, we should also have in mind the uncertainties related to the float, primarily its mechanical dimensions: if 100mm radius solid body has a ±0.1mm uncertainty, the uncertainty level is 0.2%, while 50mm radius solid body, with the same uncertainty of diameter, has an uncertainty level of 0.4%.

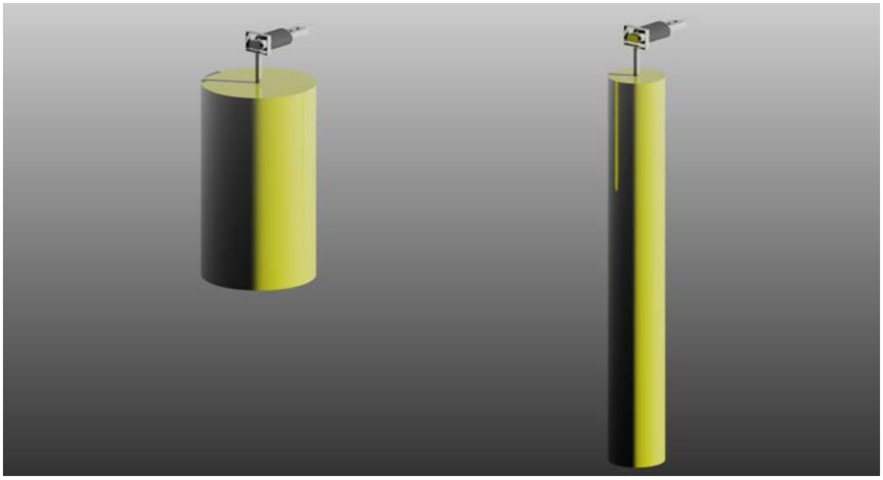

Figure 5. Load cell with a float for shorter measuring range (left) and wider measuring range (right)

3. RESULTS OF THE MEASUREMENTS

Measuring system with the load cell's weight of 10kg, the float with 240mm diameter and measuring height range of 500mm was made for the "BENI SLIMANE" [1] hydraulic model. Two measuring methods were used for system verification (Figure 6), the vernier depth gauge and the magnetostrictive probe (Nivelco NOTRACK M-500 [12]) in conjunction with the HBM MX840 [10] acquisition module. This measurement had proven that the measuring system has potential for quality, but has a problem with air bubble retention at the bottom of the float, thus further improvements are needed to prevent that. On the next hydraulic model, BOČAC 2 [2], the improvements were included in the measuring system and the system was verified once again using above methods.

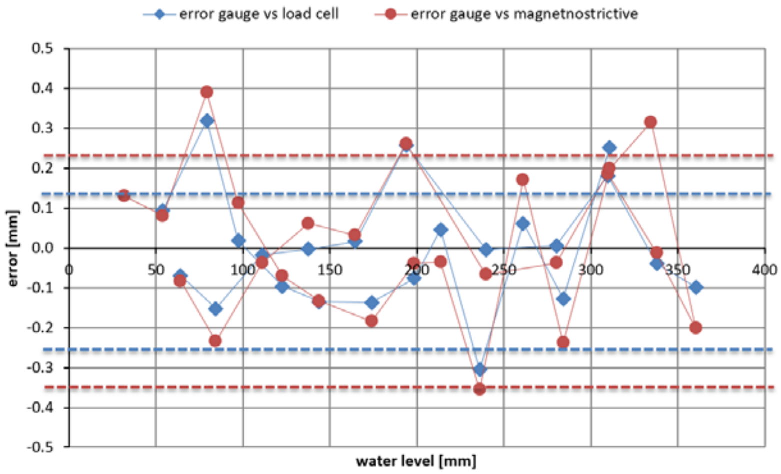

Figure 6. Level measurement error on the hydraulic model BENI SLIMANE [1]

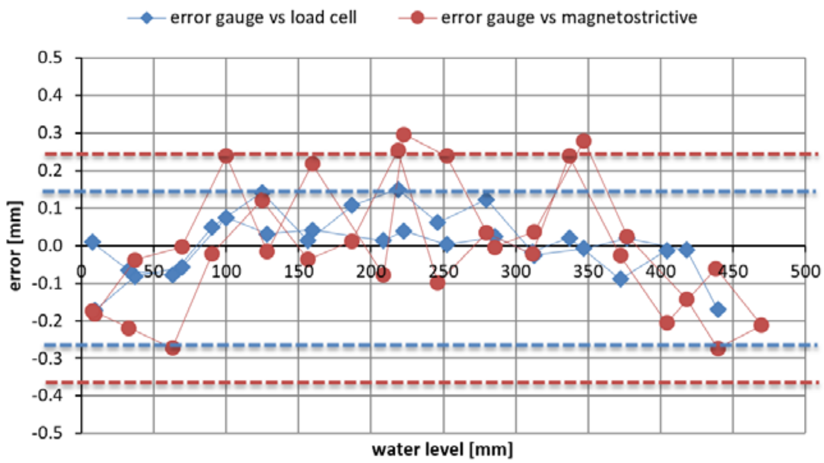

Figure 7. Level measurement error on the hydraulic model BOČAC 2 [2]

After analyzing the readings on hydraulic models (Figure 6 & 7), higher measuring range was required on next hydraulic model RIGA [3] and new 170mm diameter float, that meets new 1000mm measuring height criteria was made. Since the required measuring range is increased, HBM AED [12] was used for higher precision readings, instead of the current acquisition module. However, the results did not present expected higher precision readings.

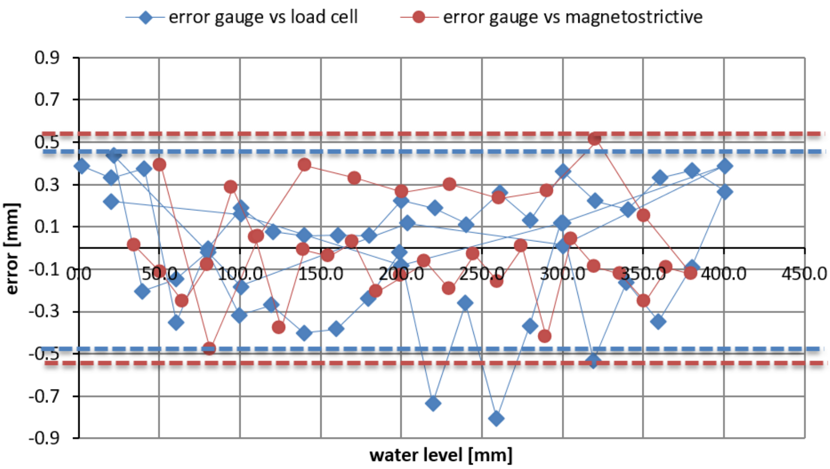

Figure 8. Level measurement error on the hydraulic model RIGA [3]

The next hydraulic model TARZOUT [4] was made of the measuring system containing the load cell weighing 10 kg, with the acquisition module HBM MX840 [10] and the 240mm diameter float, with measuring depth of 500mm.

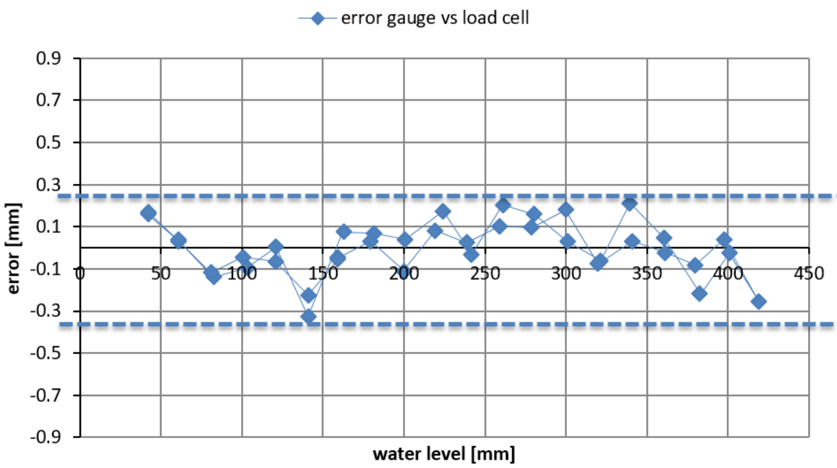

Figure 9. Level measurement error on the hydraulic model TARZOUT [4]

Final tests of the measuring system are related to the hydraulic model TABEGGART [5] which has similar error readings as the previous hydraulic models. In order to better investigate the measuring system, the system's dynamics were examined. Filling and discharging was performed at speeds of 1 mm/s, as well as sudden stop of filling and discharging of the measurement well (Figure 10). Research was purposely carried out firstly by filling up the well to keep the float completely dry. During sudden stop of well's discharge (Figure 11), the system response was relatively quick, while during sudden stop of filling (Figure 12), retention of slowly dripping droplets on the float is observed, however, it has minimal impact on the measurement readings after the stabilization is carried out thus the system response can be considered quick in this case as well.

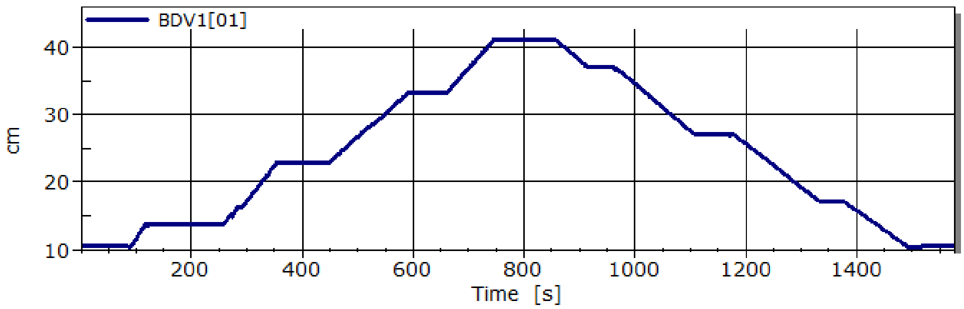

Figure 10. Time series of verification on the hydraulic model TABEGGART [5]

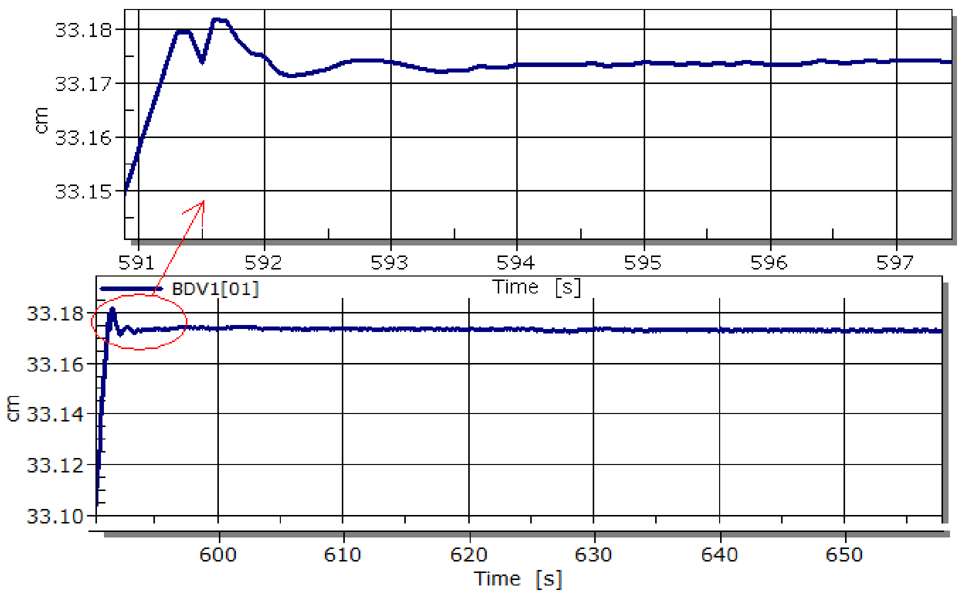

Figure 11. Sudden stop of well filling - hydraulic model TABEGGART [5]

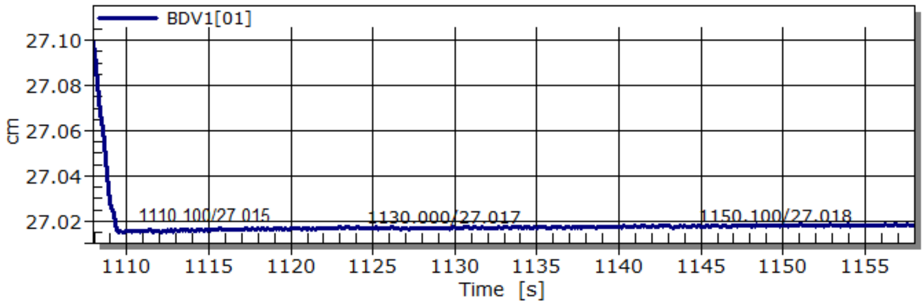

Figure 12. Sudden stop of well discharge - hydraulic model TABEGGART [5]

4. DISCUSSION

The errors during calibration (Figure 6,7,8,9) for the float with a larger diameter, or shorter measuring range (500mm), is about ±0,3 mm, while the error for float with bigger measuring range (1000mm) and smaller diameter is about ±0,6 mm. We can conclude that the level measurement system error, including the hysteresis and linearity, is about 0,06%. Regarding dynamic characteristics (Figure 10, 11, 12), the responses were instantaneous (approx. few seconds, system's own frequency is about 1 Hz) at the filling or discharging rate of 1 mm/s.

5. CONCLUSION

Buoyant force based measuring system, developed using laboratory-available load cells and measuring devices, has proven to be an usable and cheap level measurement system. It meets the high criteria required for use on physical hydraulic models. The only problem with the measuring system is that it requires a measuring well, to prevent the lateral components impacting the float.

Acknowledgements
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РАЗВОЈ ПРЕЦИЗНОГ НИВОМЕРА ЗА ЛАБОРАТОРИЈСКЕ ПОТРЕБЕ

Резиме:*За потребе рада на хидрауличким моделима у лабораторији Института за водопривреду „ЈарославЧерни“ развијен је сопствени нивомер на бази силе потиска.У овом раду су описане техничке карактеристике нивомера, посебно линеарност, поновљивост и динамичке карактеристике као и његове могућности за коришћење на хидрауличким моделима. Његова релативно једноставна констукција и флексибилност омогућавају кориснику да са њим изврше мерење нивоа у високој прецизности.*

Кључне речи:*Нивомер, хидрауличкимодели, мерење, силапотиска*