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Automated System of Operational Hydromonitoring of Ukrainian Water Bodies

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Abstract—Presented are the results of working out an extensive hydromonitoring system for water bodies based on the use of the optoelectronic phase level gage (as a water level meter) and cellular network (to transmit the digital data signal to the data acquisition and processing center). The "Riven' " telecommunication device converting information using the SMS-protocol is worked out for the connection of the phase level gage with the acquisition and processing center using the GSM system. Developed are the structure and algorithm of the hydromonitoring system. Produced is the level gage prototype for the hydrometric station. The hydromonitoring system is intended for the advanced flood warning of population and for providing environmental safety.

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The present-day state of the hydrosphere of the land surface is characterized by the increase in the number of catastrophic events such as floods (including seasonal ones), showers, etc. [3, 8]. The variations of water body regime during the event are characterized by high dynamics, and traditional hydrometric instruments at the gaging stations of Ukraine (for example, stationary devices of GR-38 and Valdai type, semiautomatic level meters–recorders KSM-4, GR-116, USR, etc. [5, 16]) can not provide the operational change in the measurement regime and reduce the period of acquisition and processing of the data on the water body state under such conditions. To prevent the consequences of hazardous phenomena, the permanent operational monitoring of the water level is needed which makes it possible to predict a possibility of the flood formation.

Thus, the existing general climatic trends towards the increase in the number of extreme conditions of water objects set an urgent problem of modernization of metrological support of hydrometric measurements in Ukraine.

This problem is of complex nature and needs a solution of some interrelated problems. The range of variations of hydrological characteristics and the scale of water body areas subjected to extreme events define a need in creating a system of the permanent monitoring of the state with the large coverage area. The system of permanent monitoring requires using automatic hydrometric sensors being able to form the measuring signal suitable for transmission to significant distances and for the processing with the modern information methods. The organization is needed of the most operational and reliable telecommunication between hydrometric stations and the center of acquisition and processing of measurement data as well as the working out of the methods of testing the monitoring systems in order to make it possible to carry out the comparative analysis of existing and under-development measuring complexes.

The present paper describes the automated system of water body monitoring intended for the operational determination of the water level and for the advanced flood warning of population that enables forecasting a strategy of the prevention of hazardous environmental and anthropogenic situations and providing environmental safety.

The system is based on hydrometric instruments adapted to the measurements under conditions of high dynamics of the water object. A key element of the proposed system is the water level meter defining the accuracy and operating speed of measurements which define the current assessment of water body state, the control of water level correspondence to the standard, and the forecast of potential changes.

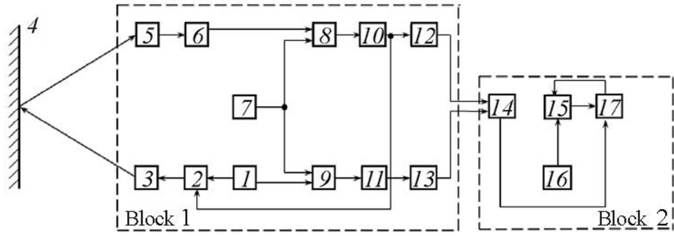

Fig. 1. The block diagram of the phase level gage. Explanations are given in the text.

At present, level gages operating at Ukrainian hydrometric stations are insufficiently accurate, do not have a possibility to transmit the information using communication facilities, and are not connected with each other. Therefore, it was necessary to work out the water level meters with high meteorological and exploitation characteristics for the water bodies which can operate in automatic mode under conditions of high dynamics of the water object and can transmit the measurement results using reliable and inexpensive telecommunication facilities.

The preliminary information for the period of the seasonal flood or extraordinary changes in hydrological conditions define a need in frequent measurements (each 2–4 hours), and in receiving hourly or continuous data on the water level. As the water level variations increase, the differentiated requirements arise to the optimum accuracy of water level measurements. The permissible error of a level measurement under conditions of extraordinary events should not exceed 2–3 mm [5].

The worked out optoelectronic phase level gage (PLG) [9] consisting of the phase difference measurement block (block 1) and distance computation block (block 2; Fig. 1) is used as a level meter included into the monitoring system and being able to measure the current water level with the desired accuracy. Block 1 contains the main generator *1*, power amplifier *2*, radiator *3*, photoelectric detector *5*, tuned amplifier *6*, oscillator *7*, multipliers *8* and *9*, low-pass filters *10* and *11*, and limiting amplifiers *12* and *13*. Block 2 consists of the time-gap generator *14*, counter *15*, scaling generator *16*, and microcontroller *17*.

The water level measurement using PLG is carried out by means of measuring the phase shift between the signal irradiated in the direction of the water surface and the reflected signal received by the photosensitive device [13].

The current value of the measured water level S is computed in the microcontroller *17* in accordance with the basic formula of the phase method of distance measurement [6]

$$S \quad (\quad /2 \quad)(c/2f), \tag{1}$$

where   is the phase shift; f is the signal modulation frequency; c is the sonic speed in the air.

The phase shift   corresponding to the certain level S is preliminarily computed in microcontroller *17* for two time intervals using the expression

$$(1 \quad t/T)2 \ , \tag{2}$$

where t is the duration of the measuring pulse; T is the duration of the measuring signal repetition period.

A problem of increasing the accuracy of the phase difference measurement was solved by means of introducing the contour of automatic amplification control in the radiative channel that enables, for example [9], narrowing the dynamic range of the input signal of photoelectric detector from 120 to 60 dB at the measurement of a level within the range of 0.3–10.0 m and to reduce the systematic error by three times.

An absolute meteorological advantage of PLG is a linearity of the output characteristic because, according to (1), the value of the output parameter (in this case, of phase shift) is proportional to the water level value.

It is known [4] that the coefficient of reflection of the optical radiation by the water surface varies from 2–8% at the normal radiation fall to 25–30% at the grazing angle of the sounding radiation being insufficient for the optical location measurements. To increase the reflectance of the water surface, the float with the cat's eye lining is used providing the reflection coefficient of 80–60% at the angle of incidence of 0 –20 , respectively.

In PLG, the optical radiation is used with the wavelength of 0.63   m with the power of 1 mW modulated with the frequency of 10 mHz.

The development of PLG construction is based on the solid-state model created in the software environment of the Autodesk Invertor 10 system of three-dimensional construction. The worked out level gage has the following major metrological characteristics: the range of measured levels is 0.5–15 m; the error of level measurement is 3 mm; the time of the measurement with the accuracy of 3 mm is 1.5 s.

The operational and reliable communication between PLG at hydrometric stations and the center of the acquisition and processing of the data is needed for the automated system of water level monitoring. The wire communication systems have well-known shortcomings: limited technical potential in the information reception, high value of its delivery and technical support, etc.

The existing cellular radio network of GSM standard that is recently widely used in the systems of remote control and alarm is free of the mentioned shortcomings [1, 4]. Besides, the GSM network is notable for the rather low cost of equipment and network support as a communication subsystem within the structure of the system of acquisition and processing of the data. The reliability parameters of the delivery of the message of an information unit guaranteed by the cellular operator are rather high: the probability of the successful delivery is not less than 98%. In the GSM network structure, there are the tools of the confirmation of the delivery of the measurement information block as well as of the delayed delivery in the case of the temporary absence of communication. This makes cellular communication preferable to the other types of communication.

To realize a function of telecommunication between the equipment of hydrometric control station and the center of acquisition and processing of the data using the cellular GSM communication, the “Riven’ ” (“Level”) block was worked out which transmits the information signal of PLG [12]. The basic elements of “Riven’ ” block are the ATMEGA-64 microcontroller and SIM-300 GSM modem. The most reliable and clear SMS technology was chosen for the data and service information exchange.

The management of PLG operation algorithm with the subsequent transmission of the measurement data is carried out via the GSM network using SMS messages that programm the “Riven’ ” for organizing an algorithm of the measurement of the current value of the water level at the hydrometric station. A format of a SMS message is simultaneously a password that rules out the emergency operation of equipment in the case of the reception of random SMS messages. The text of SMS messages is sorted and processed in the software environment of the computer in the center of acquisition and processing of the data on the water object.

The reverse informational SMS messages about the changes in the water level state can come not only to the center of data acquisition and processing but also to the GSM network subscribers who have sent an inquiry in the proper format. This allows carrying out the operational acquisition of the data and regulating the equipment at the hydrometric station.

The Siemens SL-45 GSM modem of the center of data acquisition and processing that has an agile software of the embedded microcontroller and is suitable for solving specific applied problems, is used as a radio signal receiver of the GSM network.

To organize the connection of the SL-45 GSM modem with the computer, the matching cable is used including the PROLIFFIC PC-2303HX interface microchip carrying out the data translation from the USB port to the virtual COM port of the computer being available for the programs.

To record, to process, and to store the information coming from hydrometric stations in the form of the database, the Siemens Mobile Control adapted software environment is used [10]. The active window of the program in the Excel Microsoft Office format contains the columns of the database, where the following main and service data are stored:

—column *A*: the date and time of sending the current SMS message;

—column *B*: the number of the modem of the current hydrometric station;

—column *C*: the registration number of the current hydrometric station;

—column *D*: basic measurement data on the water level and the service information about the storage battery state.

The structure and algorithm were worked out of the operation of the automated system of environmental control and operation monitoring of the water level of water bodies consisting of the laser controllable level gage, “Riven’ ” GSM device, and power unit [10]. PLG and “Riven’ ” are installed at the hydrometric observational station.

The feeding of the system is carried out using the accumulator 8 (12 V; 200 A/hour). The parameters of the normal mode of energy consumption are the following: the continuous feeding of the microcontroller and GSM modem; the hourly measurement of the current distance to the water surface; the delivery of pre-

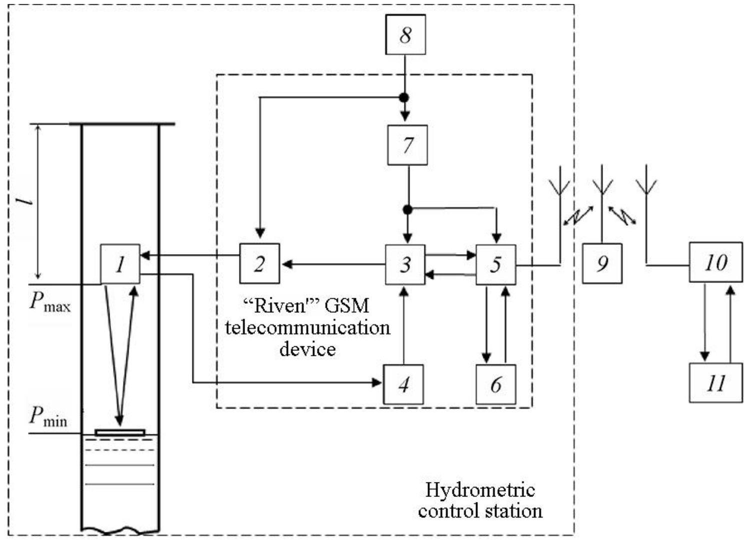

Fig. 2. The structural scheme of water level monitoring system: (*1*) PLG; (*2*) transistor key; (*3*) microcontroller (ATMEGA-64); (*4*) ADC (MCP 3204/SL, 12 digits); (*5*) GSM modem (SIM-300); (*6*) SIM card that allows obtaining the identification number in the GSM network; (*7*) feeding voltage stabilizer; (*8*) accumulator; (*9*) GSM operator; (*10*) GSM modem (SL45); (*11*) center of data acquisition and processing.

liminarily formed data package using the cellular communication twice a day (08:00 and 20:00) using the SMS message to the address of the data acquisition center.

In the normal (non-accelerated) measurement mode, the hydromonitoring system consumes the power of 0.22 W/hour (or 158.4 W during a month) from the constant-current source. The significant capacity of the accumulator of 200 A/hour (1680 W) is needed for the energy supply of the system in the mode of more frequent measurements during the flood period (up to one month) and for the subsequent operation in the normal mode. The algorithm of the system operation stipulates the measurement of the current water level during the flood period every 10 minutes and the transmission of the SMS message with the accumulated information every half an hour. The averaged energy consumption of the system increases from 0.2 to 1.0 W/hour (or 720 W) during a month. Thus, the power accumulated in the accumulator provides the unattended operation of the system during six months including five months in the normal mode and one month in the accelerated mode during the flood period. The structural scheme of the monitoring system is presented in Fig. 2.

Let us consider the algorithm of the monitoring system operation. To measure the current water level at the hydrometric station, the computer *11* of the center of data acquisition and processing operator *9* sends the control message *M1*TEXT to the phone number of GSM modem *5* of the measurement system of the station using the GSM modem *10* of GSM. When the control SMS message of such format only is received, the microcontroller *3* of the GSM telecommunication device of the station system applies the voltage to PLG *1* during the time period *t* given in the text of the control message using key *2*.

When the measurement time needed to complete the transition processes in the PLG scheme is out, the measurement of the PLG signal output level is carried out using ADC *4*. The current value of the water level computed by microcontroller *3* and converted into the GSM format is sent to the number of a GSM network subscriber who has sent a command for carrying out the measurement.

The frequency of measurements and the processing of their results are regulated by the system operation mode which can vary from hourly measurements and formation of data package during several hours (in the normal mode) to the once-a-minute measurement periodicity and the accumulation of measurement information (in the accelerated mode). Besides, the duration of the process of the reception and transmission of measurement data allows the operation of the monitoring system in the online mode.

The exploitation characteristics of hydrometric equipment under conditions of open-air operation or in non-heated premises are mainly limited by seasonal temperature variations. In winter, reliable measurements are impossible due to the water freezing, because the access to the water surface is blocked for level meters with any operation principle. Hence, the lower limit of the temperature range of the monitoring system use is 0 C. The power unit accumulator capacity is also notable for the significant dependence on

Fig. 3. A photo of the prototype of hydrometric station equipment.

temperature, and this capacity decreases by 20% of the rating on average at negative temperatures that provokes the reduction of the period of unattended operation of the system. The upper limit of the temperature range is defined by the conditions of the use of the element base of PLG and GSM device and amounts to 70 C.

Using this structural scheme, the prototype was worked out and produced of the level-measuring equipment for the hydrometric station consisting of the PLG, "Riven' " GSM telecommunication device, and power source (Fig. 3). An advantage of the worked out monitoring system is operation in the automatic mode and the transmission of measurement results using the GSM connection to the information center that provides the reception of the reliable data using telecommunication tools in the online mode and enables carrying out the operational data acquisition and permanent monitoring of the water level. The prototype was put to laboratory and field tests under normal climatic conditions in accordance with the worked out method [14]. Not only technical characteristics of PLG were measured but also the time and reliability of measurement data transmission determined by the "Riven' " GSM telecommunication device.

The basic technical and exploitation characteristics of the hydromonitoring system were determined as a result of the tests: the range of water level measurement is 0.5–15 m; the error of water level measurement is 3 mm; the time of the measurement by one reception is 1.5 s; the speed of the GSM communication network operation is 30–40 s; the probability of an SMS message delivery is 98%; the feeding voltage is 12 V (accumulator); the temperature range is 0–70°C.

Thus, the use of optoelectronic phase level gage in the hydromonitoring system enabled obtaining the digital data signal being suitable for the transmission in cellular communication networks that increased the operability and reliability of the system as a whole and defined the direction of its considerable modernization.

REFERENCES

1. *IGT-4D Hardware and Software Complex, TESS Electronics Company*, www.telemetry.ru [in Russian].
2. E. L. Butkevich, *Writing Programs and Games for Cell Phones* (Piter, St. Petersburg, 2006) [in Russian].
3. O. I. Gorelits, I. V. Zemlyanov, A. E. Pavlovskii, et al., "Catastrophic Flood in the Terek Delta in June–July 2002," Meteorol. Gidrol., No. 5 (2005) [Russ. Meteorol. Hydrol., No. 5 (2005)].
4. *A Gold Rush of Russian Telemetry*, www.konalink.ru [in Russian].
5. I. F. Karasev, A. V. Vasil'ev, and E. S. Subbotina, *Hydrometry* (Gidrometeoizdat, Leningrad, 1991) [in Russian].
6. Ya. M. Kostetskaya, *Light and Radio Range Finders* (Vishcha Shkola, Lviv, 1986) [in Russian].
7. G. Le-Bodik, *Mobile Messages. SMS, EMS, and MMS Services and Technologies* (Kudits-Obraz, Moscow, 2005) [in Russian].
8. V. N. Mikhailov, M. V. Mikhailov, V. N. Morozov, et al., "Catastrophic Flood on the Danube River in August 2002," Meteorol. Gidrol., No. 1 (2004) [Russ. Meteorol. Hydrol., No. 1 (2004)].
9. V. I. Santonii, V. V. Yanko, I. O. Ivanchenko, and L. M. Bydyanskaya, Ukrainian Patent 21631, MKI G01C 3/08, Phase Optoelectronic Range Finder, No. u 200611395; Patented on October 30, 2006; Published on March 15, 2007 [in Ukranian].

10. V. A. Smintina, V. I. Santonii, V. V. Yanko, I. O. Ivanchenko, and L. M. Bydyanskaya, Ukrainian Patent 60595, MKI G 01 F 23/28, 23/00, Automated System of Hydromonitoring, No. u 2010 13880; Patented on November 22, 2010; Published on June 25, 2011 [in Ukranian].
11. *Siemens Mobile Control Program*, cibulka.pavel@tiscali.cz.
12. V. A. Smintina, V. I. Santonii, V. V. Yanko, et al., "The Use of GSM Network in Hydrologic Monitoring Systems," in *Proceedings of the 8th International Scientific and Practical Conference "Modern Informational and Electronic Technologies" (MIET 2007)* (Odessa, 2007) [in Ukranian].
13. V. A. Smintina, V. I. Santonii, V. V. Yanko, et al., "Laser Level Gage for Hydrometric Monitoring Systems," in *Proceedings of the 2nd International Scientific and Practical Conference "Environmental Monitoring: Scientific, Methodological, Regulatory, Technical, and Software Support"* (Koktebel', 2007) [in Ukrainian].
14. V. A. Smintina, V. I. Santonii, V. V. Yanko, et al., "Methodological Support of Water Level Monitoring System Testing," in *Proceedings of the 3rd International Scientific and Practical Conference "Environmental Monitoring: Scientific, Methodological, Regulatory, Technical, and Software Support"* (Koktebel', 2008) [in Ukrainian].
15. V. M. Timchenko, *Ecological and Hydrological Studies of Reservoirs of the Northwestern Black Sea Area* (Naukova Dumka, Kiev, 1990) [in Russian].
16. N. M. Khusainov, B. G. Khusainov, and N. N. Antonov, "Modern Methods and Tools of Level Gage Verification," Metrologicheskoe Obespechenie Izmerenii, No. 2 (1980) [in Russian].