

Impedance Spectrometer for *in situ* Dike Monitoring

Ivan Krejčí², Jana Pařílková¹

¹ Brno University of Technology, Faculty of Civil Engineering, Department of Water Structures, Laboratory of Water Management Research, Veveří 95, 602 00, Brno, Czech Republic, phone +420541147284, Fax +420541147288, e-mail: parilkova.j@fce.vutbr.cz,

² HAAL Elektro, Ltd., Zeiberlichova 23, 644 00, Brno, Czech Republic, phone +42054121 9719, e-mail: ikrejci@haalik.cz

Abstract- Promising laboratory results of the electrical impedance spectroscopy application in observing of internal processes in the dike body, during its loading by rush water, led the authors to the decision to use this method in real conditions at real dike constructions. For these purposes, the new instrumentation capable of the operation in open landscape should be built. Design aspects and signal processing of electronic circuitry used in the instrument is the main topic of this contribution.

I. Introduction

The electronic design of the equipment determined for the operation in field conditions is controlled by specific rules, respecting full functionality of the apparatus in sever conditions – humidity, wide temperature range, mechanical robustness, etc. Besides, new requirements of large number of measurement points, new types of sensing probes and flexibility that makes possible to use the instrument for different types of impedance measurement (two- and four-terminal). The instrument itself takes advantage of the three voltmeters method of the impedance determination (Fig. 1).

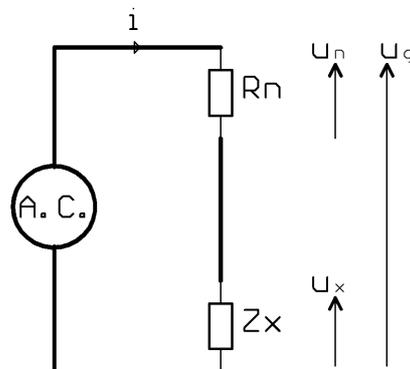


Fig. 1. The basic principle of the impedance measurement using the method of three voltmeters.

The measurement circuit consists of two impedances connected in series. One of these impedances is the standard resistor R_n the impedance of which is well known within the range of operating frequencies, and the second one is the unknown, investigated impedance Z_x . The circuit is supplied from the source of a.c. voltage signal capable of the generating signals of needed amplitude and frequency. Measurements of voltage drops on both impedances u_n and u_x respectively, together with the measurement of the a.c. supply voltage u_g makes possible to create the circuit voltage vector diagram (Fig. 2.).

Using the method of the quadrature detection of measured signals, and comparison of voltage drops, both, the real and imaginary parts of measured impedances, or its reciprocal quantity, admittances, can be calculated. Signals u_g , $u_{n_{re}}$, $u_{n_{im}}$, $u_{x_{re}}$, and $u_{x_{im}}$ are products of the quadrature detection. From these measured voltages, the asked vectors, u_{Z_R} and u_{Z_I} are calculated using following formulas:

$$u_n = \sqrt{u_{n_re}^2 + u_{n_im}^2},$$

$$\sin \varphi = \frac{u_{n_im}}{u_n} = \frac{u_{Z_I}}{u_g}, \quad (1)$$

$$u_{Z_R} + u_n = \sqrt{u_g^2 - u_{Z_I}^2}.$$

From the point of view of the signal processing, two basic operations should be done to solve the task of the impedance measurement – the measurement and reference a.c. signals generation, and measured signals detection, including quadrature multiplication, filtering, digitizing of detected signals, and calculation of measured quantities. Besides, the embedded signal processor has to set parameters of the experiment before the measurement is started (setting of a.c. signal parameters – frequency range, amplitude, and then, during the measurement, ensures experiment organization, e.g. switching of measured places, transport of results to the host computer, etc. Discussion of these tasks is given in following paragraphs.

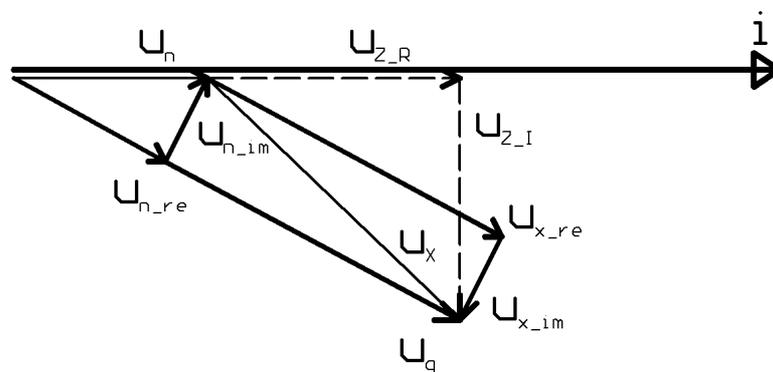


Fig. 2. Vector diagram of the measuring circuit. The basic vector is the current vector i , the basic voltage vectors are u_g , u_n , and u_x . Vectors, gained by quadrature detection, are emphasized. Target vectors use dashed lines.

II. A.c. signal generation

Coming out of our experience, the generator must be capable of the producing a.c. harmonic signals within frequency range of 100 Hz – 20 kHz with selectable range of amplitudes 500 mV – 5.00 V for the test circuit supply, and rectangular reference signals, of the same phase as the harmonic signal, and phase shifted by 90° , capable of the switching quadrature detectors. Two direct digital synthesizers (DDS – Analog Devices AD9832) involving oversampled 10-bit digital-to-analogue converters (DAC) solve the basic task of of generation of asked signals. The synthesizers use the clock frequency of 20 MHz generated by the signal processor. The use of oversampled DACs makes possible to achieve high degree of parasitic signals rejection (these signals – images – are caused by the interference of sampling and generating frequencies [1]), because their frequencies are much higher than that of the generated signal. Thus, a simple low pass filter can be used for filtering those parasitic signals. The first synthesizer generates signals for the supplying of the measuring circuit, and the reference signal for the real part of measured voltages detection, while the second one generates the 90° shifted reference signal for the impedance imaginary part detection. The DACs used are of the one quadrant type, so that their output signal contains, except the asked a.c. component, an additional d.c. component, which must be filtered out. Therefore, two types of analog filters are connected in series with the DACs output. The first is a simple 1 Hz high-pass filter for d.c. component separation followed by the three pole Butterworth filter for rejection of images. The first signal channel is divided in two branches, the signal in the first one generates sinusoidal signal, which is boosted to be able to supply low impedance measuring circuit - Sin, and, in the second one, the signal is rectangle shaped, and inverted, so that it generates signals with zero and π phase shifts for switching of the semi-parallel real part quadrature detector. The second channel signal shape is converted into rectangle and inverted to generate signals phase shifted by $\pi/2$ and $3\pi/2$ for keying of the semi-parallel imaginary part quadrature detector. The principal block diagram of the generator is shown in the Fig. 3. Output of the boosted amplifier serves to the supplying of tested circuit, standard resistor, and current pair of

electrodes placed in the dike body. The embedded signal processor selects and switches suitable value of the standard resistor (autorange) during measurement to ensure the best accuracy and resolution of the voltage measurement.

III. Detected signals processing

Measured impedance is connected with the instrument via two pairs of terminals. The first pair is connected to the generated measurement signal and serves to the supply of current electrodes, the second one, voltage electrodes, placed as close as possible to the current once, connected to the measuring part of the instrument, measures potential between current electrodes. Measured places are changed by switching of electrode quartets by the multiplexer, capable of the selecting one from 128 [3] places. The electrode pairs (two terminals measurement) or quartets (four terminals measurement) switching is controlled by the embedded signal processor, Analog Devices ADSP 2181.

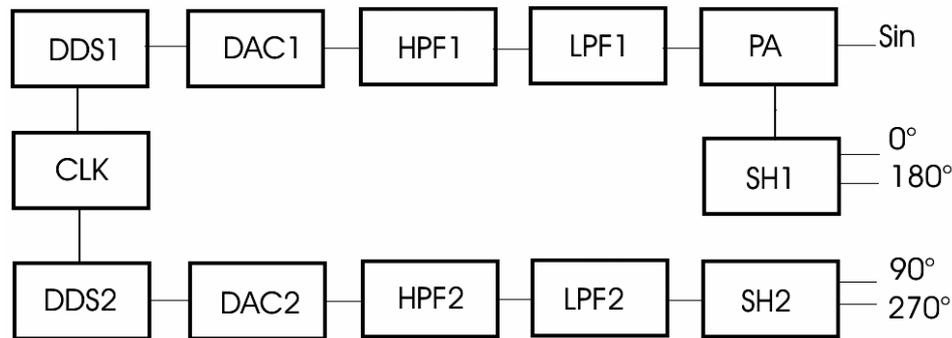


Fig.3. Generator block diagram. DDS – direct digital synthesizer, DAC – digital-analog converter, HPF – high pass filter, LPF – low pass filter, PA – power amplifier, SH – shape converter, CLK – master clock

Three voltages are measured, as mentioned above. Each measuring channel has the same signal trace, so that the channel measuring voltage drop at measured impedance is described. The signal is led to the high input impedance and wide frequency range buffer. Its output is connected with the normalizing amplifier followed by the quadrature phase detector with low pass filters that serve to parasitic a.c. detection products rejection [2]. Output d.c. voltage is digitized using 16-bit analog to digital converter (ADC) – Analog Devices AD 7714. Its output data are led to the signal processor working out all impedance calculations, experiment control (switching of measuring places, autoranging, synthesizer's control, communication, etc.). The principal block diagram of the measuring channel is shown in Fig.4.

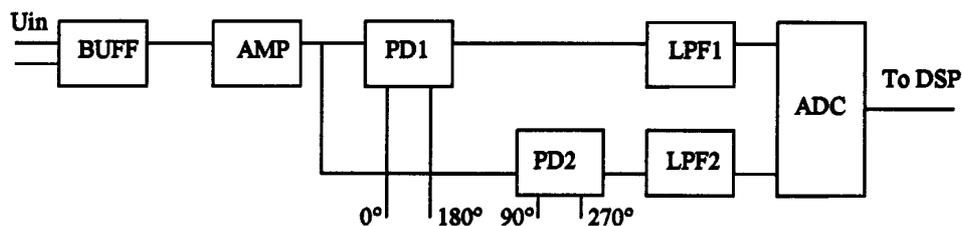


Fig.4. Principal of the measuring trace. BUFF – input buffer, AMP – normalizing amplifier, PD – phase detector, LPF – low pass filter, ADC – analog-digital converter.

IV. Digital signal processing

The digital signal processor (DSP) controls the experiment and its tasks can be divided, owing to the experiment period, to several groups:

- Preparing of the experiment. During this period, type of the experiment is programmed from the host computer (PC). Operating frequency (one-frequency experiment) or frequency range with frequency step (frequency characteristic measurement), amplitude of the harmonic signal, programming of the DDSs and ADC, and number of measuring channels are the most important parameters that have to be set before the experiment starts.

- Measurement period. The voltage measurements in all three channels (the ADC used contains the 3 channel multiplexer), autoranging, optimizing of the signal amplification, calculating of mentioned formulas, reprogramming of DDSs (in the case of the frequency characteristic measurements), and channel switching are carried out during this period.
 - After finishing the measurement, evaluated data, stored in the processor data memory are transferred via the USB link to the host processor, where the data can be stored and visualized, either using their displaying in alphanumeric shape or in the form of diagram (frequency characteristic). Stored data can be processed by any standard program, for instance EXCEL.
- The principal block diagram of the processor circuitry is shown in Fig. 5.

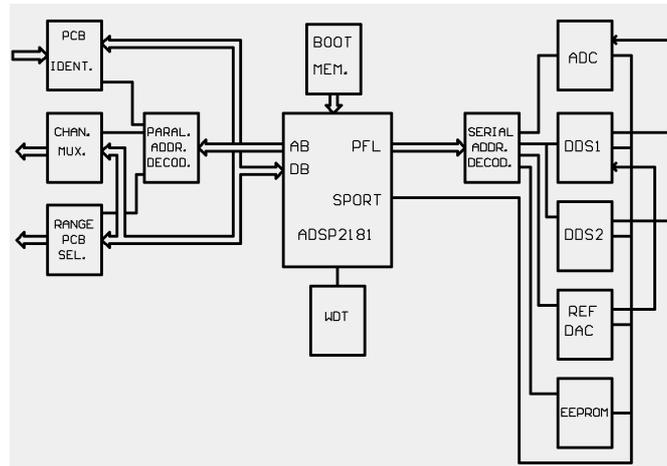


Fig. 5. Digital signal processor and its parallel and serial peripherals

V. Realization of the instrument

The described impedance spectrometer has been designed and built. All the measuring circuitry included the signal processor and the multiplexer addressing is placed on the PCB of the standard European dimensions 100 x 160 mm, (Fig. 6).

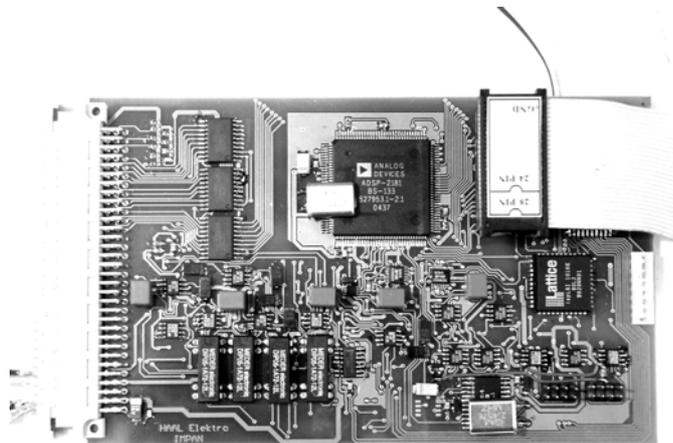


Fig. 6. Digital signal processor and measuring circuitry.

The system contains eight identical cards of the standard dimensions. Sixteen channels multiplexer, capable of the switching of sixteen electrode systems (two or four electrodes) equipped with address jumper card identification is placed on the card. Presence of the card is indicated by the signal processor (Fig. 7).

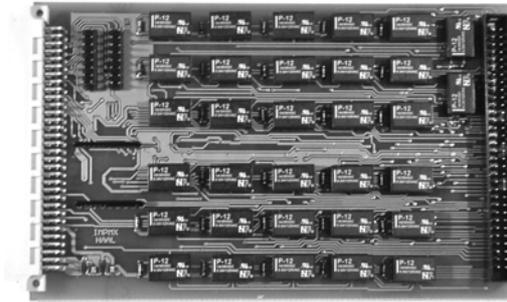
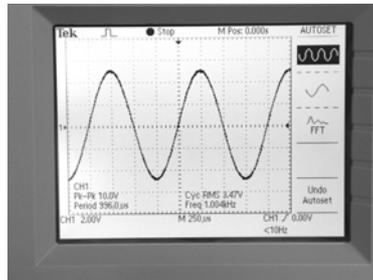


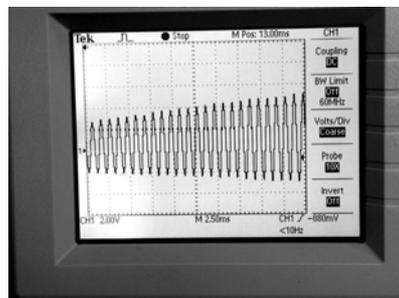
Fig.7. One of eight multiplexer cards.

The system is built in the 19" box.

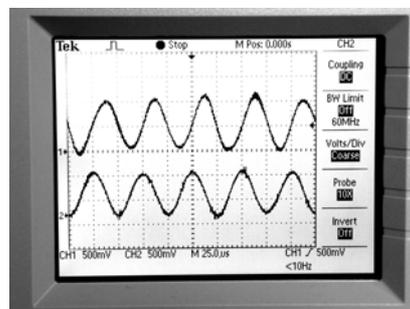
The DSP software was carried out. Several possibilities of the DDS programming is shown in Fig. 8, where generating of different frequency of signals, or amplitude change of the signal are demonstrated.



a)



b)



c)

Fig. 8. Several examples of the DDS properties. Generation of simple sinusoidal signal (a), successive amplitude growth (b), realization of the 90° phase shift (c).

VI. Conclusions

At present, the system measuring impedances within the range of $100\Omega - 1M\Omega$, capable of the communication with the host PC via the USB interface, is built and prepared for in situ measurements. Before its application in the real condition, the system will be tested to evaluate its properties in laboratory and outside conditions. The research is worked out within project 103/04/0741 granted by the Grant Agency of Czech Republic (GAČR).

References

- [1] Murphy ,G.J.: “Basic Automatic Control Theory”, D. van Nostrand Company, Princeton, U.S.A., 1966, p.607.
- [2] Krejčí, I., Pařílková, J.: “Processing of Signals in the Electrical Impedance Spectrometer”, Proceedings of the conference on The New Trends in Signal Processing, vol.1, Tatranské Zruby, SK, 2002, p. 87.
- [3] Krejčí, I., Pařílková, J., Veselý, J.: “Electrode Systems and Their Switching Used in Monitoring of the Dike Status”. Proceedings of the 10th TC-10 IMEKO Conference on Technical Diagnostics, Budapest 2005, p. 63.