Ultrasonic Measuring System for Deposition of Sediments in Reservoirs

M. Mărgăritescu *1, A. Moldovanu *1, P. Boeriu *2, A.M.E. Rolea*1

*1 National Institute of Research and Development for Mechatronics and Measurement Technique – INCDMTM
6-8 Pantelimon Road, District 2, Bucharest, ROMANIA
E-mail: mihai.margaritescu@gmail.com

*2 Institute for Water Education UNESCO-IHE-Delft, The Netherlands

Abstract

The silting process affects the useful volume of the reservoirs, with important economic implications. The bathymetric maps of dam lakes are drawn measuring the water depth in x-y coordinates and show the dynamics of the silting process if they are updated periodically, but the accuracy of these determinations is related to the precision of the x-y coordinates. For a more accurate assessment of the deposition process, the SEDCONTROL project proposes a measurement system based on acoustic principle attached to one or a few representative points which transmit real-time the measured values.

Key words
Sediments, reservoir, ultrasonic transducer

Introduction

The dynamics of the silting process presents interest to those who exploit the lake, but also has environmental implications. The reservoirs, as water management instruments, according to Bătucă and Jordaan [1] have the following functions: power generation, flood control, water supply, discharge regulations, level regulations, fishing, navigation and recreation. Each of these functions require specific parameters related to water quality, level and depth. From power generation reasons, water depth is the most important parameter. Starting from the default bathymetric map of the reservoir, it is watched the evolution of the water depth in order to estimate the period of exploitation of that reservoir. Due to the particles of different sizes of sand, silt and other materials transported in water, the deposition of the incoming sediments starts from the head of the reservoir and progressively extends towards the downstream of the reservoir (Fig. 1) - Boeriu et al. [2]. Furthermore, this simplified model becomes more complex due to the lateral influx of water. The result of a simulation is presented in Fig. 2. It can be observed that the sediment distribution is not uniform as expected along the border of the reservoir.

Instruments for the water depth measurement

Van Rijn mentions in his work [3] in 2006 the following methods for accurate measuring of bed level detection:
1. mechanical bed level detection in combination with DGPS (differential GPS);
2. acoustic bed level detectors (single and multi beam echo sounders);
3. optical bed level detection.

The classical method to measure the depth in sea water or in reservoir is the use of ultrasound devices – an ultrasound source as emitter and an ultrasound transducer as receiver. The receiver is sometimes called hydrophone. Measuring the delay of the reflected signal (usually 210 KHz for surface detection) and knowing...
the speed of propagation in water (approx. 1500 meters per second), the distance from the surface to the bed level is so determined. This method is similar to distance measurement in air with a radar and is the principle of the sonar.

The sound pulses are sent out regularly as the ship moves along the surface, which produces a line showing the depth of the ocean beneath the ship. This continuous depth data is used to create bathymetry maps of the survey area. More recent, the multibeam bathymetry sonar uses many beams of sound at the same time to cover a large area of the ocean or reservoir floor. These multibeam systems can have more than 100 transducers, arranged in precise geometrical patterns. All of the signals that are sent out reach the seafloor and return at slightly different times. These signals are received and converted to water depths by computers, and then automatically plotted as bathymetric maps. Multibeam bathymetry sonar is used to locate topographical features on the seafloor such as sediment ridges, rock outcrops, shipwrecks, and underwater cables.

According to McRobbie et all [4], an underwater ultrasonic transducer is in fact an underwater antenna. It is an electromagnetic device that converts electrical energy to mechanical energy (sound waves), and reciprocally, converts mechanical energy (sound waves) to electrical energy. In a given underwater sonar system, a transducer may be employed as a transmitting device, or as a listening device, or as both. When transmitting, the transducer is referred to as a projector. When listening, it is referred to as a hydrophone. In a typical sonar system, the transducer converts a high voltage electrical pulse at a given frequency to a mechanical vibration. This creates a sound wave that is transmitted through the water. If the sound wave intercepts an object within its path a portion of the energy is reflected back to the transducer. The received echo mechanically deflects the transducer, producing a low voltage return signal that is amplified and processed by receiver electronics. Since the speed of sound in water remains relatively constant, it is possible to determine the distance to the object by measuring the time difference between the transmitted pulse and the received echo.

SEDCONTROL system

SEDCONTROL relates to an ultrasound system for measuring deposition of sediments in the reservoirs [5], the system being fixed to the bottom of the lake in a representative point and recording the evolution of the sediment (silt) in a specified period, for example one year. Due to the sediment transport, the reservoirs presents the process of silting, that is the filling with silt over time, with gradual decrease in the volume useful. This process is extremely complex and depends on several factors: the size and geometric shape of the lake, geological structure of the hydrological basin which determines the composition of sediments, climatic factors, human activities, etc.

To explain the process of silting were created different mathematical models that describe the mode of deposition of particles in suspension in function of grain, the nature of particles, sediment density, water transport speed, shape of the lake section and other specific factors. However, it was proved that mathematical modeling, even accompanied in recent years with very advanced software tools, only partially meets the requirements of exploiting a lake. For this reason direct measurements are preferred, which are usually done determining periodically the depth of the lake in a lot of points of known coordinates, by the displacement of the measurement system with a mobile mean floating on the surface of the lake; all these measurements leads to the so-called bathymetric maps. The disadvantage of this method is that the measurement accuracy is affected by the position accuracy of the mobile mean, of the accuracy determining its coordinates in the horizontal plane.

SEDCONTROL project proposes a system for measuring the deposition of sediments on the bottom set in a fixed point, completely eliminating the disadvantage presented above. It consists of two subsystems of ultrasonic elements:

- a distance measurement subsystem that consists of four ultrasonic elements oriented vertically downwards and arranged circularly at 90°; each ultrasonic element is based on a piezoelectric crystal that electrically excited in a certain way, emits an acoustic wave in the ultrasonic field; this wave is reflected by the bed sediments and meets after a period the piezoelectric crystal, producing an electrical signal; knowing the propagation speed of the wave in the medium is determined the distance between the fixed ultrasonic element and the bed sediment, resulting its evolution over time; in this case, the ultrasonic elements are of transmitter and receiver type; they are mounted circular at a certain radius from the anchor point to reduce errors introduced by the measurement system; the four measurements can be averaged and reported to the central point; the measurement resolution of this subsystem is limited by the emitted wavelength, so it depends on the operating frequency of the ultrasonic elements, which is the limited at several MHz; for example, for a transducer of 200 kHz, the resolution is:

\[
\frac{\lambda}{2} = \frac{v_{pa}}{2 \cdot v} = \frac{1500 m/s}{2 \cdot 200000 Hz} = 0,00375 m = 3,75 mm
\]  

(1)
This subsystem can be completed by a temperature sensor allowing software compensating of the environmental temperature changes, which influences the wave propagation speed; it works best in the case of a firm bed sediment, of sand-stony type, with a good reflectivity;

- a sediments detection subsystem that consists of pairs of ultrasonic elements, arranged vertically in the device body; it consists of pairs emitter - receiver set horizontally face to face at a certain distance; depending on the propagation environment - water or sediment – due to the difference of acoustic impedance there will be a different propagation time between transmitter and receiver, thus allowing to determine whether the respective pair silting occurred; frequency emitter and receiver operation is several tens of kHz; the sediment layer height is thus given by indirect measurement and the vertical distance between two pairs of emitter - receiver is in fact the measurement resolution of this subsystem; there are now similar optical systems based on LED components: the advantage of ultrasonic elements of the system is that it is much less affected of deposits on the walls that block the system after some time running any optical system; this subsystem is designed especially for sediment of silt type and is complementary to the first which may give uncertain results for of such sediments.

Measurement system also contains the power electronics module and processing sensor signals from sensors, ultimately resulting in numerical information; it is sent by cable to the surface, where it is processed in a PC computing unit. Application program allows changing sampling rate measurements, processing and presentation of data, including activating an alarm in an event previous specified.

SEDCONTROL system is composed (fig. 3) of anchoring elements (1), the module of ultrasonic emitter type elements E (2) arranged in front of the module of ultrasonic receiver type elements R (3) to a distance d, the two modules (2) and (3) forming the sediment detection subsystem; the system also contains the power electronic modules and processing sensor signals from sensors (4) and (5), the support arm (6) which provides measurements at a sufficient distance from the anchor so as to limit the influence of the measuring system, the four ultrasonic emitter - receiver type E - R (7) arranged at 90° on a circular ring of radius r that will produce an average distance reported in the anchor and a hanging element (8). Support arm (6) with ultrasonic elements (7) form the distance measurement subsystem.

![Fig. 3: SEDCONTROL embodiment](image)

In order to choose the distance ultrasonic underwater transducer 7, some theoretical aspects must to be taken into account. The differential equation of the plane wave is:

\[
\frac{\partial^2 \psi}{\partial x^2} - \frac{1}{v^2} \frac{\partial^2 \psi}{\partial t^2} = 0
\]  

where \( \psi \) is the wave function, \( x \) is the displacement direction, \( v \) is the displacement speed and \( t \) is the time.

In a more general case, when the wave propagates in space, the equation (2) becomes:

\[
\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} - \frac{1}{v^2} \frac{\partial^2 \psi}{\partial t^2} = 0
\]  

or in the classical form:

\[
\nabla^2 \psi - \frac{1}{v^2} \frac{\partial^2 \psi}{\partial t^2} = 0
\]
McRobbie [4] used this equation to simulate the wave propagation generated by a piezoelectric crystal in an underwater environment. The pressure plot is represented in fig. 4 and the corresponding beam transmit plot in fig. 5:

For many transducers, the pattern from fig. 5 has multiple lobes, as in fig. 6; it belongs to the sensor TC2024 from RESON (fig. 7), which correspond to this project requirements, working at 200±10 kHz (fig. 8):

Figure 9 represents a cross view through the module with ultrasonic sensors, showing the linear array of sensors.
Conclusions

SEDCONTROL system - a POSCCE - A2-O2.1.2-2009-2 project, contract 131 / 04.06.2010 - has the following advantages:
- allows for direct measurements in a fixed measurement position is not affected by the inevitable errors of mobile systems;
- allows for real time information on changes in sediment layer;
- is little affected by sedimentary material deposits on the walls of the system compared to optical systems.

References