

Sensitivity of the acoustic discharge measurement on silt content

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Introduction

Acoustic discharge measurement (ADM) employing multipath acoustic transit time flowmeters is a non-intrusive, accurate method for permanent flow measurements. Generally the method is robust and shows excellent long term repeatability. In case of high silt content in sewage treatment plants, irrigation channels or hydroelectric plants, however, the acoustic signals may be greatly disturbed and the repeatability of measurements is less reliable.

In collaboration with the University of Applied Sciences of Central Switzerland, HTA Lucerne, and the Swiss Federal Institute of Technology Zürich, ETHZ, Rittmeyer Ltd has initiated a research project to investigate parameters of influential factors, such as particle size, particle concentration, particle type, flow velocity, length of the acoustic path and frequency of the emitted signal. The project is co-funded by the Swiss Commission for Technology and Innovation (CTI). Key aspect of the project is to acquire knowledge regarding the limits of application of the acoustic method using different types of sensors, emitters and receivers. Furthermore, potential of improvement of the range of application shall be identified and implemented.

The effect of particles on flow measurement is of interest in various fields of application of acoustic discharge measurement. In hydro power plants the silt content varies seasonally. In rainy seasons or when the winter's snow thaws, the silt content may increase dramatically and acoustic discharge measuring devices fail. Typically the particles vary from μm to mm size and differ in shape. The suspended material contains mostly silt and clay in form of single particles or colloids. On the other hand, in waste water treatment plants mostly organic substances are observed, which often form colloids. Due to free surface flow, turbulence and aeration, gas and air bubbles are commonly observed in waste water. The effect of air bubbles is in a way similar to that of solid particles: scatter and dispersion of acoustic pulses occurs.

The reliability of instruments and competent consultancy are important sales arguments. Satisfied customers are the best references for new contracts for these high investment products. For this reason proper data on the consequence of silt and air content in the water are needed.

Sediment transport

The entrainment of particles in the flow depends on their size and density. The weight of particles determines the force of gravity pulling them downward. Entrainment also depends on the shape of the particles. Particles with larger surface to volume ratios will experience higher fluid forces and will thus be more susceptible to being entrained by the flow. The interaction of small and large particles becomes important in high particle concentrations.

The velocities that are required to entrain particles of certain sizes are commonly plotted in Hjulstrom diagrams (Fig.1). Hjulstrom diagrams show particle entrainment plotting log particle size versus log flow speed. This diagram shows the areas where grains of different sizes are deposited on the river bed, where they get transported, and where they get lifted up (eroded) and entrained. In general, larger particles require higher velocities. The minimum water speed that is required for transportation is called "critical velocity".

Deeper flows can move larger particles at the same flow velocity because they have a higher turbulence level since for the same velocities the Reynolds number is larger. Actual flow characteristics and transport phenomena are much more complex in reality than Hjulstrom diagrams suggest.

At the lower end of the scale of particle size, for silt and clay, the speed of flow required for erosion actually increases. This is because the surfaces of clays tend to be negatively charged and the particles stick together. The smaller the particles, the bigger the effects of surface charge. The stickiness of the clay particles also depends on the amount of water between them and the mineralogy. Finer silts and clays remain suspended even at very low flow velocities. Suspended load comprises sand, silt, clay-sized particles that are held in suspension because of the turbulence of the water. The suspended load is further subdivided into the wash

load, which is generally considered to be the silt and clay-sized material (< 62 μm in particle diameter). The wash load is mainly controlled by the supply of this material (usually by means of erosion) to the river. The amount of sand (>62 μm in particle size) in the suspended load is directly proportional to the turbulence level in the river. Due to this, particle size distribution and concentration not only vary in the vertical section, but may also vary considerably across a river section.

Clay particles are plate-like in shape and have a maximum dimension of about 4 μm. Silt particles, like sand, have no characteristic shape; their size is between those of clay and sand, with diameters ranging from 4 μm to 62 μm.

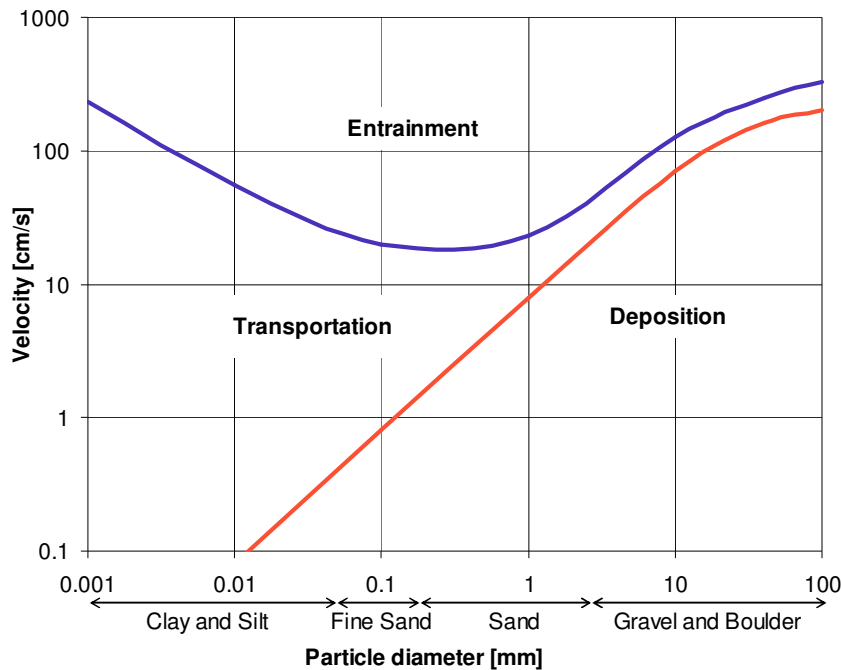


Fig.1 Hjulstrom diagram

Measurement of suspended particles

The total amount of suspended solids can be measured in the field by high precision continuous pressure difference measurement, which allows determination of the density of the flow. In the laboratory the total amount of suspended solids can be determined by evaporating samples and weighing the solid material content [ISO 2591, ISO 4365, ISO 9276].

With respect to the acoustic discharge measurement, not only the total amount of suspended solids is of importance but also the particle size distribution. The sizes of clay and small silt particles prevailing in the flow cannot be determined by sieving, since the smallest mesh size of commercially available sieves is about 40 μm. In laboratories sedimentation techniques are used. The sedimentation rate of the particles is measured and their diameter calculated from the semi-empirical equation known as Stokes' Law. For continuous monitoring of the suspended particle concentration and particle size range, however, sedimentation techniques are not suitable.

Two optical techniques are used for monitoring: optical backscatter and optical transmission. The backscatter method uses infrared or visible light directed into a sample volume and photodiodes to measure the scattered light. In the optical transmission method the sensor is located opposite the light source and measures the attenuation of light intensity. These turbidimeters need to be calibrated and the calibration unfortunately varies with particle size and color. The units of turbidity from calibrated instruments are called Nephelometric Turbidity Units (NTU).

Acoustic techniques use the backscatter of pulsed acoustic bursts. The intensity of the backscattered signal depends on the concentration, particle size, and frequency. By using multiple frequencies both particle size and distribution can be determined [Thorne et al. 2002].

Currently the best, but also most expensive, method is the laser diffraction method. Here a laser beam is directed into the sample volume, where the suspended particles scatter, absorb, and reflect the beam. Light blockage produces a diffraction pattern that overrides the light intensity in the original direction. This diffraction pattern is received by an array of detectors. The diffraction pattern is weaker and wider for small particles, but tall and narrow for large particles. The width helps determine particle size while the magnitude gives evidence of concentration [Agrawal, Pottsmith 2000].

Influence of suspended particles on acoustic wave trains

The scatter of acoustic signals at individual particles (solid or gas) in motion is widely known and described in literature [e.g. Dukhin, Goetz, 2002]. Theoretical approaches for describing forward and back scatter are available. Statistical methods are needed in order to describe scatter with a large particle number .

In a first phase of the project, a comprehensive analysis of the models presented in literature to estimate solid content and average particle size in solid-liquid dispersions will be carried out. The models will be chosen for their ability to relate the measured variables (sound speed and sound attenuation at a single frequency) to the main variables - particle concentration and average particle size. Theoretical models for determining the wave propagation speed and the attenuation of the sound wave as a function of particle concentration and size are derived from the interaction of the incoming sound wave with the particles (forward and backward scattering, absorption) [Kytöma 1995, Hipp, Storti, Morbidelli, 2001/2002]. These models can be simplified by classification of different wavelength regimes dependent on the particle size (radius r) and the wavelength λ of the incoming sound wave:







Long Wavelength Regime LWR	$r < 0.05 \lambda$			$r < 74\mu\text{m}$
Intermediate Wavelength Regime IWR	$0.05 \lambda < r < 50 \lambda$			$74 \mu\text{m} < r < 74\text{mm}$
Short Wavelength Regime SWR	$50 \lambda < r$			$r > 74\text{mm}$
				Particle in water (20°C), frequency 1MHz

Fig. 2 Identification of three simplified wavelength regimes

Figure 3 displays the boundaries of the three regimes in double logarithmic scales. In the applications covered in this study, the frequency lies between 200 kHz and 2 MHz and the particles radius between 0.5 μm and 500 μm . This means that the long wavelength (LWR) models apply for most of the relevant cases.

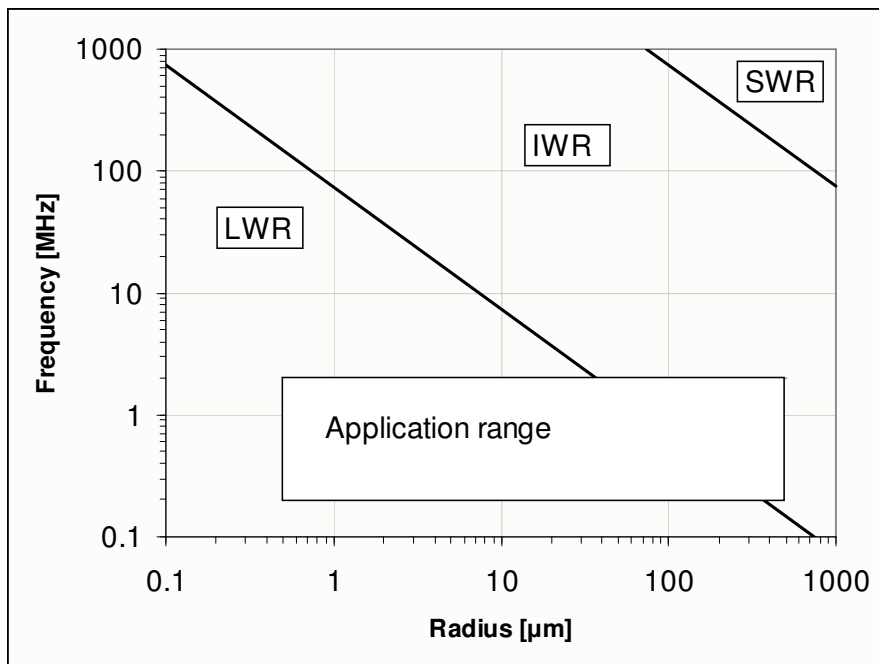


Figure 3: Application range of simplified wavelength regimes (Diagram applies to solids in water at 20°C)

Typically, in hydro power stations the particle concentration covers a wide range. Small concentrations of less than 0.1g/l provide ideal conditions for the transit time method. However, in highly loaded rivers silt content may reach 10g/l or even higher concentrations. Such concentrations have a detrimental effect (abrasion) on the turbines. Generally it is recommendable to shut down the turbines to prevent damage if particle concentration is higher than 5g/l. Accordingly, acoustic discharge measurement should also work reliably up to this concentration. Flowmeter manufacturers are challenged to develop systems allowing measurement of the flow rates under such difficult conditions for path lengths of typically up to 10 to 15m.

In waste water applications with high particle concentrations the Doppler method is very often adopted. The reliability of this method is clearly superior to that of the transit time method due to the high particle concentration. However, the accuracy of the measured flow values obtained by the Doppler shift will be inferior to those obtained by the transit time method – if this method can be implemented. Accordingly, it is preferable to use the transit time method up to the highest concentrations possible.

Laboratory tests

To our knowledge no systematically performed experimental study of the disturbance of acoustic wave trains by heavily silt loaded water flows exists or, at least, these studies have not been published, as could be concluded from preliminary review of the literature. In a prospective experimental study all essential influencing parameters shall be quantitatively investigated:

- volume fraction of particles,
- size of particles,
- length of the acoustic path,
- flow velocity,
- flow conditions,
- emitted frequency
- possibly: particle shape and material properties (quartz sand, clay colloids).

The effects on the received wave fronts shall be characterized (dissipation, magnitude, scatter, travel time detection, possibly Doppler frequency shift).

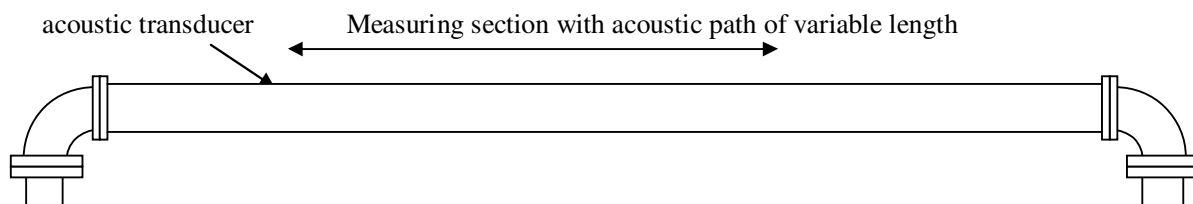




Fig. 4 Test rig

The intended test rig will allow performing tests at flow velocities typical to hydro power plants. It will be possible to vary the acoustic path length between 2 and 12 m. Since the silt laden water will have to be replaced often, the water volume in the test rig will have to be kept to a minimum. For this reason the acoustic pulses are sent in flow direction and opposite along the pipe axis. A major challenge will involve eliminating effects of acoustic reflections from the pipe walls.

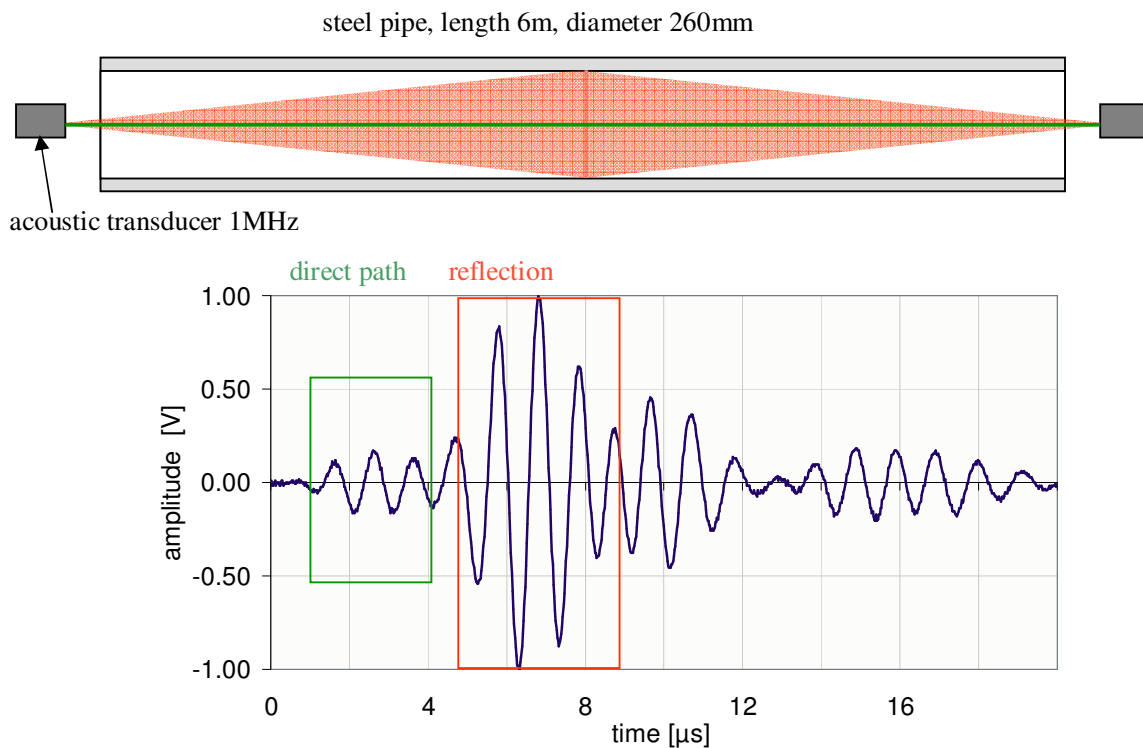


Fig. 4 Signal reflections

Figure 4 shows a signal sent through a straight pipe 6 m long. The first order reflections, which have a slightly longer transit time, possess greater signal strength than the direct signal arriving first at the receiver. These signal disturbances are to be eliminated by inserts in the pipe.

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Further experiments, carried out at the ETHZ by the Morbidelli group (www.morbidelli-group.ethz.ch), will focus on acoustical identification of the solid-liquid properties. Two kinds of experiments will be carried out. First, measurements of sound speed and attenuation at a single frequency in a stirred, closed tank will be performed. Different conditions in terms of solid concentration, average particle size and stirring rate will be examined. Secondly, the same experiments will be repeated inside available ultrasound spectroscopy equipment, in order to gain deeper understanding of the system behavior for different frequencies and to validate the results obtained at the single frequency in the first experiment. The deliverables should consist in a comprehensive set of experimental data for the selected model system.

Field tests

In a series of field test transferability of the laboratory tests shall be verified. These field tests will be performed in conditions with varying particle concentrations. The goal is to acquire quantitative knowledge on the applicability of the acoustic transit time method in the field and also of the limitations when high silt concentrations prevail.

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