Transducer emitter-receiver system for a pulsed ultrasonic fluxmeter

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Introduction

The knowledge of velocity fields in flows and of mechanical interactions between fluid and suspended particles is a base of waste water management. The measurement of pollutant flow is one of the main parameters. Several methods can be used to extract these informations, like laser and warm film for velocity, or sampling for particle density. Nevertheless, one of the most interesting techniques in this domain is the use of ultrasonic waves, for nonintrusive flow measurement in large diameter pipes for opaque complex fluid flows.

This communication presents a fluxmeter prototype for instantaneous measure of velocity, concentration and granularity profiles in particle loaded fluids. This sensor is mainly a laboratory tool with the possibility to vary several working parameters. The interest holds in defining a topology that permits the delivery of the best velocity and granularity informations.
This prototype is a start point for the study of an industrial on-line real-time fluxmeter in partnership with two private companies and one public laboratory. This development will be held in the frame of a RITEAU project (Réseau de recherche et d'innovation technologique eau et technologies de l'environnement).

Principle

Two main techniques are used to extract the velocity information from the liquid with the use of ultrasounds: transit time measurement and Doppler effect method. The fluxmeter developed at IMFS uses pulsed ultrasonic echography together with the detection of the instantaneous Doppler frequency [1][2]. By this way, a velocity profile can be obtained with good spatial resolution.

The system works alternately in emission and reception. It sends an ultrasonic burst into the pipe, then receives the combination of the retro-diffused echoes. The volume crossed by the ultrasonic wave is divided into several subvolumes whose respective submeasures are obtained by temporal sampling of the echoes (Figure 1).

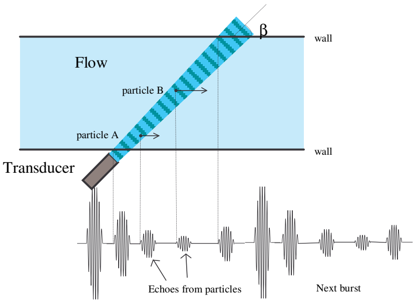


Figure 1: principle of flow scan

For every spatial volume, the reception of repeated echoes, modulated with the ultrasonic frequency and low filtered, would construct a waveform with Doppler information inside. Finally, the velocity and its accuracy are calculated from the Doppler frequency (1) obtained via Fast Fourier Transform (Figure 2):

$$V = \frac{c \cdot f_D}{2 f_0 \cdot \cos \beta} \qquad (2)$$

with:

V: fluid velocity,
c: acoustic velocity,
f_D: Doppler frequency,
f_0: ultrasound frequency,
β: angle between flow and transducer.

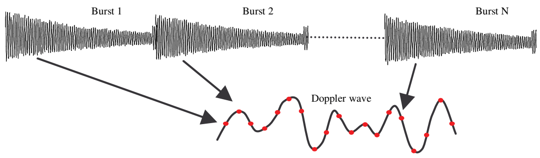


Figure 2: construction of Doppler waveform from reception of repeated echoes

As the sampling rate of the Doppler echo depends on the pulse repetition frequency, this method has a direct limitation resulting in a bond between the measurable depth and the maximum detectable velocity (3) :

$$V_{\max}.d_{\max} = \frac{c^2}{8 f_0} \qquad (4)$$

with:

d: flow depth

For performing granularity measurement, ultrasonic bursts will be send to the medium at different frequency in order to privilege reflection of particles with specific diameter according to (5) [3]:

$$a_{op} \approx \frac{c}{2\pi f_0} \qquad (6)$$

with:

a_{op}: optimum particle radius

Thus, concentrations of different radius range particles can be extrapolated from the retro-diffused echoes.

System topology

The system is based on an industrial PC structure. Indeed the studies carried out require the possibility to sweep in frequency and amplitude for transducer control. The use of a PXI based computer allows both to benefit from the PXI systems Alliance modules, and to incorporate specifically developed PCB boards with front-end control and readout device. The selected topology consists in an arbitrary waveform generator, for emission in the medium through a front-end board and an ADC board to digitize the signal (Figure 3).

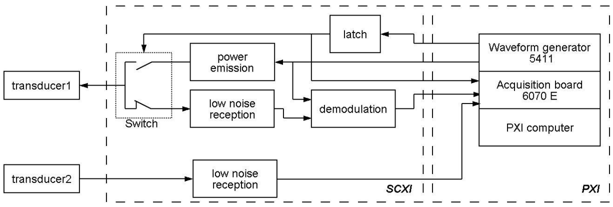
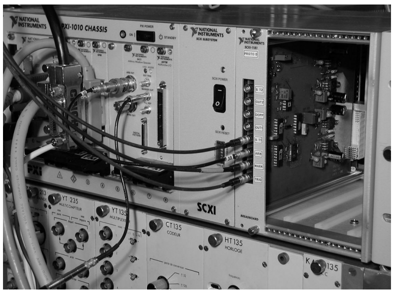


Figure 3: system topology

The front-end board is built up around three main blocs:

- analogue switches: for switching between emission and reception. To drive maximum power to the transducer, their R_{ON} must be as low as possible. This involves a higher charge injection, which produces parasitic shapes problematic at given frequencies;
- an emission line: based on two parallel integrated power amplifiers (to drive low impedance transducers). Waves up to 20V can be generated from DC to 8MHz;
- reception lines : both lines have low noise preamplifiers, with large bandwidth for good matching with differently frequency centered transducers. The first channel uses an AD600 with variable gain adjustment, and shows good linearity for inputs from 0 up to 140mV from DC to 10MHz. The gain is around 30dB and the input noise equals 72µV. This channel contains a multiplier and a lowpass filter in order to generate the Doppler information. The linearity curve of the second channel is a little higher (0 to 150mV), with the same bandwidth and a gain of 28dB. Based on an OPA687, this stage had a weaker equivalent input noise (49µV).



Experimental results

Experiments were carried out in a laboratory pipe (Ø5cm) using vaseline oil seeded with particles. Our experimental data validate the principle of instantaneous measurement of velocity profiles of particles in suspension in a fluid. A second pipe (Ø20cm) permitted measurements closer to waste water context. Both charged and open channel flows conditions were present, and good agreement between theoretical and measured values were observed. Raw data raise the problem of multiples echoes and depth-velocity limitation, but different solutions in the processing of the data will be tested, like Multi Repetition Frequency, or Random Phase coding (Figure 4).

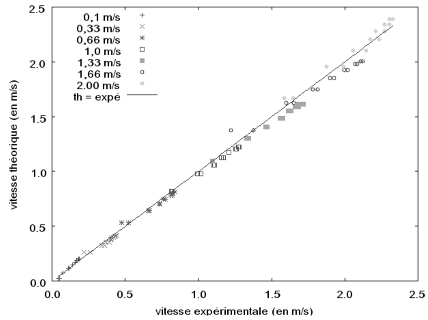


Figure 4: theoretical versus measured velocities

Ultrasound beam directivity and frequency sweep measurement were carried out to introduce granularity studies. The first system equipped with three transducers will be developed in the next months. Nevertheless, first results were obtained by analysing the Doppler signal amplitude. Good proportionality was observed between this signal and particle concentration in a calibrated fluid (Figure 5).

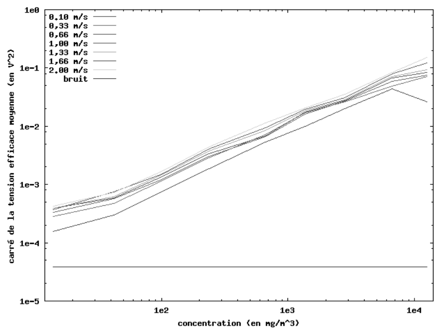


Figure 5: Doppler signal versus concentration

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