Flow-Viz™ – A fully integrated and commercial in-line fluid characterization system for industrial applications

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A new fully integrated ultrasound based in-line fluid characterization system, Flow-Viz™, has been developed especially for opaque, non-Newtonian industrial fluids. The new embedded and commercially available system is designed to meet industrial requirements. Flow-Viz™ enables true non-invasive, real-time Doppler measurements and is able to visualize the flow and to rheologically characterize industrial fluids continuously while providing continuous feedback to an existing process control system for enhanced efficiency. The Flow-Viz™ system consists of an operator's panel, a multi-touch monitor and an industrial PC unit and pulser-receiver electronics. The electronics has been improved and extended by adding a second ultrasound channel, augmenting the on-board data processing for obtaining the optimal performances in high attenuating suspensions. A new Motherboard provides an additional 8-channel digital and analog input and output capabilities for simultaneous data acquisition and connection to a process control system. The new electronics is combined with a non-invasive ultrasound sensor unit, which allows measuring the flow velocity profile even through industrial high grade stainless steel pipes. This unique solution makes possible to adapt the high resolution UVP+PD technique for industrial processes performed at high temperatures and/or pressures using a wide range of different industrial fluids. The Flow-Viz™ system is already installed in industry, e.g. for chocolate and grouting applications and an international patent has been filed.

Keywords: ultrasound, Doppler, Ultrasonic Velocity Profiling (UVP), rheometry, industrial process monitoring

1 INTRODUCTION

The enhanced tube viscometer concept aiming to derive information on the flow behavior of industrial fluids using the UVP+PD methodology, i.e. Ultrasound Velocity Profiling (UVP) with Pressure Difference (PD) is older than 30 years [1]. Despite this, no in-line fluids characterization instrument based on Doppler velocimetry has been made commercially available meeting industrial requirements [2].

In this work we present an embedded in-line fluids characterization system, "Flow-Viz™", specifically designed for the in-line velocity profile measurements and rheological assessment of opaque, non-Newtonian industrial fluids. The Flow-Viz™, system is the result of the work of several research groups that have systematically improved this concept for a period of more than 14 years to ensure that the system can be used in industry for a quantitative analysis of the rheological properties of real industrial fluids, [2-5]. New improved and extended UVP+PD electronics, based on former work [6-8] have been developed. In industrial processes it is an absolute requirement to measure non-invasively through stainless steel pipes. Despite this, no such transducer technology has been made available as an off-the-shelf product [2,5]. To overcome this limitation, new non-invasive sensor technology has been developed, optimized and validated for SS316L stainless steel process pipes of different diameters and wall thicknesses [2,5]. The instrument has been validated to meet industrial requirements for many different applications and to deliver accurate real-time data, such as instantaneous velocity profiles and rheology of opaque industrial fluids [2-4, 7-8]. The Flow-Viz™ system is already installed in industry, e.g. for chocolate and grouting applications.

2 THE FLOW-VIZ™ IN-LINE FLUIDS CHARACTERIZATION SYSTEM

2.1 Overview of the Flow-Viz™ system

The Flow-Viz™ system consists of three main components:

1) Operator's panel

2) Sensor unit

3) Software

2.2 Operator's panel

The operator's panel houses the newly developed digital Flow-Viz™ hardware platform; the pulser-receiver and data acquisition (DAQ) electronics, described in detail in section 3, power supply, a 19"-multi-touch monitor, a sensor connector block and an industrial PC unit. The built-in 19"- monitor offers a user-friendly interface with multi-touch gesture navigation.

Flow-Viz

Figure 1: The Flow-Viz™ operator's panel featuring the electronics, main Industrial PC unit, sensor block and multi-touch monitor.

2.3 Sensor unit

The industrial grade sensor unit, shown in Figure 2, is installed in the process piping network and makes up the measuring section. It comprises a stainless steel cabinet protecting the heat-jacketed stainless steel pipe with inner diameters ranging from 10 mm up to 165 mm (or larger). The measuring section is equipped with a pair of custom developed non-invasive transducer assemblies, a differential pressure sensor with remote seals (ABB Automation Technology Products AB, Sollentuna, Sweden) and a non-invasive PT-100 sensor (Pentronic, Gunnebo, Sweden).

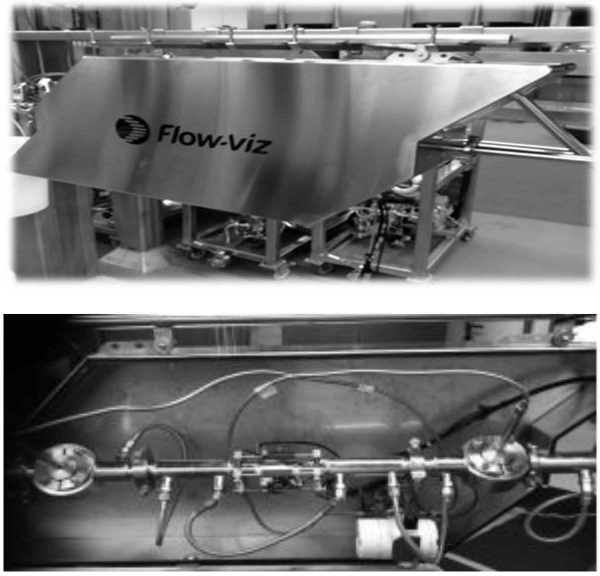

Figure 2: The industrially approved sensor unit featuring the unique custom made non-invasive transducer assembly.

2.4 Non-invasive transducer technology

To meet industrial requirements, a new non-invasive 0.7-7 MHz sensor unit technology has been developed, optimized and validated for SS316L stainless steel pipes of different diameters and wall thicknesses [2, 5]. The Flow-Viz™ non-invasive sensor unit, shown in Figure 2, is the only sensor solution that allows true non-invasive velocity profile measurements in highly attenuating suspensions through stainless steel wall materials.

2.5 User-friendly GUI software

The Flow-Viz™ system comes with a user-friendly GUI software interface optimized for the multi-touch gesture monitor. The software is used for setting the parameters (of which most are automated), controlling the data acquisition, signal-processing and for visualization and export of the data. The data is stored in an SQL database. An result display screen sample is shown in Figure 3.

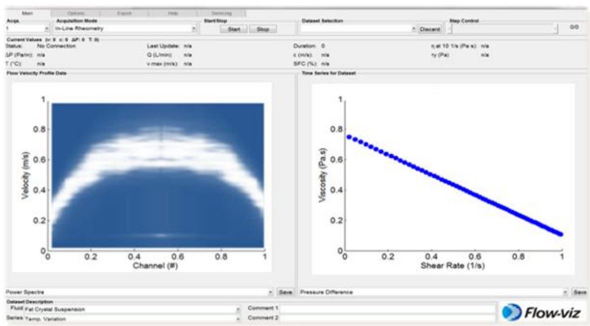

Figure 3: The Flow-Viz™ GUI software interface.

3 ELECTRONICS & SIGNAL PROCESSING

3.1 Overview of the Flow-Viz™ electronics

The Flow-Viz™ system is a newly designed and fully integrated hardware platform comprising a total of four analog and digital electronics boards. The new Flow-Viz™ electronics has been developed in collaboration with the University of Florence, Schmid Elektronik AG (Münchwilen, Switzerland), Sika Technology AG and Sika Services AG (Zurich, Switzerland) [6-8]. The electronics are controlled by an industrial PC unit comprising a >2.5 GHz Intel® Core™ i7 quad-core CPU with CFast and SSD memory cards, 8GB RAM, 6 USB 3.0 ports and 2 independent Gbit Ethernet interfaces for remote control. The system also features a powerful PLC system for improved signal-processing capabilities.

3.2 Motherboard

The Motherboard (Schmid Elektronik AG) provides filtering and stabilization of the power, 8 analog and digital input and output channels; 4–20 mA, 0–10 V, +/-5 V; 16 Bit, 4 PT100 circuits and serial ports. The Communications board is a National Instruments (NI) sbRIO-9606 module. The sbRIO board has a 400MHz processor, a Field-Programmable Gate Array (FPGA), 96 DIO lines and provides Ethernet, RS232, CAN and USB connectivity. The IOs on the base board are controlled from the FPGA on the sbRIO. The electronics enables simultaneous UVP, pressure and temperature acquisition and signal-processing from multiple sensors. It also provides real-time communication capabilities to an industrial PC, see Figure 4.

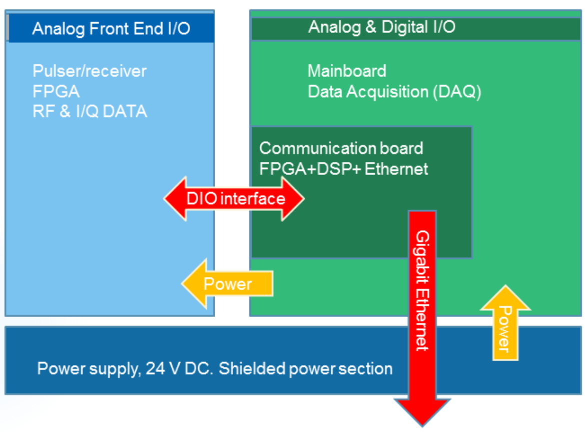

Figure 4: The embedded Flow-Viz™ pulser-receiver, sbRIO and motherboard electronics.

3.3 Pulser-receiver electronics

The upgraded pulser-receiver electronics are based on a previous research board developed by the University of Florence [6]. They include all the electronics needed for the acquisition and processing of ultrasound signals. It features 2 transmit/receive (TX/RX) channels that can work in stand-alone or pitch-catch configuration. The transmitters, based on an Arbitrary Waveform Generator (AWG), is capable of producing bursts, typically at up to 80 Vpp with a frequency between 0.7–7 MHz. The inputs are amplified with Time Gain Control (TGC) units featuring a gain up to 55 dB, converted to digital at 16-bit 100 MS/s, and processed in an FPGA (Cyclone family from Altera, San Jose, CA). The FPGA include coherent demodulators, filters and a Fast Fourier Transform (FFT) processor for spectral analysis. The boards are equipped with 64 MB of SDRAM memory where acquired raw samples or demodulated data can be buffered.

3.4 Signal processing

The Flow-Viz™ system and software allows velocity estimation using several algorithms: FFT, time-domain, spectral, etc. that can be used simultaneously to improve the measurement accuracy under industrial process conditions. By using FFT, the velocity profile is typically estimated through a weighted mean of the Doppler power spectra from each depth. The non-invasive sensor unit and new improved electronics makes it possible to obtain the full profile over the complete pipe diameter, depending on the fluid characteristics. It also allows measurements of velocity data close to pipe walls, which is critical for accurate fluid characterization. The application of a model-fitting approach for the rheological characterization has been demonstrated to lack robustness for some industrial applications due to several reasons [2-3, 8]. Therefore, an alternative method was developed in which the shear viscosities as function of shear rates are determined directly from the measured velocity profile and pressure drop data. The yield stress is automatically determined from the plug radius. The Flow-Viz™ direct non-model approach has been verified to be both more robust and accurate compared to traditional model-fitting approaches as it can capture e.g. a Newtonian plateau [2].

4 RESULTS – APPLICATION EXAMPLE

Particular care has been devoted to optimize the noise performance for investigating attenuating media, i.e. industrial fluids such as chocolate, pulp, grouts etc. For example, the board can be connected to balanced transducers, the AWG can synthetize coded bursts for pulse compression, an high-performance Low Noise Amplifier (LNA) with a 0.74 nV/√Hz noise level is used, the switching power noise is cancelled in Doppler by the synchronization of the power section to the Pulse Repetition Interval (PRI), programmable filters allow a fine tuning of the RX bandwidth, the filters and FFT processor work at 24 and 32 bit, respectively. Figure 6 shows a typical example of a spectral profile of industrial fluid, ketchup, measured non-invasively through an SS316L stainless steel pipe with an inner diameter of 51mm. Settings: PRI 91500 clock cycles, 30V, 25 dB.

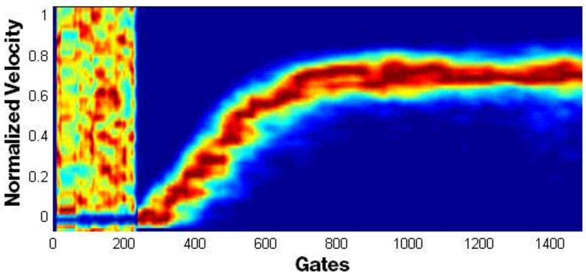

Figure 5: Spectral profile of an industrial fluid, ketchup, measured at a volumetric flow rate of 56 L/min.

The large 64 MB memory buffer allows wide signal averaging in case of constant flows. The acquisition and processing parameters are fully programmable. PRI length, extension and position of the acquisition window, transmission and demodulation frequency, transmission amplitude, TGC and filters coefficients, can be changed by the user. The noise performance was tested with an input load of 50 Ohm and using a maximum gain of 55 dB and a noise level of 2 nV/√Hz was measured.

5 SUMMARY

A new fully integrated ultrasound based in-line fluid characterization system for industrial applications has been developed and validated under real industrial process conditions over the past 14 years. The commercial version of the Flow-Viz^{TM} system features upgraded electronics combined with novel non-invasive sensor technology allowing true in-line flow visualization and rheological characterization of opaque, non-Newtonian industrial fluids flowing in industrial grade stainless steel pipes. An international patent has been filed and the Flow-Viz^{TM} system has already been successfully installed in Europe and USA within large international companies. It has been successfully applied to a wide range of industrial applications, e.g. oil, petroleum, food, minerals, chocolate, explosive emulsions, pharmaceutical industry.

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