1. Introduction

In the annual report 1996 a new wire-mesh sensor for gas-liquid flows was presented [1]. In the last two years the sensor was applied to an air-water flow in a vertical pipeline (inner diameter \(D=51.2\text{mm}\)) to study the flow structure in a wide range of superficial velocities. Besides the void fraction distributions, the high resolution of the sensor was used to calculate bubble size distributions from the primary measuring data. This allowed to study the evolution of the flow structure along the pipe [2]. The maximum time resolution available to perform these experiments was 1,200 measurements per second. Now we can report about the increase of the measuring frequency to 10,000 frames per second. In the result it is possible to visualise and quantify individual bubbles or droplets at a much higher flow velocity, than before.

2. Working principle of the wire-mesh sensor

The function is based on the measurement of the local instantaneous conductivity of the two-phase mixture. The sensor consists of two electrode grids with 16 electrodes each, placed at a small axial distance behind each other (Fig. 1). The conductivity is measured at the crossing points of the wires of the two grids. One plane of electrode wires is used as transmitter, the other as receiver plane. During the measuring cycle, the transmitter electrodes are activated by a multiplex circuit in a successive order, as illustrated in Fig. 2 for an example of 2 \(\times\) 4 wires.

The measurement for one row is started by closing one of the switches S1-S4. The currents arriving at the receiver wires are transformed into voltages by operational amplifiers and sampled by individual sample/hold circuits. After an analogue/digital conversion the signals are transferred to a data acquisition computer and stored for each receiver electrode separately. This procedure is repeated for all transmitter electrodes [3].

After the first laboratory prototype was successfully built, the wire-mesh sensor including the signal acquisition unit was qualified for...
series production in co-operation with the TELETRONIC Ingenieurbüro GbR. It is now commercialised by this company. The signal acquisition unit of this device contains the elements shown in Fig. 2. The timing of the transmitter activation, the sample/hold triggering and the AD conversion is controlled by a Freely Programmable Gate Array (FPGA). The unit must be linked to a data acquisition computer (PC) to be operated. A parallel interface (16 bit) is used to transfer the AD conversion results to the personal computer. This interface is coupled to the ISA-bus of the PC. This is the main factor limiting the measuring frequency of the system to 1.200 frames per second.

When we look at this time resolution from the point of view of flow visualisation, we find for example that bubbles of several millimetres magnitude are mapped in several successive instantaneous gas fraction distributions (frames), if the flow velocity is not too large. At 1 m/s the bubble travels about 1 mm in 1 ms, i.e. a bubble of 5 mm diameter is displayed in approximately 5 - 6 successive frames. When the flow velocity is increased, the situation soon becomes worse. In the interesting region of transition from slug flow to annular flow, which takes place at velocities of about 10 m/s, bubbles or droplets of the mentioned size can even cross the measuring plane without being visualised. For this reason efforts were made to increase the measuring frequency to 10,000 frames per second. In December 1999 the first prototype of the new generation of signal acquisition units was successfully tested at the two-phase flow loop of the institute.

The analogue part of the first generation of signal acquisition units was already designed for a higher measuring frequency. A sufficient improvement of the signal quality was achieved by placing the preamplifiers of the receiver electrodes as well as the driver circuits for the transmitters into the casing of the connectors at the end of the cables to the sensor.

The main optimisations had to concern the digital part, i.e. the AD conversion, the data storage and the data transfer to a data evaluation computer. The main feature of the second generation unit is an integrated digital signal processor (Analog Devices Sharc DSP 21065L) managing a data storage of 64 MB external SDRAM. The activation of the transmitter electrodes and the work of 16 AD converters is again controlled by an FPGA (Freely Programmable Gate Array). The pulse width for the transmitter electrode activation is 3 µs. Within this time, the transient of the receiver amplifiers is settled. The ADCs, one for each receiver electrode, have a conversion time of 2.3 µs. For noise reduction, every measurement is carried out twice - once for the positive half-period of the transmitter pulse and a second time for the negative half-period. Afterwards, the conversion results are subtracted from each other by the FPGA, the DSP takes over the data into the RAM. The AD conversion for both half periods is carried out during the build-up time of the signal of the other half period. In this way, a total measuring period for one transmitter wire of 6 µs and the corresponding measuring frequency of 10,000 frames per second were achieved.
The transfer of the measured data to the data acquisition PC is performed only after the completion of the measuring series. For this purpose, the DSP is equipped with an ETHERNET interface. The memory size is sufficient to store 170,000 individual measuring results for all 16 x 16 crossing points of the sensor, i.e. a continuous measurement over 17 s is possible.

3. **Flow pattern visualisation**

The output of the wire-mesh sensor consists of a time sequence of local instantaneous void fractions that characterise the presence of the gaseous phase in a grid of measuring positions in the cross section. These data sets can be used for a visualisation of the two-phase flow. With the help of a special software the individual gas fraction distributions can be displayed as a sequence of frames. Eulerian sectional views of the gas fraction distribution in the vertical center plane of the pipe can be obtained, if successive void fraction distributions over the diameter are plotted in a vertical stack, beginning from the top and moving downwards. The resulting graphs give the impression of a side view of the flow. In Fig. 3, the increase in resolution gained by the new signal acquisition unit is illustrated for a slug flow. At the right side the flow pattern is shown in the high resolution of 10,000 frames per second. At the left, the same data is shown with a time axis compressed by a factor of 8. In this way, a comparison to the resolution of the first generation of signal acquisition units for one and the same experiment run is possible. It is clearly visible, that the bubble cloud in the wake of the slug is resolved in much more detail.

The comparison of signals, obtained at different experiment runs with both the old and the new device is shown in Fig. 4. Here, different realisations of the flow pattern at identical superficial gas and water velocities are presented. The examples are taken from the region of higher flow velocities. The signal recorded at the higher measuring speed offers much more details. Furthermore, it is very important for the bubbles size measurement, that individual bubbles are visualised in several successive frames at the high measuring speed, while they are found only in one single frame at the low speed (one line in the sectional plots).

4. **Conclusion**

The new generation of signal acquisition units is able to deliver a flow visualisation with a resolution of 10,000 frames per second. This gains much more details of the flow structure, than before. The achieved measuring frequency extends the applicability of the wire-mesh
sensors towards the two-phase flow at velocities in the range of 10 m/s. In the next step, it is planned to increase the number of electrodes in order to make it possible to increase the sensor diameter without losing spatial resolution.

Fig. 4: Two-phase flow structure at $J_{\text{Water}}=4$ m/s and high air flow, A: first generation of signal acquisition units (1,200 Hz), B: second generation (10,000 Hz)

References

