EXTENDED ABSTRACT

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PhD work title: **Algorithms for Flow Velocity Determination Based on Spatio-Temporal Analysis Using Electrical Capacitance Tomography Images**

The PhD work concerns the use of computer science for measurements of multiphase flow parameters. The high precision of flow metering is unrelentingly required in order to provide the best control of system processes. One of the key parameters in the flow measurements is the velocity. Basic flow information about local velocity helps to provide better control of the process in different flow conditions. However, the measurement of the phase flow velocities is a big challenge. The main problem of flow velocity measurement occurs when an asymmetric and non-uniform flow profile is observed during the flow evolution, especially when the flow behaviour significantly differs from a laminar profile. Therefore, many classical methods and commonly-used software are not applicable in the case of complex multiphase flows. In order to meet the requirement, novel algorithms of flow velocity measureme in cases of swirl multiphase flows are proposed. Ones are based on statistical analysis of tomography images captured by an Electrical Capacitance Tomography system (ECT) and analyze the spatial and temporal relationships in tomographic images representing flow propagation in a given cross section (interest of the volume). The aim of this research was to develop novel algorithms that can be used to measure the velocity components of solid-gas flows when it is observed that the flow regime is undergoing dynamic spatial and temporal changes (from laminar to swirl flow). Such changes in flow behaviour necessitate further development of the relevant measurement systems. Moreover, the correct way to determine the velocity has been a subject of investigation.

In this dissertation, pneumatic conveying was considered as multiphase flow. With the aid of an Electrical Capacitance Tomography (ECT) system, the gas and solid phases are characterized by different permittivity values. The ECT is largely used as a non-invasive visualization technique based on sensing the differences in the dielectric properties (electric permittivity) of two phases appearing in the flowing medium (e.g. Gas and solid). ECT allows visualizing the material distribution inside the sensor. A typical 2D ECT sensor consists of electrodes located around the interest of the volume (for instance pipe cross section). A single image of the spatial distribution in a mixture volume of two materials is reconstructed based on a single set of capacitance measurements between each pair of electrodes, taken at one

time point. The analyzed images come from the high accuracy (typically 0.1FF) and high-speed acquisition unit (more than hundred frames per second for 8-electrode sensors) measures. The main advantages applying the ECT system are: no direct contact between the object under inspection and the sensors; no change in the characteristics of the explored object and the acquisition system is fast enough to control the dynamic industrial process in real-time.

In the case of dynamic multiphase flow, variations in magnitude and direction of the velocity are one of the most important issues generating errors during flow measurement. When these variations occur, flow velocity measurement requires looking for the three velocity components (axial, radial and angular). The swirl flow phenomenon appears in many industrial applications, and methods for axial velocity measurement have been widely developed and discussed in the literature. However, few studies calculate the angular velocity component when the flow turns out to be more complex. Therefore, in order to meet the requirement, a unique combination was elaborated and an algorithm for multiphase flow velocity determination was developed, taking into consideration the spatial and temporal changes of the flow during the evolution of the process and a tomographic data set obtained from an electrical capacitance system representing the flow's various behaviors. Swirl flow, especially requires the analysis of these three velocity components to determine the swirl angle and to explain the mechanism of the swirl phenomena. The significance of swirl flow measurement is confirmed very broadly in different industrial types of flow phenomena, where the control system is more efficient when the axial, radial and angular velocity components are known.

The proposed algorithms for velocity determination are based on calculations of the spatio-temporal cross-correlation. They allow to overcome the disadvantages of the classical methods because they combine the spatial analysis with temporal analysis of tomography images.

The dissertation thesis was formulated as follows:

Spatio-temporal analysis of images obtained from a twin-plane tomography system based on extraction of the homogeneous flow structures allows determining both angular and axial velocity components of the multiphase swirl flow.

In the frame of the work, the following tasks have been done:

1) Carried out different experiments using the two planes ECT system.
2) Prepared a physical model which allowed to simulate the swirl flow phenomenon.
3) Developed algorithms for flow velocity component estimations based on the spatio-temporal cross-correlation approach.
4) Tested and validated the flow velocity calculation algorithms using multiple data obtained from different experiments for solid-gas flows.

Multiphase flow studies and metering required a combination of different technologies, sensors and software in order to provide reliable and effective solutions. One of the proposed algorithms is the centre-of-gravity , which was developed and used to determine flow velocity components (vertical and horizontal directions). The results obtained have shown that the centre-of-gravity method enable to extract the average velocity components for the phase fraction values taken from the volume distribution on the pipe's cross-sectional. It was mentioned that the ECT system applied has limited to low sampling and is insufficient for applications with high speed of flow. However, it is expected that the developed approach to be applicable in the case of dynamic flows when can be used an ECT system with higher acquisition data speed

To avoid disadvantages, the alternative approach based on the spatio-temporal cross-correlation method was developed. It has been verified for test cases, as well as compared with the results obtained through the proposed swirl flow velocity estimation method with the known velocity components values of modelled swirl flow phenomnen. The angular velocity of the swirl flow was successfully estimated. The spatio-temporal approach provided calculating the velocity components when the flow changes are in a dynamic regime. The results were consistent with the known flow parameters and demonstrate the potential capability of the Electrical Capacitance Tomography to measure flow distribution inside pipelines. The proposed methodology was confirmed by real swirl flow measurements, where the granular material was swirled by air injection, disturbing the normal gravity flow. In this case, the obtained results demonstrated consistency with flow conditions. Known methods for transit time measurement do not consider the choice of time intervals in their calculations. Contrary to classical methods, the proposed concept takes into account an additional criterion, that is, the presence of flow patterns within the sensor volume. The developed flow pattern dependence method enables one to calculate transit time more precisely, and in this way, to increase the scale of the measurements. The proposed approach presents an algorithm of flow pattern analysis with, in addition, the cross-correlation technique, which refines the flow velocity calculation. Results were obtained for gravity flow experiments; however, the proposed method can also be used for other flows with different tomographic modalities.

The main contribution of this PhD has been published in high impact journal Flow Measurement and Instrumentation (25 points).