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REAL-TIME VELOCITY PROFILE GENERATION OF POWDER CONVEYING USING ELECTRODYNAMIC TRANSDUCER

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Abstract. This methodology explores the probability in determining the real-time velocity profiles of a vertical and horizontal flow. Generally, the measurement is based on the electrostatic charges produced by dry solid powder during their movement in the flow rig and accumulated at the sensors' electrode. Two arrays of dedicated electrodynamic sensors are used as static-to-electrical signal converter and they are located at the pipe wall. The sensors generated electrical signal corresponding to the amount of flow it detects and this is based on the fact that the amount of flow contributes to the level of the static charges accumulated at the sensors. The collected data is retrieved and manipulated by an application program, which is developed using Microsoft Visual Basic 6.0. The application features the ability to obtain velocity in real-time mode, which is previously unrealisable.

Keywords: Tomography, electrodynamic, real-time, velocity profile, interfacing

Abstrak. Kaedah pengukuran tomografi ini bertujuan mengkaji pengukuran profil halaju pengaliran dalam paip secara talian terus ataupun masa sebenar bagi pengaliran yang menegak dan melintang. Secara umumnya, pengukuran yang dibuat adalah berdasarkan cas elektrostatik yang dijana oleh hasil pergerakan serbuk pepejal kering di dalam paip. Pengumpulan cas-cas ini akan dikesan oleh dua rangkaian penderia elektrodinamik. Konsep asas yang digunakan oleh penderia-penderia ini adalah penukaran keamatan cas yang dihasilkan kepada magnitud voltan yang setara. Penderia-penderia ini akan ditempatkan di luar ukur lilit permukaan paip dan jarak antara dua rangkaian penderia ini telah ditetapkan. Isyarat-isyarat voltan yang dihasilkan oleh penderia akan disampel, dimanipulasi dan dipaparkan pada skrin komputer dengan program aplikasi yang dibangunkan melalui pengaturcaraan menggunakan Microsoft Visual Basic 6.0. Keupayaan utama aplikasi ini adalah kebolehannya mengintegrasikan sistem pengukuran ini dalam masa sebenar yang sebelum ini tidak dapat dilakukan.

Kata kunci: Tomografi, elektrodinamik, masa sebenar, profil halaju, antara muka

1.0 INTRODUCTION

The idea of signal processing with the cross correlation technique is not a new phenomena. Since 1930s, the theory has been developed, but is not used by the industries until 1960s, in which a hardware called a correlator has been invented [2]. The cross correlation technique to find the real-time velocity of a pipe flow has been

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implemented in this paper. The flow is detected by two arrays of electrodynamic sensors which are axially spaced between them, in which the length of the space is known, and will be interfaced with the computer via an interface board, Keithley Metrabyte DAS-1800HC. This paper focuses on the software development to interact with the interface board and to acquire the data from the sensors, so that the cross correlation technique can manipulate data. The velocity of the vertical and horizontal pipe flow can be calculated with the knowledge of the length of space between the sensors with the time shift obtained from the peak of the cross correlation coefficient.

The electrodynamic sensor has a high spatial filtering bandwidth [6], which makes it a very useful for velocity determination [9]. It has limitations, which arise because of the tribo-electrification phenomena [5] so that the level of charge on a particle can vary depending upon material, size, shape, humidity et cetera [9]. All the systems other than the electrical charge method have significant disadvantages whether it be due to cost, physical size, sensor complexity or combinations of these factors. The electrodynamic sensor is considered the best solution even though it is 'near sensor dominant' [4]. This means that the particles nearer to the electrode are giving a higher weighting factor on the final average velocity reading (as with capacitance sensor). But this method complies with the requirement of a robust, small and low cost sensor to measure flow velocity.

2.0 THE MEASUREMENT SYSTEM

The measurement system consists of two axially spaced arrays of electrodynamic sensors mounted on a 100 mm diameter steel pipe as shown in Figure 1. The separation between upstream and downstream sensors is set to 50 mm so that the sensor

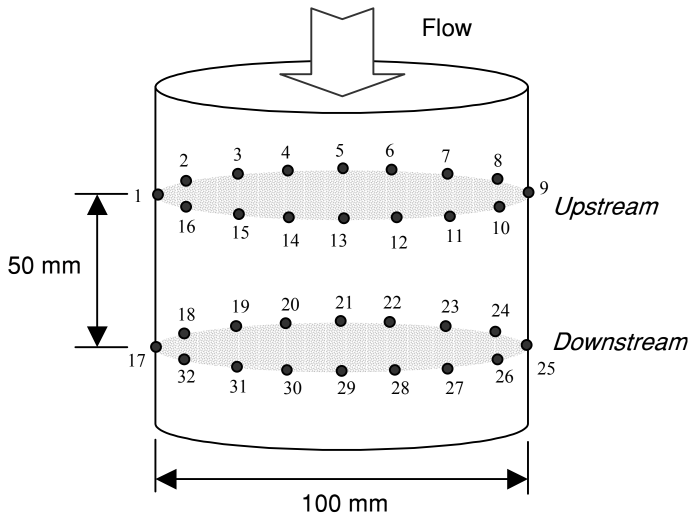

Figure 1 Arrangement of the 32 Electrodynamic Sensors on a Metal Pipe

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output can be correlated adequately. A small separation produces a high correlation coefficient and accuracy, but requires high-speed data capturing and processing, vice-versa [1]. Figure 1 shows the arrangement of sensors on the pipe wall.

The sensor consists of an electrode with 3 mm in diameter, connected to the transducer electronics. For the transducer block diagram, please refer to Figure 3 [8]. Charged particles falling in the pipe induce charge in the electrode. The induced charge is converted into a voltage, which is then amplified approximately five hundred times. The interface board will acquire the amplified voltages from all the thirty-two sensors at 1 kHz sampling rate.

The gravity flow rig diagram for vertical flow is shown in Figure 14 [8]. Solid material is fed from the hopper into the down pipe via the variable speed screw feeder at controlled rates. The solid particles are accelerated under gravity. The movement of the particles will generate static charges and affect the measurement section. Particles are collected by a material tank and sent back to the hopper by a vacuum. In this paper, a horizontal flow rig is used and the experimental work is still in progress. The horizontal flow rig is shown in Figure 2.

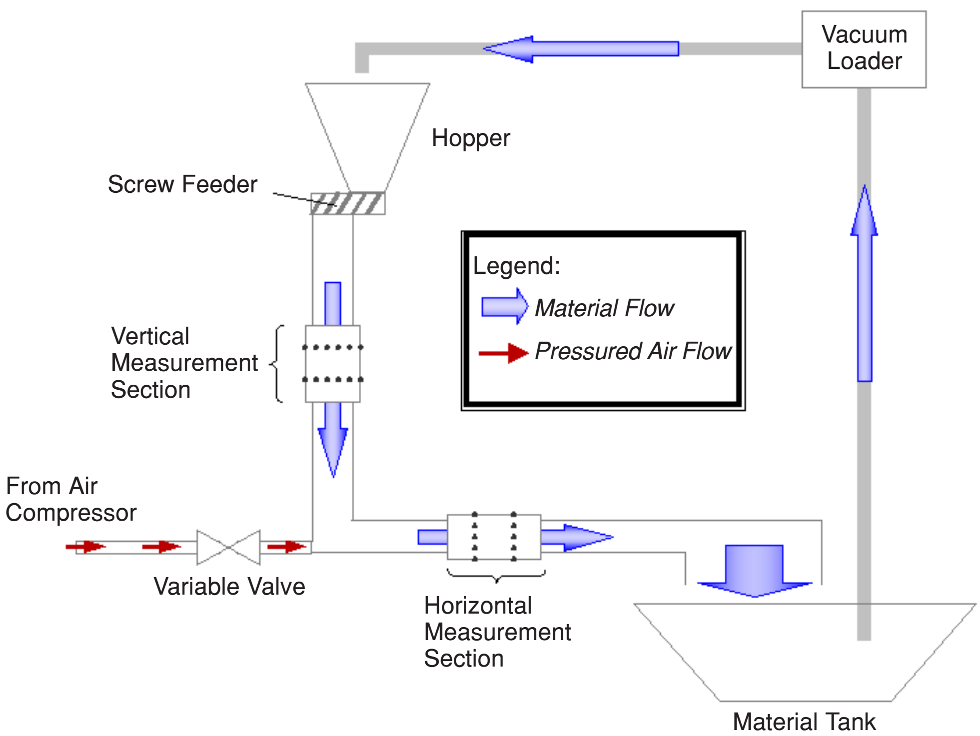

Figure 2 The Horizontal Flow Rig for Powder Conveying

2.1 Image Reconstruction System Through Pixel Concentration Time Series Cross-correlation

This measurement determines the velocity profile within the measurement cross-section. Three hundred twelve sets of data (limited by the data acquisition system), each consisting of thirty-two measurements obtained by sampling all the sensors in sequence, are collected. Each data set is captured within 1ms and processed using a linear back projection algorithm to generate an upstream and a down stream concentration profile [8]. The electrodynamic sensors detect charge, so the resulting concentration must relate to the total amount of charge being detected. However, for the tests carried out, it is assumed that for specific material all particles carry a similar charge as the particles are of similar size and shape [9]. In the case of the gravity drop system the concentration output is calibrated against solids mass-flow rate because the particles have approximately the same velocity.

The concentration profile is represented by the concentration of individual pixels mapped onto the pipe cross-section as shown in Figure 3 and the positions of the individual pixels are identified by the respective row and column. For example, the upstream pixel in second row and third column counting from the top left hand corner is written $U_{3,2}$. Therefore $U_{3,2}|_1$ represents the first set of data collected for pixel $U_{3,2}$. Similarly, the corresponding downstream pixel is $D_{3,2}|_1$.

The concentration profiles are calculated for all 312 upstream and downstream data sets. Consider a pixel, $U_{3,2}$. The calculations resulted in 312 concentration, ($U_{3,2}|_1$, $U_{3,2}|_2$, ..., $U_{3,2}|_{312}$) occurring in a time series data spaced at 1 ms interval.

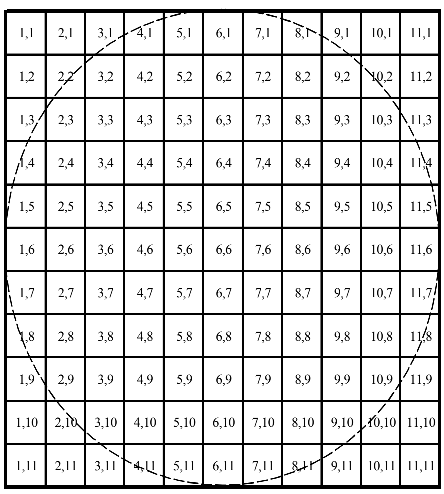

Figure 3 Pixel Position Identification

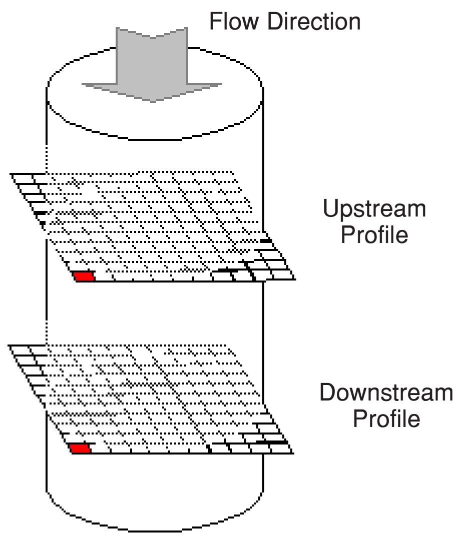

Figure 4 The Corresponding Pixel for Upstream ($U_{1,1}$) and Downstream ($D_{1,1}$)

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These values of concentration are plotted against time to produce an upstream pixel concentration time function. These time functions are generated for all upstream and downstream pixels.

An upstream and a downstream time series may be cross-correlated to estimate the transit time between the two measurement arrays relating to the flowing solid particles [7].

If the corresponding upstream and downstream pixel concentrations are cross-correlated, the flow velocity can be obtained. Figure 4 shows the corresponding upstream and downstream shown by the shaded pixels.

2.2 Flow Patterns Due to the Effect of Non-uniform Distribution of Flow

The formation of non-uniform flow patterns increases as the density difference between the conveyed components becomes greater. The phenomena certainly exists for liquid-solid flows, but it is even more noticeable for gas-solid flows, where in horizontal conveying there can be a sliding bed flow of the solid, with the gas moving at a much higher velocity above the solid [2].

Therefore, if the velocity profile measurement is to be applied to the horizontal flow system, the measuring task becomes much more complicated as the differences in signals measured by the sensors may affect the accuracy of flow measurement. This is due to the phenomena that usually occurs in the horizontal flow system where the flow is not uniformly distributed. This phenomena is usually referred to two-phase flow. The behaviour of the two-phase flow is unpredictable and dependent on many factors. The main complicating factor is that gravitational forces act on the solid phase, causing it to be displaced towards the bottom of the pipe. Flow regimes in horizontal flow are illustrated in Figure 5 [3].

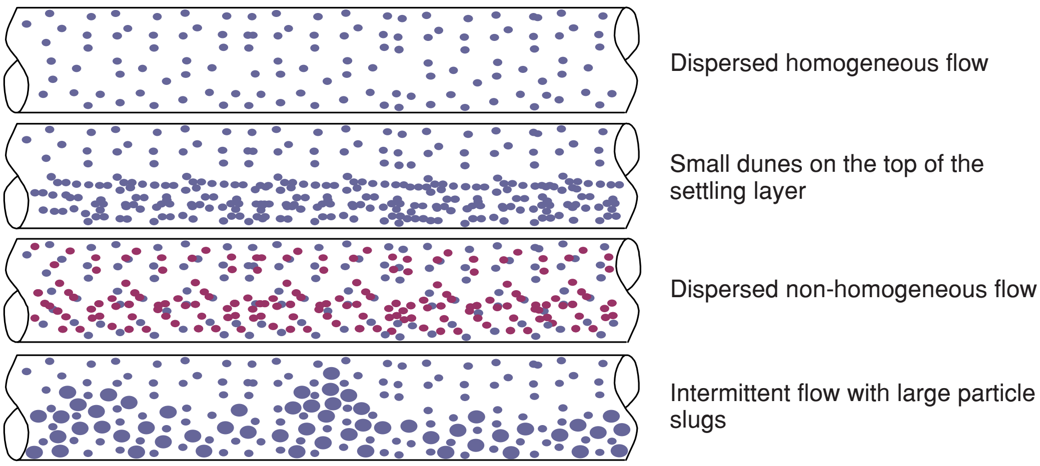

Figure 5 Gas-solid Flow in a Horizontal Pipeline

2.3 Application Program

The application program is developed using Microsoft Visual Basic 6.0. The program can be integrated with the measurement section through DAS-1802HC high-speed data acquisition system board. Since this program is purposely built to support the interface board and the measurement hardware in real-time, it provides a wide range of functions and customisable settings for users in order to meet their requirement.

By default, the sampling frequency for this application program is set to 1 kHz per channel using burst triggering under DMA mode. The burst triggering is clocked to 333 kHz or 3 μs, which means that the sampling task for 32 sensors can be completed within 96 μs. Basically, this application will sample 312 sets of data (within 312 ms) and loads them onto hardware buffer in FIFO order before they can be transferred into local memory. The data will be manipulated with the Linear Back Projection Algorithm before they can be cross-correlated. This application implements point-to-point method together with evolutionary concept to reduce the calculation time [2]. The Graphical User Interface for application program mainframe is shown in Figure 6.

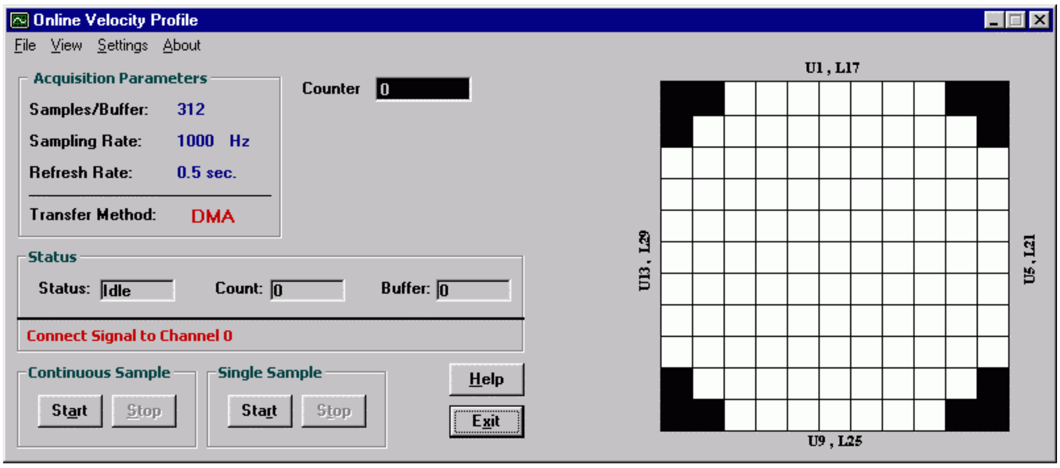

Figure 6 Application Program Mainframe

3.0 IMPLEMENTATION AND RESULT

Several experiments have been carried out to test and verify the feasibility of the developed application program. They are the vertical full-flow measurement, the vertical half-flow measurement and the horizontal half-flow measurement. In the vertical half-flow measurement, 50% of the pipe flow was blocked.

Theoretically, the velocity of the dropped powder towards ground varies with the displacement. This theory is represented by a velocity formulae v, $v = \sqrt{2gs}$ where

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g is gravitational acceleration and s is displacement. The displacement of the dropped powder is fixed as 1.4 meter and the gravitational acceleration is set as 9.8 ms^{-2}. Thus, the calculated velocity of the dropped powder is 5.24 ms^{-1}.

3.1 Analogue Input Signal

The analogue input signals sampled from the sensors are in bipolar mode and the magnitude of the signals will vary according to the flow pattern. The Figure 7 represents the analogue input signal collected from channels 8 and 24.

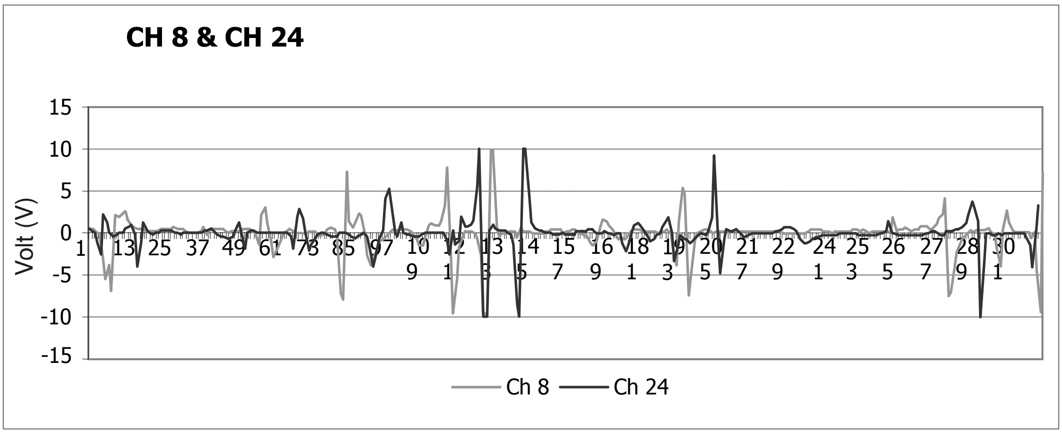

Figure 7 Analogue Input Signal of Channel 8 and 24

From Figure 7, the signal similarity between channels 8 and 24 is significant. In the measurement hardware, the sensor for channel 8 is located immediately above the sensor for channel 24 (refer to Figure 1) and thus, the signal pattern between both sensors has to be identical and shifted. The delay between both signals is 12 ms. Therefore, the velocity of the flow can be inferred as 4.167 ms^{-1}. This sensor-to-sensor velocity is called the peripheral velocity.

3.2 Velocity Profile for Vertical Full-Flow Measurement

The velocity profiles for vertical full-flow measurement have been measured in real-time at the sampling frequency of 1 kHz under DMA mode. The example of measurement result obtained by the application program is shown in Figure 8.

From Figure 8, the application form has shown the full flow result where the expected velocity range is set between 3.8 ms^{-1} and 5 ms^{-1}. This velocity range is set according to the expected time delay of 10 ms to 13 ms. Since the corner pixels are null or outside of the pipe area, the number of active pixels is 109. If the pixel velocity is within the expected range, the pixel background colour will be changed

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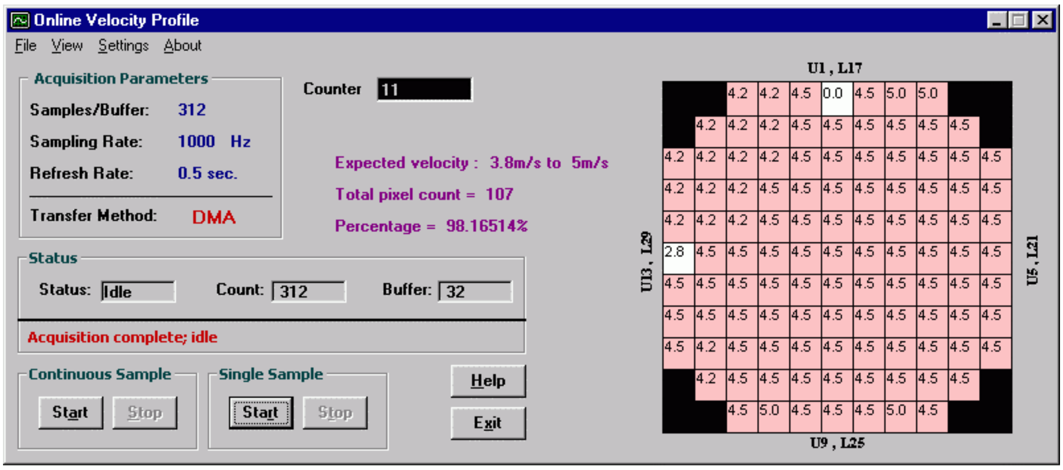

Figure 8 Real-time Velocity Result of Full-Flow Measurement by Application Program

to light red in order to facilitate users to recognize the flow distribution. The mapping is labelled with the parameters U and L, which represent the upper stream sensor and the lower stream sensor respectively. For example, 'U1,L17' represents the location of upper stream sensor 1 and lower stream sensor 17. Please refer Figure 1 for detail on the location.

Several experiments have been carried out for verification purposes and it is found that the result of the full flow is convincing. The results of other full-flow measurements are shown in Figure 9 and Figure 10.

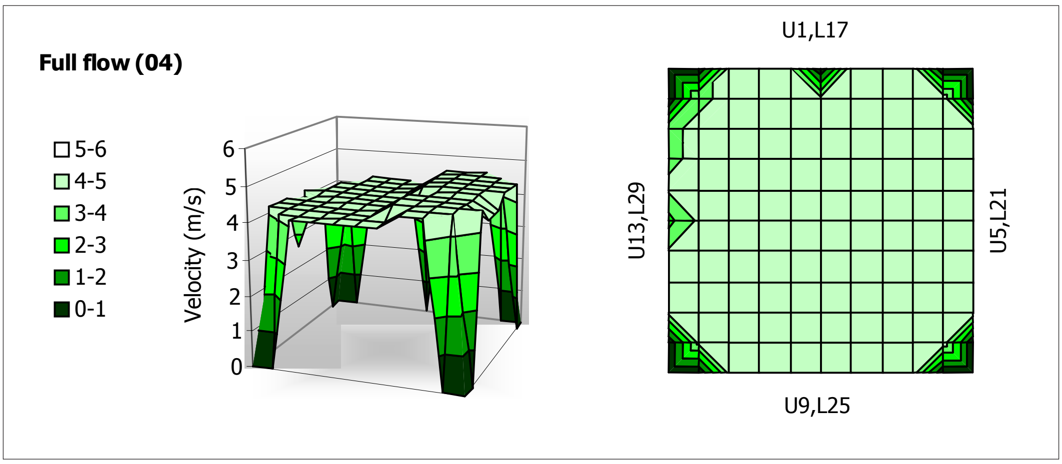

Figure 9 Real-time Velocity Result of Full-Flow Measurement

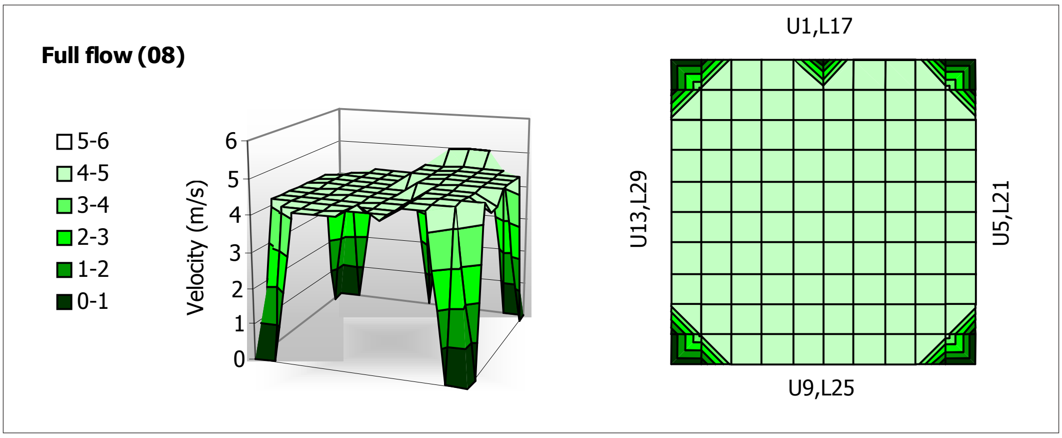

Figure 10 Real-time Velocity Result of Full-Flow Measurement

3.3 Velocity profile for vertical half-flow measurement

The example of measurement result obtained by the application program is shown in Figure 11 where the upper half of the flow region is blocked.

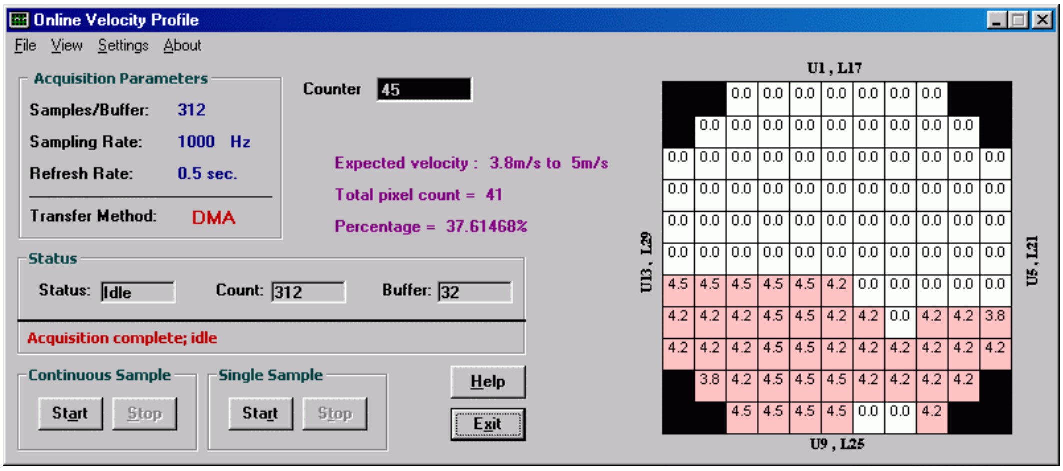

Figure 11 Real-time Velocity Result of Half-flow Measurement by Application Program

From Figure 11, it can be observed that the flow velocity between the two flow regions, the blocked region and the unblocked region are different.

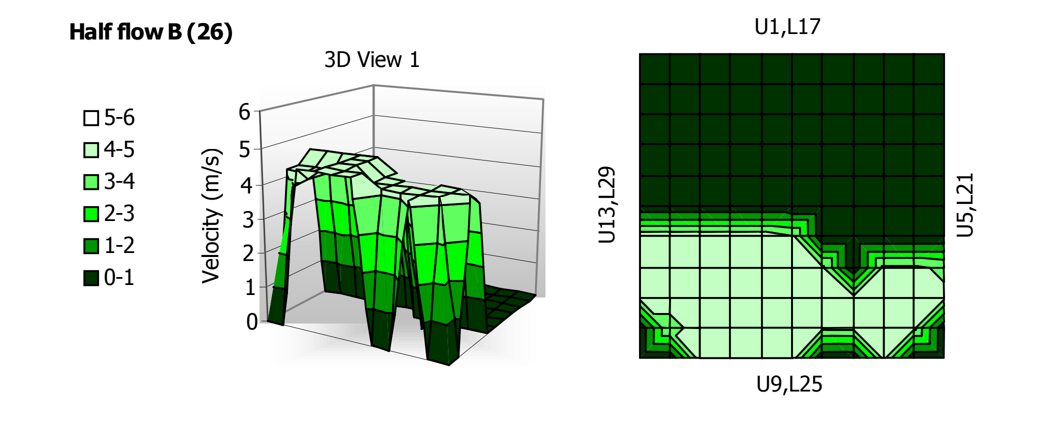

Figure 12 Real-time Velocity Result of Half-flow Measurement

3.4 Velocity Profile for Horizontal Flow Measurement

The velocity profiles for horizontal flow measurement have been measured in real-time at the same sampling frequency at 1 kHz and DMA transfer mode. An example of the measurement result obtained by the application program is shown in Figure 13.

From Figure 13, it can be observed that the flow is concentrated at the lower left region in the pipe. However, it cannot be implied that the flow pattern is always identical. The behaviour of the solid flow has been described briefly in section 2.2.

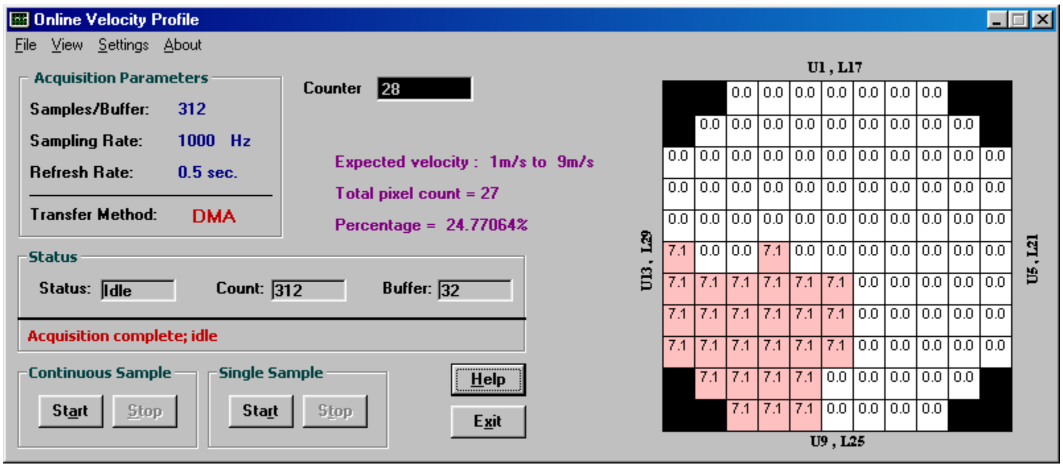

Figure 13 Real-time Velocity Result of Horizontal Flow Measurement by Application Program

The result in Figure 13 is displayed in 3D tomogram as shown in Figure 14.

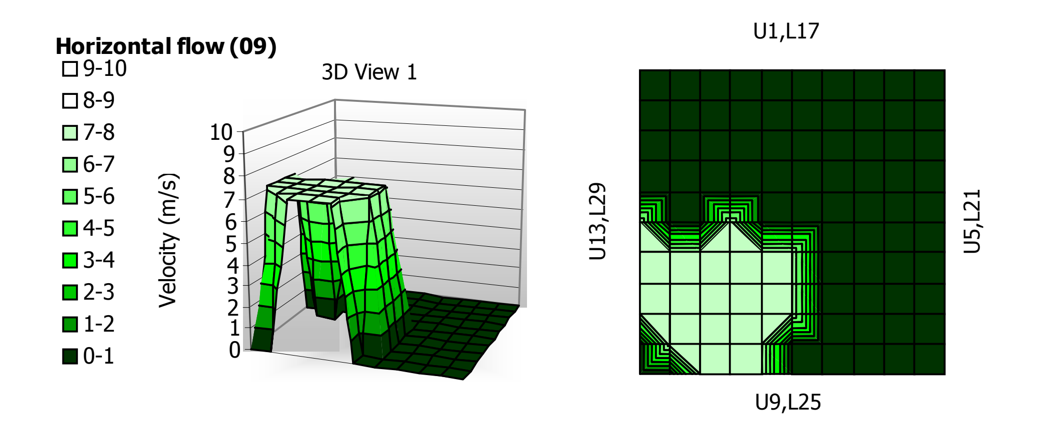

Figure 14 Real-time Velocity Result of Horizontal Flow Measurement

Another result of the horizontal flow measurement is shown in Figure 15.

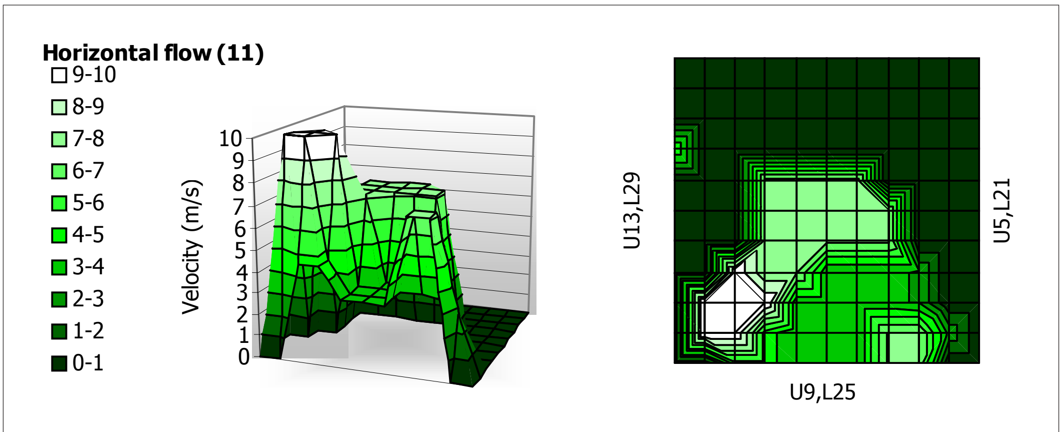

Figure 15 Real-time Velocity Result of Horizontal Flow Measurement

Other results have been obtained from this type of measurement. The overall results have shown that the patterns of the flow in these experiments are random and unpredictable. However, it can be concluded that the majority of the flows have the highest concentration and speed at the lower part of the pipe. These phenomena occurred due to the structure of the conveyor (please refer to Figure 2) where the inlet of a pressured air is fixed at the lower part of the pipe.

4.0 CONCLUSION

The real-time velocity profile measurement system for powder conveying was successfully developed. The application program seems to work as expected and the results have been verified. The average velocity value of vertical full flow is 4.2 ms^{-1} at a displacement of 1.4 meter under gravitational force. Further experimental work will be carried out to investigate the result of horizontal flow measurement.

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