REAL-TIME MASS FLOW RATE MEASUREMENT FOR BULK SOLID FLOW USING ELECTRODYNAMIC TOMOGRAPHY SYSTEM

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To my beloved parents, Yaw Ho Tian and Tan Mee Choo,

my brothers, sister and my friends

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ABSTRACT

In order to increase the efficiency of energy and raw materials usage and to improve product quality and process efficiency, the demand of continuous monitoring of the flow rate of solids in pneumatic pipelines is rising in many industrial areas. This requirement can only be achieved by installing a proper real-time measurement system. Electrodynamic sensor offers the most inexpensive and simplest means of measuring solids flows in pipes. As electrostatic sensors respond only to moving solids in the pipe, the measured data enjoy a large degree of immunity from the effects of solids accretion which adversely affect other technologies. For the developed measurement system, sixty-four channels of KPCI-1802HC are used to capture the output voltages of thirty-two sensors. The sampling frequency is 1 kHz for each channel. Data per frame was collected over 156 ms. The distance between upstream and downstream sensors is 5 cm. The falling distance of material is set to 1.4 m. Linear back projection algorithm (LBP) and filtered back projection algorithm (FBP) are implemented for image reconstruction. The tomographic technique will generate the real-time concentration profile of the sensing volume. Subsequently, real-time pixel-to-pixel velocity profile can be calculated from cross-correlation of two set of time series that obtained from a number of upstream and downstream concentration profiles. By combining the concentration profile with corresponding velocity profile, mass flow rate profile can be generated. The summation of all pixels value in the mass flow rate profile is carried out to obtain a total value of pixels. The mass flow rate of the solids flow can be calculated by substituting the total value into mass flow rate equation. The dedicated software for the electrodynamic tomography system is developed using Microsoft Visual C++ 6.0. The developed software supports real-time mode and offline mode of the system. The results obtained from the experiments are presented and compared with the calculation of MATLAB. To conclude, a real-time mass flow rate measurement system using elctrodynamic tomography is developed successfully.

ABSTRAK

Untuk meningkatkan kecekapan penggunaan tenaga dan bahan mentah di samping memperbaiki kualiti bagi produk dan kecekapan proses, keperluan untuk kawalan yang berterusan terhadap kadar aliran bagi bahan pepejal di dalam paip pneumatik semakin meruncing. Keperluan ini hanya dapat dicapai dengan penggunaan sistem pengukuran yang sesuai. Penderia elektrostatik merupakan kaedah yang paling murah dan senang untuk pengukuran aliran pepejal dalam paip. Ini disebabkan oleh ia hanya bertindak balas terhadap pepejal yang bergerak di dalam paip. Data yang diperolehi jarang dipengaruhi oleh kesan pengumpulan pepejal di mana teknologi lain akan terganggu oleh kesan ini. Bagi sistem pengukuran yang dibina, 64 saluran bagi KPCI-1802HC digunakan untuk memperolehi voltan keluaran bagi 32 penderia. Frekuensi persampelan ialah 1 kHz bagi setiap saluran. Data bagi satu bingkai dikumpulkan selama 156 ms. Jarak antara penderia ‘upstream’ dan ‘downstream’ ialah 5 cm. Jarak jatuh bebas bagi pepejal dalam eksperimen ialah 1.4 m. Algoritma ‘linear back projection’ dan ‘filtered back projection’ digunakan untuk pembinaan imej. Profil penumpuan akan dibina dengan penggunaan kaedah tomografi. Seterusnya, profil halaju dapat dikira dengan menggunakan fungsi sekaitan silang ke atas dua set data yang diperolehi daripada sebilangan profil penumpuan aras atas dan profil penumpuan aras bawah. Melalui gabungan profil penumpuan dan profil halaju yang berkaitan, profil kadar aliran jisim boleh diperolehi. Percampuran bagi semua nilai dalam profil kadar aliran jisim akan menghasilkan nilai jumlah bagi profil itu. Dengan menggantikan nilai jumlah ini ke dalam persamaan kadar aliran jisim, maka nilai kadar aliran jisim boleh diperolehi. Perisian bagi sistem ini telah ditulis dengan menggunakan Microsoft Visual C++ 6.0. Perisisan ini boleh digunakan secara masa nyata atau ‘offline’. Keputusan ujikaji ditunjukkan dan dibandingkan dengan kiraaan menggunakan MATLAB. Kesimpulannya, sistem pengukuran kadar aliran jisim secara masa nyata bagi tomografi elektrodinamik telah berjaya direkabentuk.

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LIST OF ABBREVIATIONS

AC	-	Alternating current
ADC	-	Analogue to digital converter
App	-	Application
ART	-	Algebraic Reconstruction Technique
CAT	-	Computed axial tomography
CCF	-	Cross-correlation function
CPU	-	Central processing unit
CT	-	Computed tomography
DAS	-	Data acquisition system
DMA	-	Direct memory access
DIP	-	Double in-line package
DDB	-	Device dependent bitmap
DIB	-	Device independent bitmap
ECT	-	Electrical capacitance tomography
EIT	-	Electrical impedance tomography
FBP	-	Filtered back projection
FDG	-	Fluorodeoxyglucose
fps	-	Frame per second
GUI	-	Graphical user interface
Hz	-	Hertz
IC	-	Integrated circuit
I/O	-	Input/output
IPT	-	Industrial process tomography
ISA	-	Industry standard architecture
LBP	-	Linear back projection
LED	-	Light emitting diode
MFC	-	Microsoft Foundation Class

MFR	-	Mass flow rate
NDE	-	Nondestructive evaluation
NMR	-	Nuclear magnetic resonance
PCB	-	Printed circuit board
PCI	-	Peripheral Component Interconnect
PDA	-	Personal digital assistant
PET	-	Positron emission tomography
PT	-	Process Tomography
PTP	-	Pixel-to-pixel
STS	-	Sensor-to-sensor

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CHAPTER 1

INTRODUCTION

1.1 An Overview of Process Tomography and Its Development

The developments of tomography can be dated back to early 1900s. This idea was first suggested by Mayer in 1914. It was developed to fulfill the need of medical noninvasive imaging. Since then, tomographic imaging become one of the most power tools used for clinical purposes. Tomography is a broadly used indirect mapping technology based on the idea that several images are taken from various angles in order to reconstruct the interior of the object under investigation. It is derived from Greek's word's 'tomos'(to slice) and 'graphy' (image) (William and Beck, 1995).

Tomography also utilized in many research fields. For example, the ocean's 3-dimensional temperature distribution is mapped in oceanographical research. For seismologic research, information about the inner part of the earth such as the distribution of temperature can obtained by measuring arrival times of earth quakes at various seismic stations distributed over the globe. For archaeological study, ceramics can be investigated in a same approach as in medical tomography in order to uncover hidden scriptures. Naturally, tomographic technique was introduced to industrial field. This new application of tomography is known as Process Tomography (PT) or Industrial Process Tomography (IPT).

Process tomography involves using tomographic imaging methods to manipulate data from remote sensors in order to obtain precise quantitative information from inaccessible locations (William and Beck, 1995). Undoubtedly, process tomography will improve the design and operation processes handling material by enabling boundaries between different components in an industrial process to be imaged. Depend on the requirement, information on the flow regime, concentration distribution, velocity of flow and mass flow rate can be determined using process tomography. The fundamental concept is to install a set of sensors around the pile to be imaged. Then, a computer or several computers are used to reconstruct tomographic images of the cross sectional area being investigated by the sensors. After that, the data can be processed quantitatively for subsequent use to initial process control actuator. It also can be used to develop or verify a model that describes a particular process.

In the 1970s, a number of applications of tomographic imaging of process equipment were described. In general, these involved applying radiation from X-ray or isotope sources and these were not satisfactory for the majority of online process applications on a routine basis. It was until the middle of 1980s, research started that led to the current generation of process tomography systems. At the University of Manchester Institute of Science and Technology (UMIST) in England there began a project on electrical capacitance tomography for imaging multi-component flows from oil wells and in pneumatic conveyors. At almost the same time, a research group at the Morgantown Energy Technology Center in the USA was designing a capacitance tomography system for measuring the void distribution in gas fluidized beds. By 1990, it was felt that process tomography was maturing as a potentially useful technique for application to industrial process design and operation (William and Beck, 1995).

1.2 Problem Statement

Previous researches on mass flow rate measurement using electrodynamic tomography system were conducted in offline mode. Hence, timing of the data acquisition, processing and image reconstruction is not a critical issue. For instance, Visual Basic 6.0 language was used to develop offline software by Azrita (Azrita, 2002). Nonetheless, offline system is only suitable for study carried out in laboratory. It is not practical for process control in industrial plant. This is due to real-time information of process is required for efficient control and system failure detection. Thus, an online mass flow rate measurement system needs to be developed.

Nevertheless, online mass flow measurement of particles in gas stream has been considered by researchers as technically challenging area. Intensive calculation to obtain mass flow rate from velocity profile and concentration profile is inevitable. In order to realize real-time measurement, research will be concentrated on minimizing data transfer time, graphic display time and data processing time. In depth understanding of data acquisition card KPCI-1802HC is necessary. Visual C++ 6.0 will be used to replace Visual Basic 6.0 for software programming. In addition to programming language, decent program code optimization and adequate algorithms need to be studied and applied in the system.

1.3 Research Objectives

1. To build the hardware of the system and to investigate the performance and functions of the sensor circuit.

2. To investigate the suitable algorithm that can be used in reconstruction of velocity profile, concentration profile and mass flow rate measurement. A comprehensive windows application will be developed using Visual C++ 6.0.

3. To develop a real-time mass flow rate measurement system that can measure and determine the mass flow rate of moving solids in pneumatic conveyors.

1.4 Research Scopes

The scopes of the research are:

1. Design and build measurement system based on electrodynamic sensor for pneumatic conveyor.
   Measurement part will be built for optimum performance. Simulation of the circuit will be carried out using Protel 99SE.

2. Develop data capture and data logging system for measurement section.
   KPCI-1802HC PCI bus version data acquisition card is used in data capture system. It is important to learn the method to communicate with the interface card via device driver, DriverLINX.

3. To study and develop windows application program using Microsoft Visual C++ 6.0.
   The program should provide functions such as data acquisition from hardware, data analysis, result display and data storage. DMA will be utilized for high performance data acquisition.

4. Measure and study pneumatically conveyed particle concentration and velocity profiles.

Offline program for concentration profile and velocity profile will be developed. An adequate algorithm will be applied to minimize calculation time.

5. Reconstruct velocity and concentration profile over the cross-section of the conveyor based on data from measurement section.
   This stage is necessary to collect data that will be used to investigate the performance of the software.

6. Determine the on-line solids mass flow rate in pneumatic conveyor using process tomography reconstruction techniques.
   This stage will test the software in real-time mode. It is crucial to verify the capability of the system to perform real-time measurement.

7. Verify the developed system
   Results of the developed measurement system will be compared to the results calculated using MATLAB to ensure the correctness of the mathematical algorithms applied in the system.

1.5 Thesis Organization

Chapter 1 introduces the overview of process tomography, problem statement, research objectives, research scopes and thesis organization.

Chapter 2 reviews the background of the research. Related works similar to this field are presented. Discussion in this chapter includes the tomography system and type of sensor used in tomography. This chapter also describes the modeling of electrostatic sensor used in the research, procedure to calculate concentration profile, how to obtain velocity using cross-correlation technique and image reconstruction algorithms and the calculation of mass flow rate.

Chapter 3 describes the hardware design and software development of the system, programming techniques, implementation of the image reconstruction algorithm and graphical user interface (GUI) design.

Chapter 4 presents the results obtained from the experiments. Results are analyzed and discussed. The comparison and statistical analysis are also shown in this chapter.

Chapter 5 discusses the conclusion, contribution of this research and recommendations for the future research.