Fabrication of Single Source γ-ray Computed Tomography Unit Motion Control System

Mohammed S. AlJohani

Department of Nuclear Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia
Email: mjohani@kau.edu.sa

Abstract: Recent studies on multiphase chemical reactions involving gas-liquid reactions along with solid catalyst called for using γ-ray Computed Tomography (CT) to study the flow conditions and phase distribution inside the reaction chamber. The CT unit to be fabricated was to be designed to determine the time averaged cross sectional phase holdup distribution of phases in the multiphase system. A fan beam γ-source-detector arrangement was used for the measurement of transmission data the γ-ray photons across the multiphase reactor setup. This paper presents the fabrication of an electromechanical control system for the position control of the source and detector arrangement during the experiment. Manual control of positions was never possible as the system had to rotate at an accuracy of 0.2°. Also, perfect control over time was required since the total number of movements were very high and idle time between movements should be minimized.

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1. INTRODUCTION

Chemical Engineering deals with multiphase systems in chemical and physical transformation of raw materials of renewable and non-renewable sources into intermediates and final products. Industry strives to produce them more efficiently and in a more environmentally acceptable manner. Multiphase systems turn out to be prevalent in most chemical and biological transformations. Such processes require a presence of more than one phase to proceed, such as gas bubbles spurred through a liquid, solid catalyst particles suspended in liquid or gas, liquid and gas flow through porous media, etc. The presence of the second phase makes these systems non-transparent or opaque. Yet it is of considerable interest to know how the gas or liquid or solid distribute themselves in such systems, and how do they flow and mix in them. For example, successful realization of chemical transformations that requires bringing together gas reactants in a liquid product on a solid catalyst demands that we describe the distribution and flow patterns of the phases.

So it is important to be able to "see" what goes on inside those high pressure, thick walled reactors containing multiphase opaque systems in order to develop phenomenological engineering models for them, and in order to provide data for validation of Computational Fluid Dynamic codes (CFD) that attempt to do describe multiphase flows and need closures for inter-phase interactions and turbulence.

While we can rely on visualization of transparent systems based on photons in the visible light range, unfortunately this will not work when you are confronted with an opaque system. In that case we must use 'high energy' photons, like those found in γ-rays. The Beer Lambert Law of attenuation of the gamma rays received by the detector which depends on the density of the medium and the distance between the source and the detector, can now be employed in determining the distribution of phases by Computer Tomography (CT) [1], [4], [7], [12].

2. DESCRIPTION

This is a direct application of radioisotope engineering to the field of hydrodynamic performance characterization and optimization of multiphase flow in chemical reactors. Those types of reactors are used extensively in petrochemicals and oil industry, and there is a continuous need for studying the hydrodynamics of different designs of column reactors and digesters in order to economically, and environmentally enhance the reactors performance. In addition, many such studies are needed to validate hydrodynamic models of the multiphase flow reactors in order to perform a scale up calculations in case present reactors are to be scaled up for larger production rate and product output.

The CT unit is designed to use a sealed γ-ray source, ^{137}Cs. The source is placed in a Source Collimator made from lead. A fan beam arrangement of source-detectors is used for measuring the transmission data of the γ-ray photons across the multiphase experimental setup. The fan beam consists of a longitudinal section of a cone. The point γ-ray source is placed at the vertex of the cone. The detector array is placed along the bottom section of the cone. The multiphase reactor setup is placed in the middle. The source is positioned at the geometrical centre of the Source Collimator to provide maximum shielding.

Fig. 1 shows the schematic top view of the CT setup. The setup consists of a sealed γ-ray source housed in Source Collimator. A detector array is placed on the opposite side of the point source along the fan beam such that each detector phase is equidistant from the source. The detectors count the un-attenuated and scattered gamma ray photons that pass through the multiphase experimental system. Typically a threshold of energy is set and the photons that have energy above the threshold value are counted. Later, image reconstruction is done based on the acquired data and the pattern of scanning.

The detector array consisting of 9 NaI detectors is mounted in a plate which is placed on a motion Rail such that the centre of the rail arc is the source and the distance from the source to each detector is equal. The plate is inturn connected to a servo motor through a coupling so that perfect position control of the plate can be achieved, with each detector on the plate capable of making angles from -2.4° to +2.4°.

The entire source-detector system is placed on a plate which is mounted on a circular rail to provide a rotation of 360 degrees for the whole.

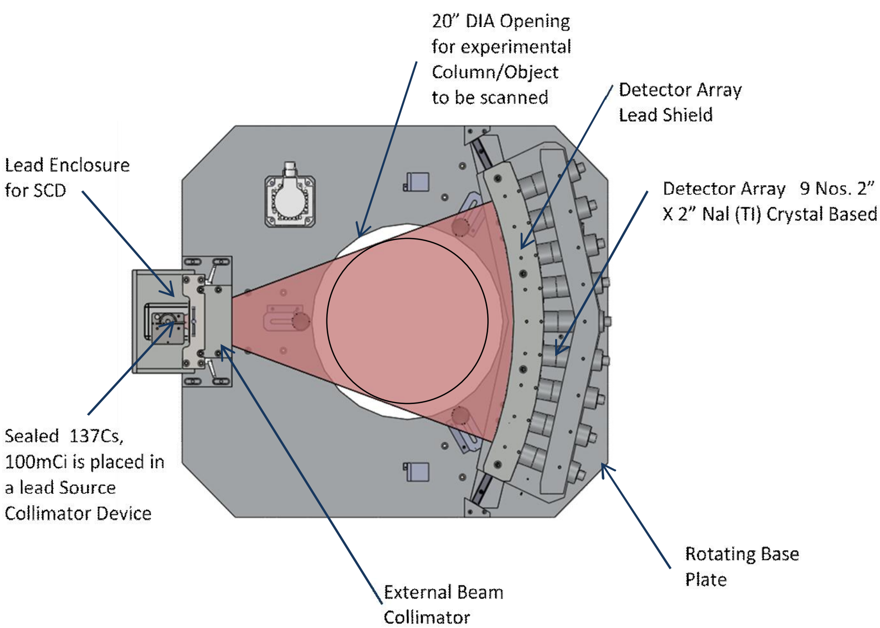


Figure 1. Top view of the CT setup

During operation, the source and detectors take the various positions relative to each other and the column. CT setup enables two types of source/detectors motions: (i) gamma-ray detectors and source together around the axis of the column (ii) the collimator and detector assembly around the source along the arc defined by the detector-array. In order to ease the description of the data acquisition process, two terms are defined as follows - view and projection. View designates fixed source position. Projections are different positions of assembly of detectors towards source; in any given view, detectors take 25 different positions in increment of 0.2 degree. The total number of projections considered in one view is then 25 x 9 = 225, considering 9 detectors. As Shown below in Figure 2.

Source makes full circle around the scanned object in increment of 3.6 degree, i.e. there are 100 views in one scan. Thus, the total number of projections during one scan is 225 x 100 = 22500. The computer connected data acquisition system records the gamma-ray counts for each of the projections.

If scans need to be conducted at different vertical locations of the column, the rotating base plate, on which the source/detector plate is mounted, can be repositioned vertically. This is possible as the base plate is mounted on LM blocks and ball screw [1], [2], [3], [4], [5], [7].

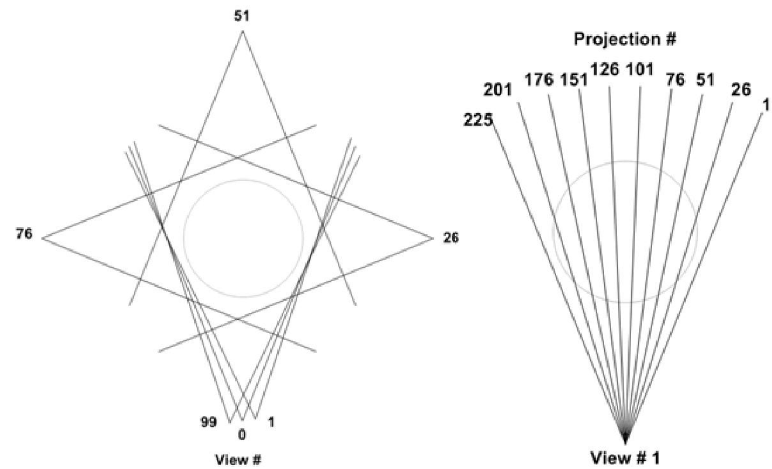
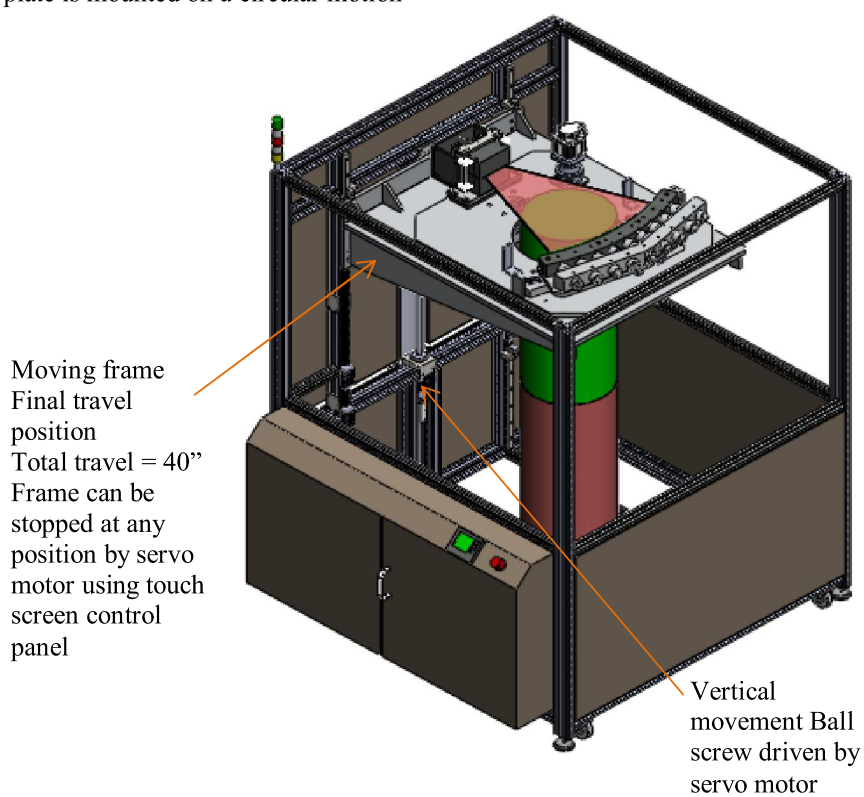


Figure 2. Projections and Views on each rotation

3. THE MECHANICAL SYSTEM

Figure 3 shows the Mechanical System 3D Model, the top view and side view of the rotating plate. The Mechanical System consists of a mix of Mild Steel and Aluminium profiles for supporting the moving bracket and other components mounted over the moving bracket. On the vertical moving bracket, another rotating plate is mounted on a circular motion rail. Over the rotating plate, the detector assembly is mounted with on the arc shaped rail. A ball screw connected to the mild steel frame by means of bearings and two Linear Motion Guide Rails on both sides of the ball screw are supporting the moving bracket in a cantilever fashion and ensure a smooth vertical movement of the moving bracket.



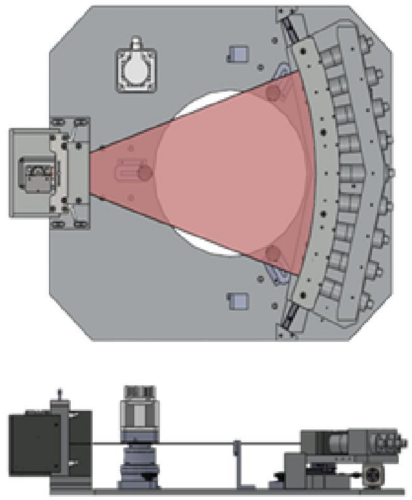


Figure 3 (i) Vertical movements of the frame along with rotating plate using ball screw and servo motor frame is guided on LM rails. (ii) Top View and Side View of the Rotating Plate

There are three servo motors in the system, (i) for position control of the vertically moving bracket, (ii) For position control of the rotating plate, (iii) for position control of the detector assembly. The motors are connected to the moving system through gearbox assemblies and suitable couplings so that high torque and low friction is ensured [1],[4],[9].

4. ELECTRONIC MOTION CONTROL SYSTEM

The Electronic Motion Control System consists of a PLC (Programmable Logic Controller) System for controlling the Servomotors through Servo Drives (Amplifiers). Figure 4 shows the architecture of the entire control system and Figure 5 shows the photograph of the control panel front view and the internal view.

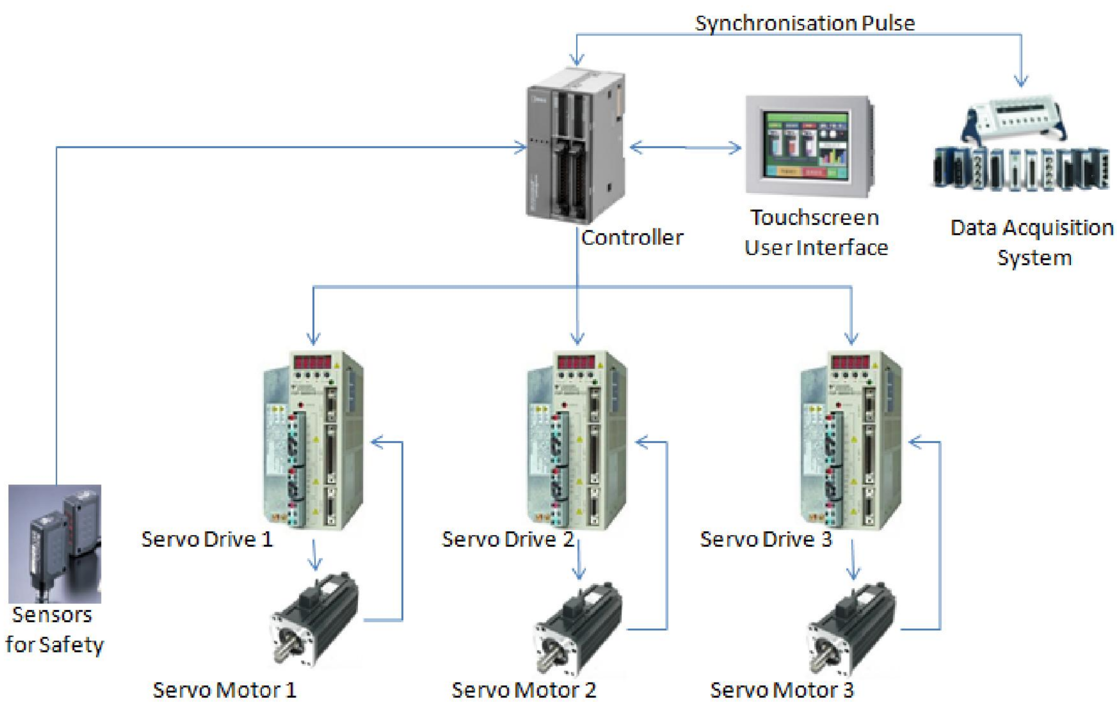


Figure 4 Block Diagram of the Electronic Motion Control System

Figure 5 Photographs of the CT Motion Control Panel

A programmable logic controller (PLC) or programmable controller is an industrial digital computer used for automation of electromechanical processes, such as control of machinery or factory assembly lines or automation of different processes in a process control system. Unlike PCs, the PLC is designed for multiple inputs and outputs; extended temperature ranges suitable for industrial use and is usually resistant to vibration and impact. Programs written in the form of Ladder Logic or Instruction List of Function Charts to control machine operation are typically stored in battery-backed or non-volatile memory.

Figure 6 shows the picture of the PLC manufactured by IDEC Corporation, Japan, which is used in this project. The FC5A series PLC used here is suitable of handling 32 Inputs/Outputs in which three outputs are high speed outputs capable providing position and speed reference information to the servo drives in the form of pulses.

Figure 6 View of the IDEC PLC FC5A-D32

Servo motors are used in closed loop motion control systems in which position is the control variable. The controller directs operation of the servomotor by sending the speed command signals to the servo drive, which drives the servo motor. An encoder, either incorporated within the servo motor or mounted often on the shaft provides the servo motor's position and speed feedback to the drive. The drive compares this to its programmed motion profile and uses to alter its signal. Servo motors feature a motion profile, which is a set of commands programmed in the controller which defines the servo motor operation in terms of time, position, and speed. The Figure 7 below shows the Block Diagram of a servomotor control system.

In this case, AC Servomotors and drives manufactured by Yaskawa Electric, Japan have been used. Figure 8 shows the photograph of the Servo Drive and Servo motor.

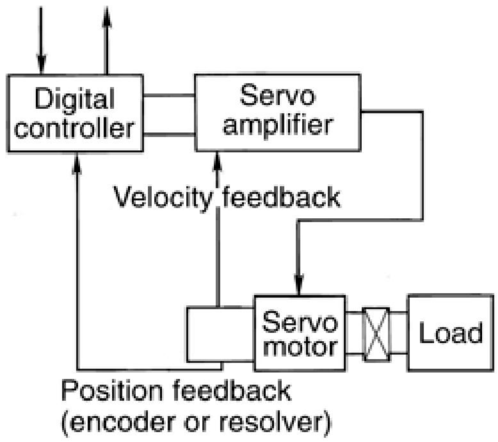


Figure 7 A typical servomotor system with encoder feedback

Figure 8 Photograph of Servo Motor and Servo Drive

The Control System designed for the CT System also has a very user friendly and aesthetically designed user interface through a Panel mount Industrial Touch Screen Display, also from IDEC Corporation, Japan. The Touch Screen HMI (Human Machine Interface) provides various options for the operator of the machine which makes it easy to carry out tests using the CT Machine. Information such as Current Scanning Position, Time Elapsed and Time to Finish are always displayed on the Screen. Options for Pausing, Aborting and Restarting the Scan are also provided.

While starting the system, options for setting the angles at which the scan should occur etc. can also be set making the system generic for various tests and experiments. Figure 9 below shows the Touch Screen Display and Screen Shot of a screen on the HMI.

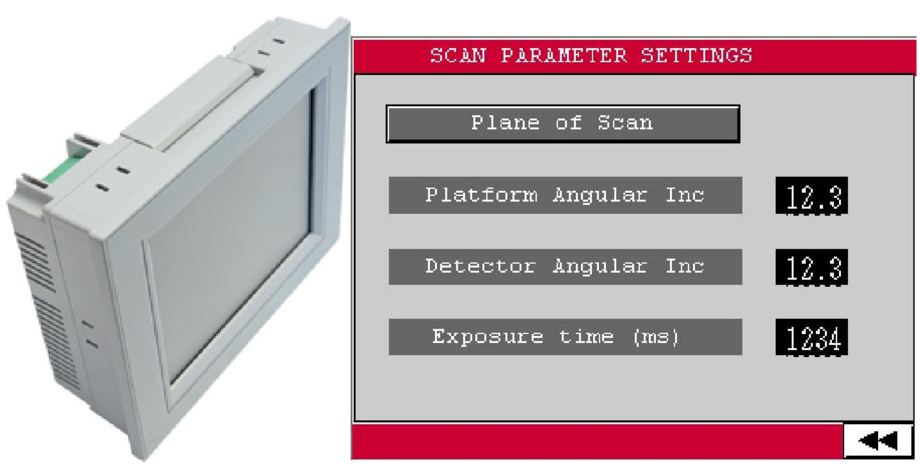


Figure 9 IDEC HG2F Touch Screen Display along with a Screenshot

Apart from the motion control system which is the core of the project, there are other safety control systems that ensure the safety of the operator from harmful nuclear radiation. This includes the automatic door lock system which functions as interlock for starting the system. The system can't be started without the doors being in locked position.

A few photon electric sensors are mounted at difference positions for homing of the system during startup and resume on power failure. This also helps in restarting the system and alignment of the detector and the source along the centre of the system for initialization of the scanning operation.

The control software for controlling the operation of the CT system was developed using IDEC WindLDR Software in Ladder Logic. IDEC WindLDR provides a very user friendly Ladder Program development environment enabling even amateurs to write ladder programs easily. Figure 10 below shows the screenshot of IDEC WindLDR Software during the development of the control software for the CT.

The HMI Screens and configurations for establishing proper communication with PLC had to be developed using IDEC WindOI software for which the screenshot has been given in Figure 11 below [1], [7], [9], [10], [11].

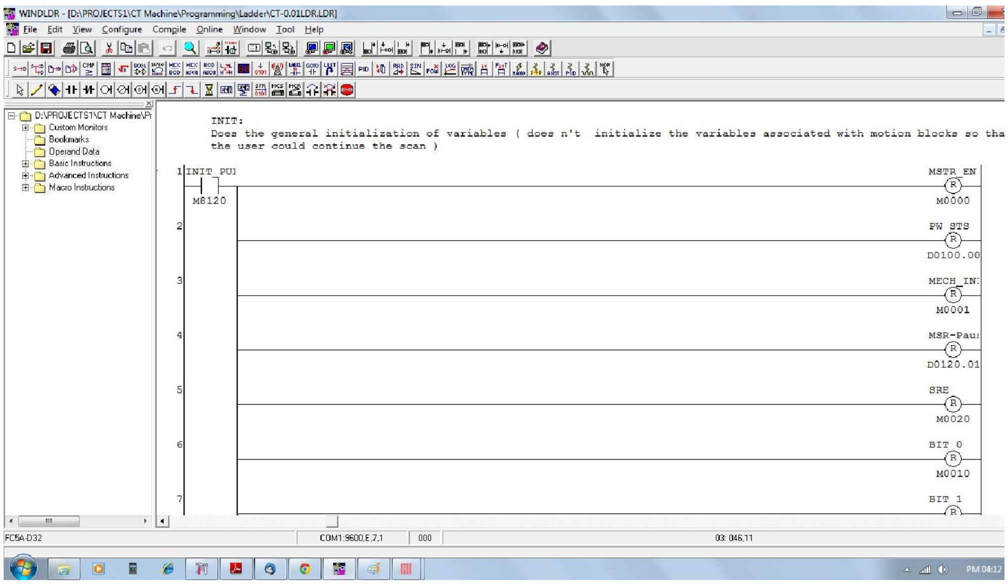


Figure 10 Screenshot of IDEC WindLDR Software

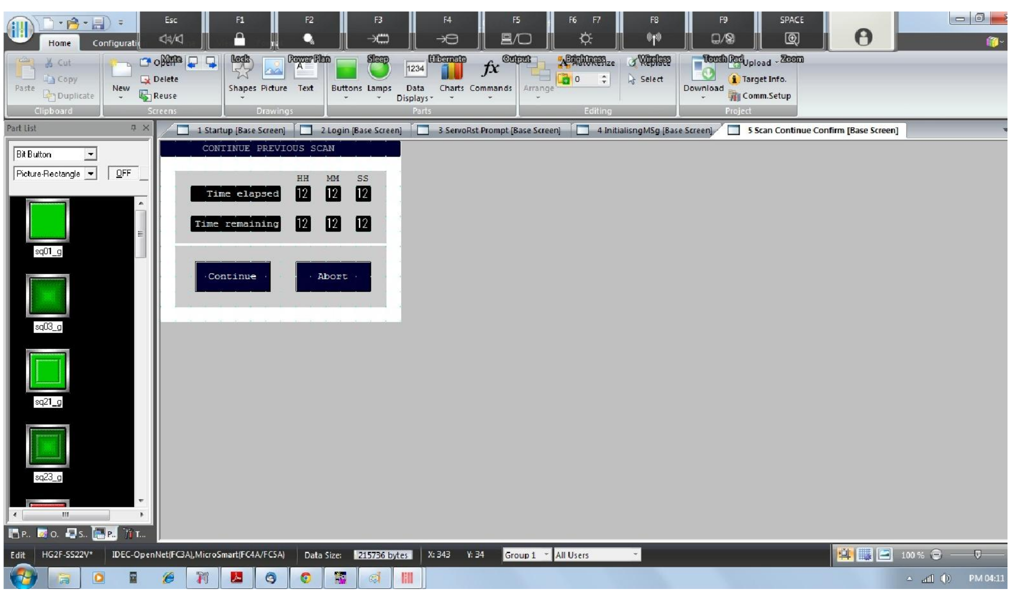


Figure 11 Screenshot of IDEC WindOI Software

5. DATA ACQUISITION SYSTEM

A Multi Channel Data Acquisition System(MIDAS) capable of collecting data from the NaI detectors installed in the system was integrated to the Electronic Motion Control System by means of a synchronising mechanism similar to a handshake in a communication protocol. For this, when the mechanical system reaches a particular position and is ready to acquire data, a signal is sent to the MIDAS to start acquiring the data. Once, MIDAS completes collection of data, a similar signal is sent to the Electronics Motion Control System instructing it to move to the next mechanical position and so on. Figure 12 below shows the front view of the MIDAS [6].

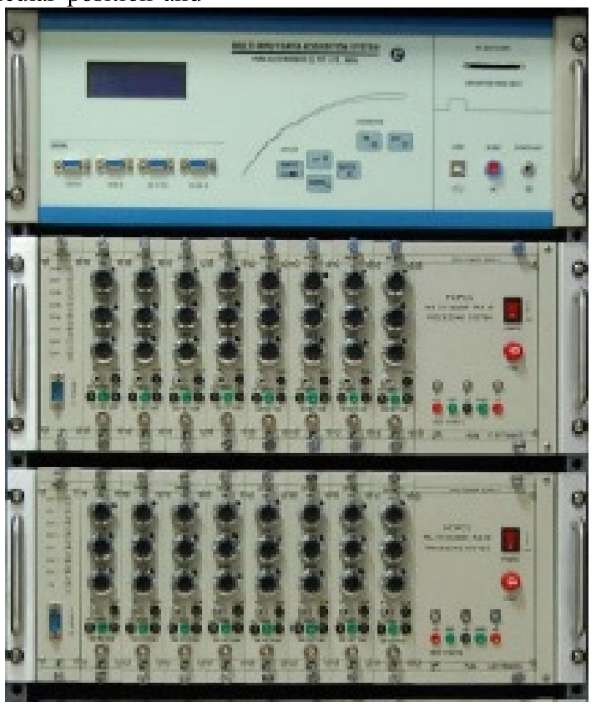


Figure 12 Front View of MIDAS

6. ELECTRONIC MOTION CONTROL SYSTEM

The MIDAS is connected to a PC based Data Presentation Software by USB Port. All the data collected from the detectors at different positions will be suitably stored in a database and is presented in an excel sheet or note pad by a matrix of numerals. This data can be later transferred to another PC based Image Reconstruction Software which will reconstruct an image that represents the time averaged state holdup inside the reaction column that was being scanned by the CT. Figure 13 below shows the reconstructed image from the acquired data by means of different Image reconstruction algorithms [1],[7],[8].

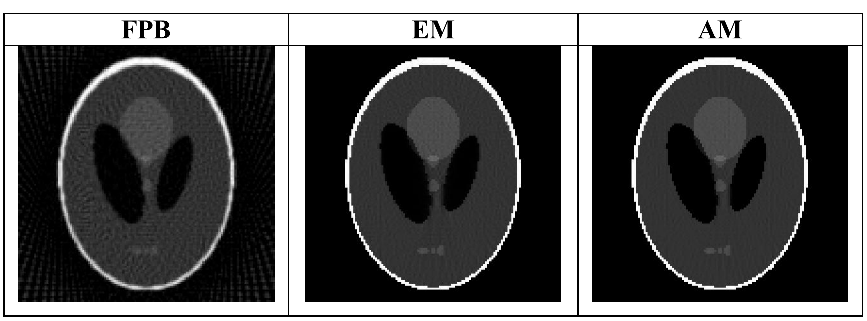


Figure 13 Reconstructed Image

7. CONCLUSION

The objective of this pilot project to design, fabricate and install a γ-ray Computed Tomography (CT) Unit to study the flow conditions and phase distribution inside the reaction chamber has been achieved. The work would not have been possible without the cooperation and involvement of different people. Planning and management skills were essential to ensure the smooth running and completion of the project.

8. FUTURE RECOMMENDATIONS

There is still room for improvement for this system and it is hoped that further study can be carried out to further develop the system. Improvements can be done to the design of the structure, for example by adding certain structures and coming with combined systems for CT and RPT. Besides that, improving the design of the sensors and safety arrangements is another improvement.

Abbreviations

CT--Computed Tomography
HMI--Human Machine Interface
MIDAS--Multi Channel Data Acquisition System
PLC-- Programmable Logic Control

Corresponding Author:
Mohammad Subian AlJohani
Department of Nuclear Engineering
King Abdulaziz University
Jeddah 21589, Kingdom of Saudi Arabia
Email: mjohani@kau.edu.sa

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