Project „Budování excelentního vědeckého týmu pro experimentální a numerické modelování v mechanice tekutin a termodynamice“

Project registration number: **CZ.1.07/2.3.00/20.0139**

The final report of internship at the University of Leeds

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Date of internship: two months in the period 29.6.2014 – 12.9.2014

Pilsen
2015

1. University of Leeds

(popis je převzat ze zprávy Katariny Ratkovské)

The University of Leeds was founded in 1904, but its origins go back to t-he nineteenth century with the founding of the Leeds School of Medicine in 1831 and then the Yorkshire College of Science in 1874.

It wasn't long, however, before each of the cities started to consider the benefits of forming their own universities. After Manchester and Liverpool had taken the decision to establish universities, Leeds also took the leap and in 1904, King Edward VII granted the University its own Charter as an independent institution.

The university has around 33,500 students the eighth-highest number of any university in the UK.

The university is a founding member of the Russell Group of research-intensive universities, the N8 Group for research collaboration,[10] the Worldwide Universities Network, the Association of Commonwealth Universities, the European University Association, the White Rose University Consortium, the Santander Network and CDIO and is also affiliated to the Association of MBAs, EQUIS and Universities UK.

Figure 1 Logo of University of Leeds

The various schools, institutes and centres of the university are arranged into nine faculties, each with a dean, pro-deans and central functions:

- Arts (English; History; Humanities; Institute for Colonial and Postcolonial Studies; Leeds Humanities Research Institute; Institute for Medieval Studies; School of Languages, Cultures and Societies;)
- Biological Sciences (Institute of Membrane and Systems Biology; Institute of Molecular and Cellular Biology; Institute of Integrative and Comparative

Biology; Undergraduate School of Biological Sciences; Graduate School of Biological Sciences)

- Business (Accounting and Finance; Economics; International Business; Management; Marketing; Work and Employment Relations)
- Education, Social Sciences and Law (Education; Law; Politics and International Studies; Sociology and Social Policy; Graduate School)
- Engineering (Chemical and Process Engineering; Civil Engineering; Computing; Electronic and Electrical Engineering; Mechanical Engineering)
- Environment (School of Earth and Environment; School of Geography; Institute for Transport Studies)
- Mathematics and Physical Sciences (Chemistry; School of Food Science and Nutrition; Mathematics; Physics and Astronomy)
- Medicine and Health (Leeds Dental Institute; School of Healthcare; School of Medicine; Leeds Institute of Genetics, Health and Therapeutics; Leeds Institute of Health Sciences; Leeds Institute of Medical Education; Leeds Institute of Molecular Medicine; Institute of Psychological Sciences)
- Performance, Visual Arts and Communications (Institute of Communications Studies; Design; School of Fine Art, History of Art & Cultural Studies; Music; Performance and Cultural Industries; Graduate School)

Figure 2 University of Leeds

Chemical and Process Engineering is department of Faculty of Engineering where operates professor of process tomography and sensing **Mi Wang**.

The School of Chemical and Process Engineering is a multidisciplinary school, addressing a range of global and societal challenges across the areas of Chemical Engineering, Energy and Materials Science.

Process Tomography, or CAT Scanning (Computer Aidded Tomography), as a generic, non-intrusive visualisation tool, offers new opportunities for full 3-D interrogation in both medical diagnosis and industrial process monitoring. This and other new imaging technologies are far more effective than our eyes for visualising the complex internal structure and fluid dynamics previously inaccessible due to a combination of the opaque nature of surrounding materials, the presence of hazardous materials, inaccessibility and, in many cases the need to be none invasive. Mi Wang deals with this topic – Tomography.

2. Processing of internship

The date and duration of the internship was communicated with Professor Mi Wang and consulted with other team members, because of coordination of the internship periods.

Contract for the Internship, which serves as an official document for all involved, students, University of Leeds and University of West Bohemia prepared by Ing. Roman Čermák, Ph.D.

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http://www.engineering.leeds.ac.uk/ipse.old/people/wangmi/wangmi.shtml

3. The course of my internship at the University of Leeds

(popis je částečně převzat ze zprávy Katariny Ratkovské)

The traineeships was focus on getting familiar with tomography measurements, both EIT (Electrical Impedance Tomography) and ECT (Electrical Capacitance Tomography).

The stay was divided into two periods, one month each.

In the first two weeks I was studing several papers and PhD thesis of students od the lab. led by prof.Mi Wang (with his asistants Dr. Yousef Faraj and Quiang Wang).

Figure 3 Work team in Leeds

Third week of the first part contained preparations to the in situ measurements in Cranfield facility. The forth week was dedicated to the measurements in Cranfield.

The fifth week (first week of the second period) was dedicated to a detailed training with using relevant HW and SW in the lab. I and other team members were trained in:

- using PIV (DANTEC system) for a simple experiment – John Vickers - described in the following section.

- using ECT tomography HW and SW for evaluation of the measurement

- using EIT tomography HE and SW for evaluation of the measurement

- using wire-mesh sensor

- operating the water loop located in the labs – briefly described in the following section

- operating the slurry loop located in the labs – briefly described in the following section

The sixth, seventh and eigth week were dedicated to designing of an experiment with using ECT for a steam detection, getting familiar with the ECT measurements, redesign and reparations of a flame sensor, calibration of the sensor and measurement system with various particles and assistance with a preparation of PIV measurements on the water loop. It will be briefly described in the following sections.

3.1 Experiment of John Vickers

The rig consists of a glass testing tank which can be seen in Figure 4, with a fluid jet inlet suspended above, and this jet inlet is connected via a pump to a feed tank. The test tank has an overflow system which empties into an overflow tank which then pumps the fluid back up to the feed tank. The entire system is on a moveable frame with removable panels to shield the operator from scattered laser pulses when the rig is in operation. A schematic of the entire rig is shown in Figure 5.

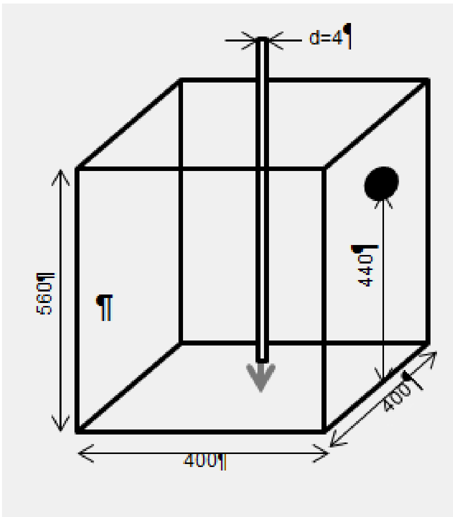

Figure 4 Diagram of test tank used

Seeding particles: The focus of this investigation is into developing the techniques for fluorescent PIV, for this reason it was important that fluorescent tracer particles were used to track the fluid motion, thereby providing experience. The particles used were FPP (Fluorescent Polymer Particles), The particles are spherical with a mean particle size of 10µm over a range of 1-20 10µm and are made of Poly (Methyl methacrylate) homogenously doped with Rhodium B. The refractive index of these particles is 1.479 and they have a density of 1.19g/cm^3.

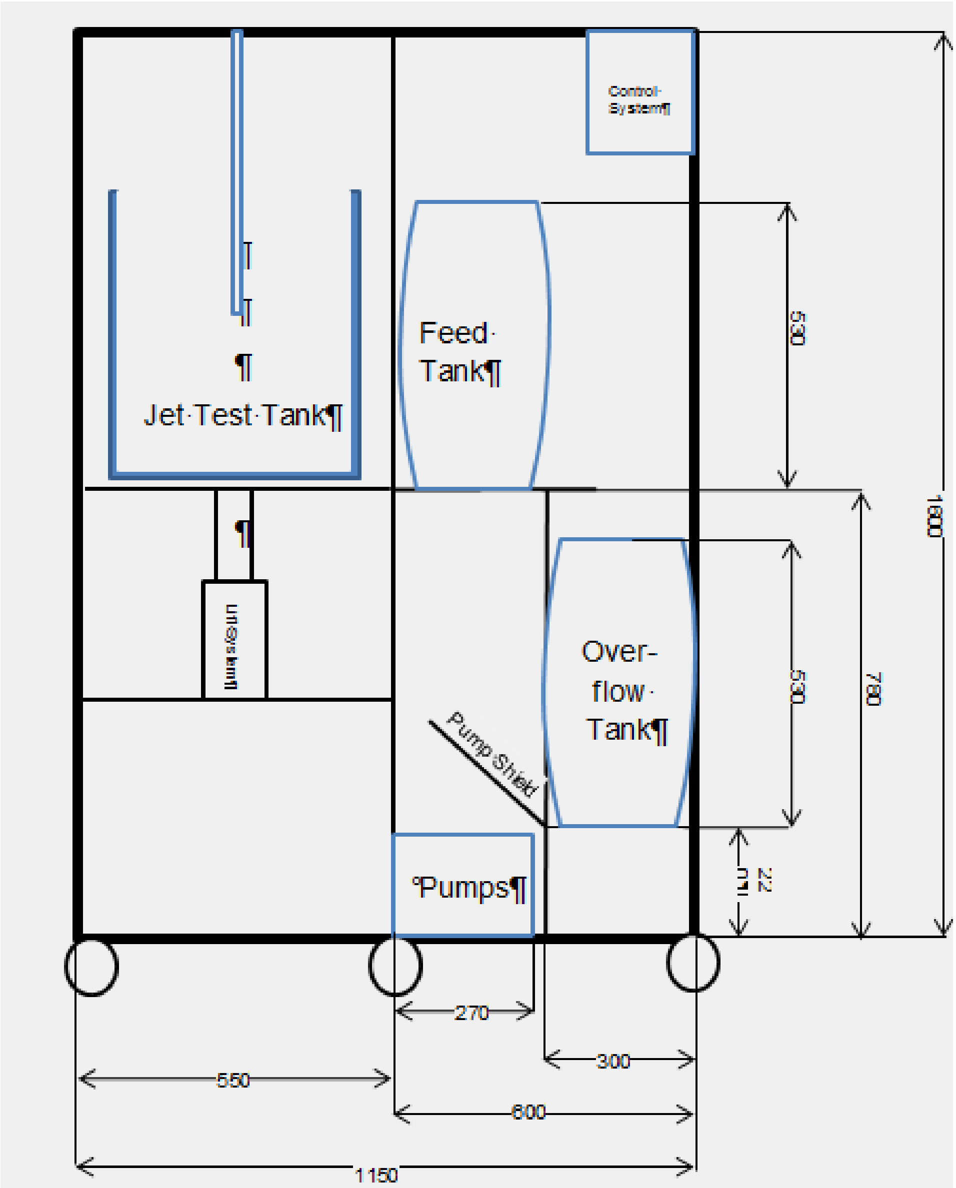

Figure 5 Schematic of impinging jet rig

Laser: The laser used was a double-cavity Nd:YAG laser firing at a rate of 15hz, before being entering the testing tank it was diverted through a series of optics to cause the beam to diverge and form a light sheet.

3.2 PIV experiment on water loop

I assisted Ms.Katarina Ratkovska in the preparation of an PIV experiments on the water loop. The goal was to compare the measurement results with the results of tomography measurements. Part of the experiment was to write COSHH form, it's a safety report, which covers all possible hazards in the workplace during an experiment, also includes measures to avoid that risk and also the solution for the case that the occurrence of complications during the measurement.

As the safety work in England is very sensitive, rulemaking and subsequently approval takes a long time, during my stay in the UK experiment has not been approved.

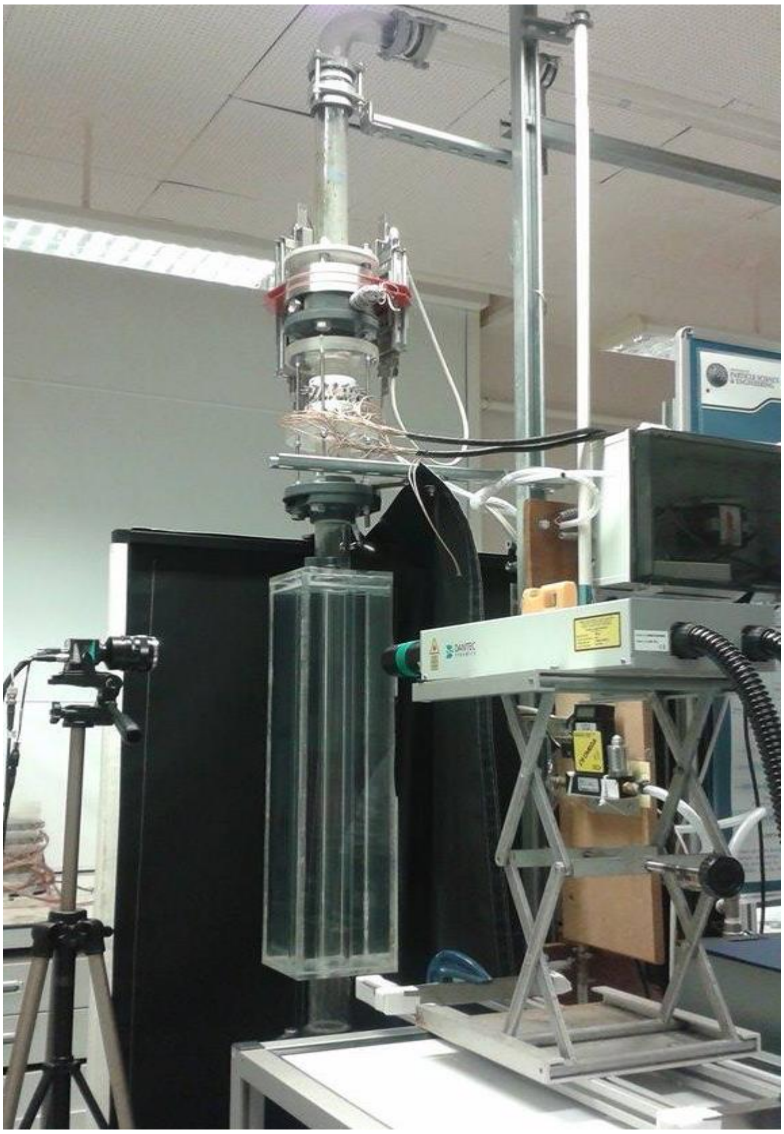

Figure 6 Set up of PIV experiment

Due to safety reason the measurement preparation was not finished till the end of my stay in Leeds.

3.3 Electrical Capacitance Tomography – principles

Multiphase flow systems are of a critical element in many industrial processes as they constitude the medium through which basic ingredients are processed to yield the final product. Examples of their use include energy generating processes, food processeing and drug manufacturing, among others. The ability to image multiphase flow interaction in real time has always been a highly desirable capability to further understand the complex dynamics among interacting phases in any flow system. Such understanding is critical, for examlple, to effectively model, optimize and scale up the reactors that host the process. From early on, electrical sensing techniques have attracted much attention as a noninvasive means for imaging of multiphase flow systems, in addition, the rates in which phase interactions occur often demand fast imaging modalities, again making electric sensing techniques a natural choice [3].

Electrical capacitance tomography (ECT) is an electric sensing modality that easily meets the high – speed demands of multiphase flow real – time imaging. ECT has also a noninvasive characteristic, a feature much desirable in industrial applications as noted. The basic system components used for ECT then, and still used today, are a set of capacitance plates constituting the ECT sensor, data acquisition system for measuring the mutual capacitance between different plate pairs, and a processing device for image reconstruction and visualization. Each of these individual components has been further developed over the years in terms of both hardware and software capabilities. Most notable are the efforts aimed at developing new imaging reconstruction techniques to extract better images from the limited set of capacitance data. [3]. ECT can be used in a wide range of applications, including monitoring fluidized beds [4], flow rate measurement in pneumatic conveying systems 5], flame and combustion imaging [6] , product uniformity monitoring and sensing [7], high-speed check-weighing and the monitoring of oil-gas flows [8].

ECT is used to obtain information about the spatial distribution of a mixture of dielectric materials inside a vessel, by measuring the electrical capacitances between sets of electrodes placed around its periphery (Fig.11.) and converting these measurements into an image showing the distribution of permittivity as a pixel-based plot or image averaged over a volume whose length is equal to that of the measurement electrodes [9].

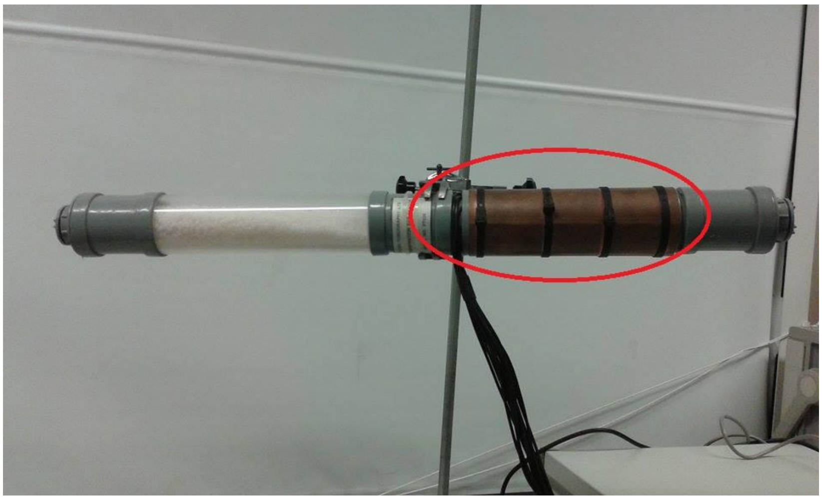

Figure 6 . An electrical capacitance tomography demo sensor

The images are approximate and of relatively low resolution, but they can be generated at relatively high speeds. Although it is possible to image vessels of any cross section, most of the work to-date has been carried out on circular vessels. ECT can be used with any arbitrary mixture of different non-conducting dielectric materials such as plastics, hydrocarbons, sand or glass. The permittivity image resolution achievable depends on the number of independent capacitance measurements, but is generally low [9,10].

<u>Principle of operational</u>

Figure 12. shows a schematic view of the basic components of an ECT, consisting of capacitance sensors, data acquisition electronics, and image reconstruction/visualization software. The capacitive sensors are used here to blanket the region to be imaged with a static electric field, from which sensitivity maps indicate the regions in the imaging domain from where the changes on the mutual capacitances are being affected. The data acquisition electronics measure the capacitance variations as changes in dielectric material distribution that take place inside the imaging domain. The set of mutual capacitance data measured by the acquisition system is one dimensional (ID). Nevertheless, imbedded in such data is the spatial information per the sensor design and relative spatial arrangement among the electrode plates. The reconstruction algorithm essentially aims at decoding such two-dimensional (2D) or three-dimensional (3D) spatial information from the ID capacitance measurements [3].

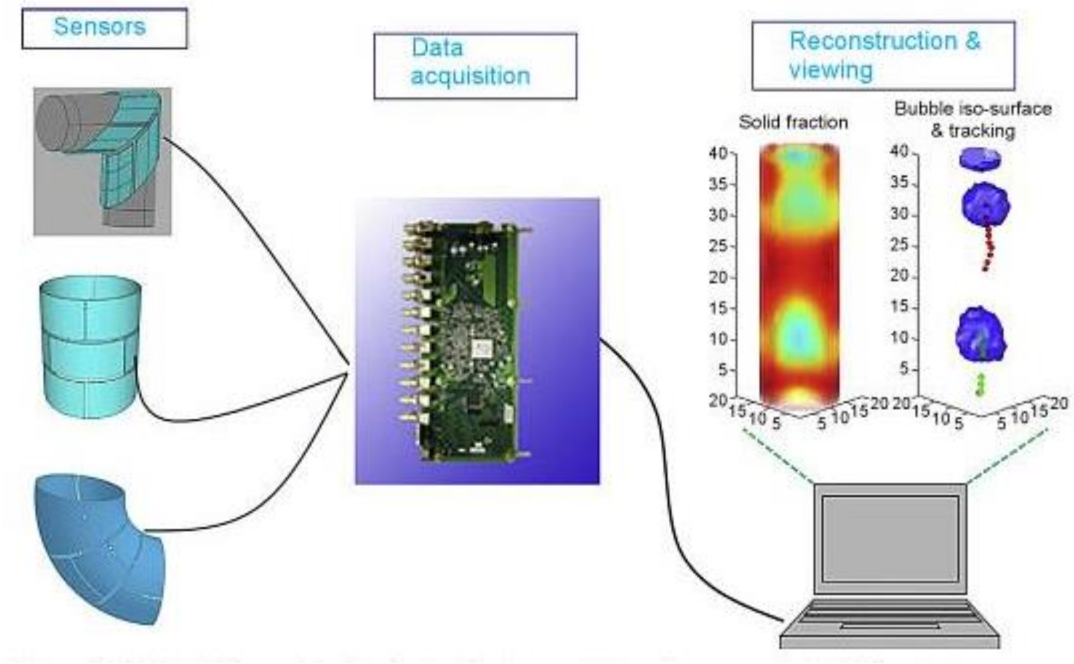

Figure 7 Illustration of the basic electrical capacitance tomography system components

<u>Capacitance measurement principle</u>

The basic capacitance measurement principle used in ECT is shown in figure 13. An alternating voltage (Vs) is applied betwen one electrode (the source electrode) and ground and the resulting currents A which flow between the source electrode and the remaining electrodes to ground are measured. These currents are directly proportional to the capacitances between the source and detector electrodes. The set of capacitance measurements made when one electrode is excited as a source is known as a projection.

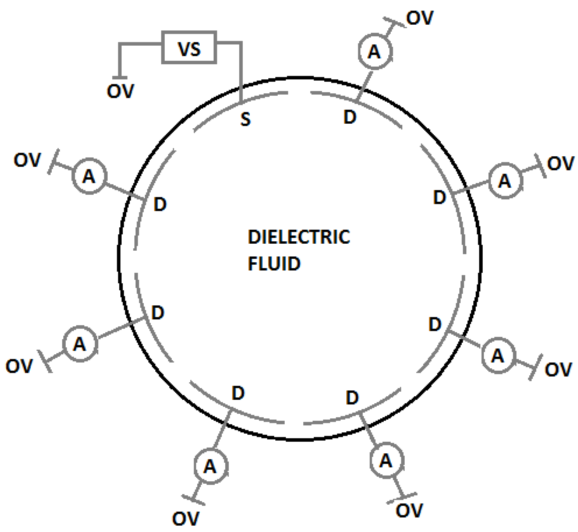

Figure 8 Capacitance measurement principle

Format of permitivity images

Images can be generated at high frame rates, typically up to 5000 frames per second. Successful applications of ECT include imaging 2-phase liquid-gas mixtures in oil pipelines and solids/gas mixtures in fluidised beds and pneumatic conveying systems. Where the mixture is flowing along the vessel, measurements of the concentration distributions at two axial planes permit the velocity profile and the overall flow rate to be found in some cases. A typical ECT permittivity image format uses a square grid of 32 x 32 pixels to display the distribution of the normalised composite permittivity of each pixel. For a circular sensor, 812 of the available 1024 pixels are used to approximate the cross-section of the sensor [9].

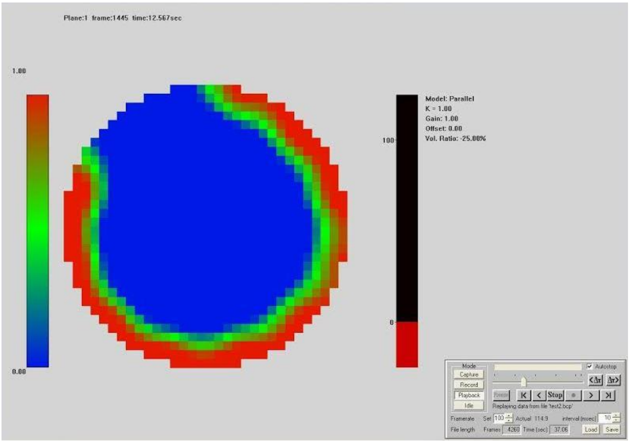

Figure 9 . ECT image for contents of a circular sensor

The concentration distribution is normally plotted on a fairly coarse pixel grid, because the relatively small number of available measurements limits the possible image resolution. In the sample images shown below, a red/green/blue colour scale shows areas of high concentration as red and areas of low concentration as blue – is shown in figure 14.

ECT Sensor for steam-in-air detection

For ECT measurement the design of he sensor is crucial. There are several rules published in the literature (esp. users‘ guides for the laboratory hardware).

Design rules are described in the users guides for the measurement hardware. It is very important to pay attention to proper size of electrodes, grounding and guarding electrodes, etc.

There is a prototype sensor developed in the lab at the University of Leeds in the picture 15. The purpose of the sensor was a flame detection. The sensor was used for first experiments with the steam.

Figure 15 . ECT sensor for flame detection

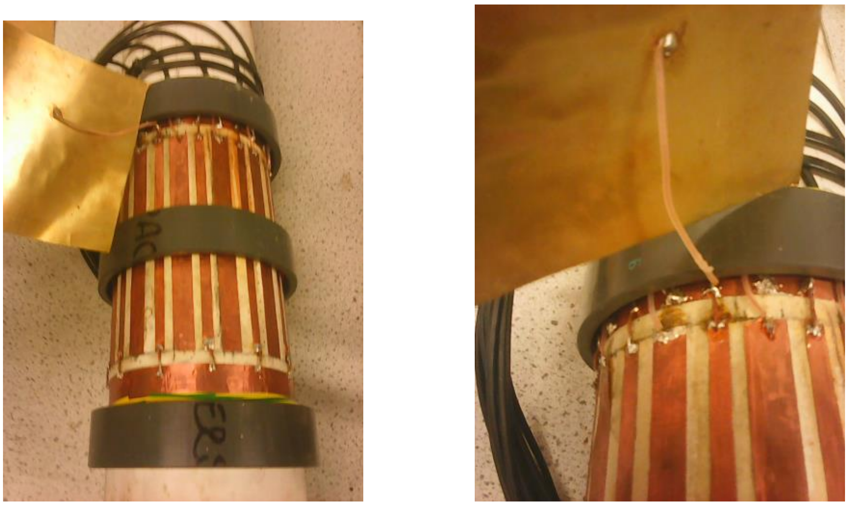

Figure 16 . View inside the ECT sensor for flame detection

On the picture 16 a system of electrodes and grounding is clearly visible. All the cables are connected to the measurement unit which provides the basic data processing and sends the results to the PC via ethernet. The measurement unit is shown on the figure 17.

Calibration is very important part of the measurement procedure. Several materials were tested as a limit value of the permitivity. Several experiments were carried out with glass and clay elements – see figure 18.

Users guides to the PTL300E describes in detail all the steps necessary for the sensor calibration, measurements and visualisation of the results. Methods used in the process are briefly described in the guides. A picture of user interface is shown on figure 19.

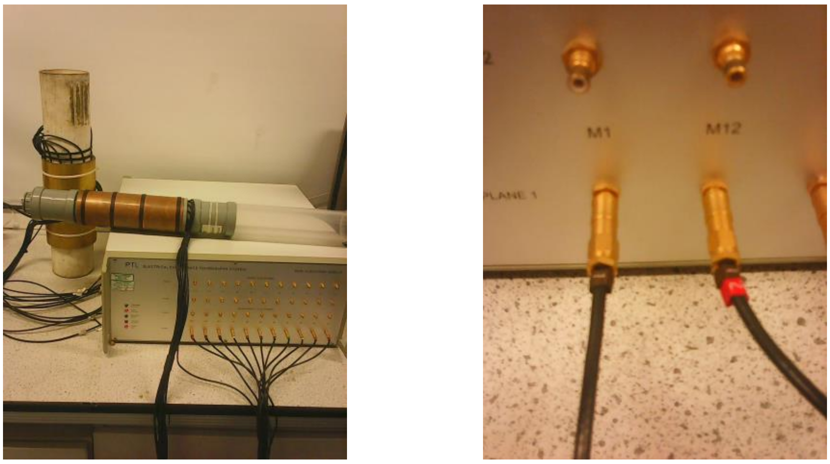

Figure 17 . Twin-plane measurement unit PTL300E from Process Tomography Ltd. and the cable connection detail

Figure 18 . Particles used for calibration

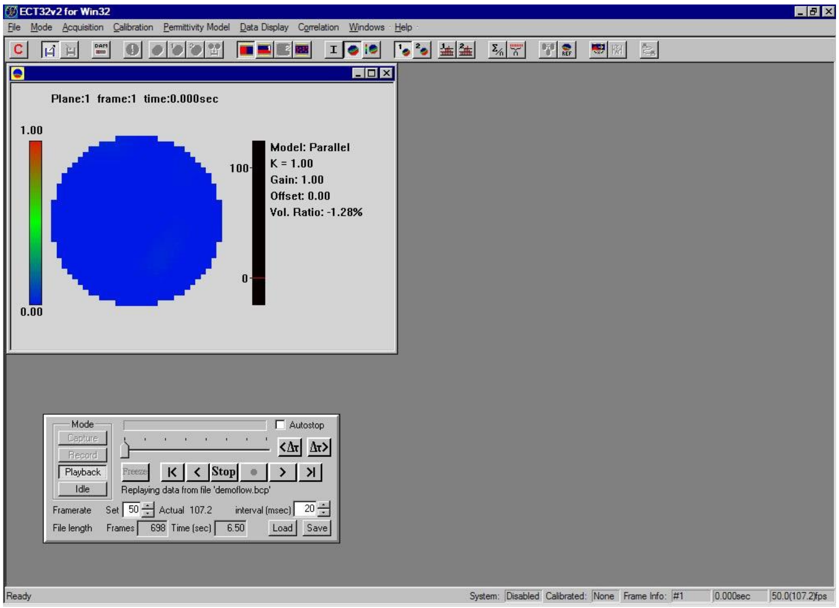

Figure 20 . Visual interface - main ECT32v2 software window (Process Tomography Ltd.)

Experiment with steam-in-air detection

A simple experiment was proposed for demonstration of abilitity of ECT to detect steam droplets in the air. The layout is shown at fig.21.

The main idea is to generate wet steam and lead it to a preheated ECT sensor with one or several condensation planes. It should cause generation od steam droplets which influence the permitivity and will be detected by the ECT sensor.

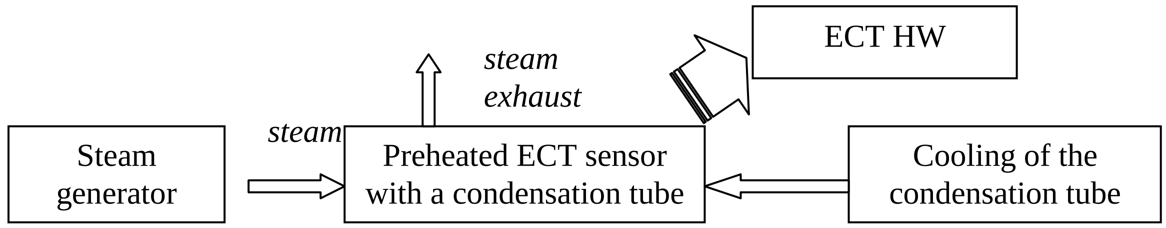

Figure 21 . Block diagram of the experiment

The experiment was designed and several tests with different media for calibration and with different sensors were used.

Unfortunately, due to safety reasons we didn't get approval for operation the experiment with a steam generator until the end of my stay in Leeds. The experiment with steam was tested by my co-intern, who stayded in Leeds one month later.

3.4 Electrical Impedance Tomography

The internship contained a short intensive training in EIT and using various devices from ITS company, the manufacturer of the tomograph hardware.

Electrical impedance (or sometimes addressed as resistance) tomography is based on similar principles as above mentioned ECT. Significant difference is in the physics of the problem. While ECT uses non-conductive media and the electrical capacity between two electrodes (the source electrode and the detector) is measured, the EIT uses conductive media and the conductivity is detected.

The arrangement of the electrodes is also similar. The difference is, that they are in direct contact with the media inside. The wall is supposed to be non-conductive or at least very well insulated from the electrode (there are plenty of papers published on the topics of conductive wall and the proper electrode and insulation design).

The EIT method uses a couple of electrodes as a source. They inject the electric current into the system and other couples of electrodes to measure the conductivity.

The most common principle is measurement with so called adjacent electrodes – see Fig.17. It uses an adjacent couple of sensors for current injection and the other adjacent pairs for detection (e.g. 1-2 injection, 3-4, 4-5, 5-6, 6-7, 7-8 for detection). The whole measurement is repeated for all pairs (next 2-3 is injected, then 3-4, etc.).

There are various strategies, which can be used for injection – adjacent, opposite, random, etc.

It is clear, that the whole measurement takes quite a lot of time even in the case, that the hardware – electronics- is fast enough.

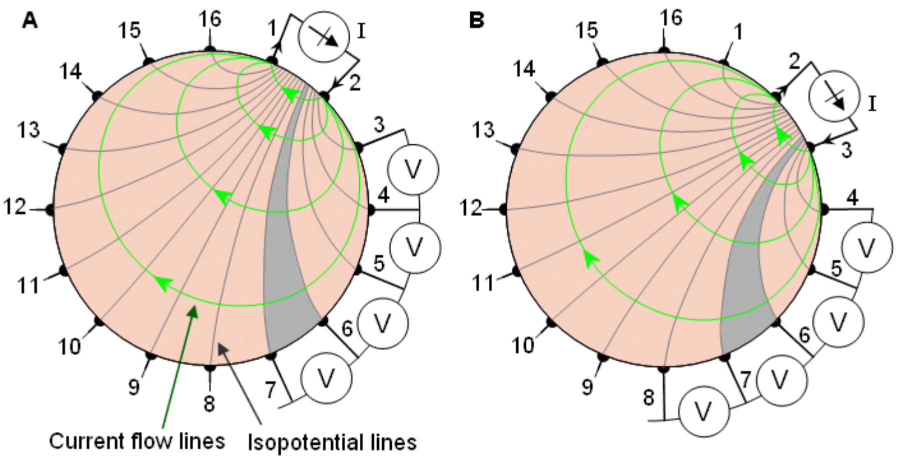

Figure 22 . EIT with the adjacent electrodes (http://www.bem.fi/book/26/26.htm)

The measurement is in principle possible with both DC and AC injected currents. To avoid unwanted effects in the conductive media (like electrolysis or similar) the AC current is used in almost all applications. Frequency of the injected current varies from several Hz to several tens of kHz (mentioned in various papers). The higher frequency eleiminates the effect of capacitance and only the resistance can be taken into account.

The hardware used for EIT measurement in the lab at the UoL was manufactured by ITS (Industrial Tomography Systems, http://www.itoms.com/), and it was an older version of their current products – see Fig.23. The lab was equipped with Z8000 (high speed) and P2K (low speed) systems. The current version available (and also the version purchased to the UWB labs) is V5R for high speed measurements and P2+ for multiple planes.

Figure 23 . EIT hardware from ITS (source http://www.itoms.com).
V5R left, P2+right

The V5R model is designed for fast measurements in the two parallel planes. It contains automatic adjustment of the injected current.

On the other hand the P2+ system is a slower high precision device, which can measure in up to the eigth parallel planes. There are several configurations available – full with the eight planes with 128 electrodes, compact with 1 or 2 planes with up to 32 electrodes.

Figure 24 . EIT sensors examples

The crucial part of the measurement is a interpretation of the conductivity maps. There are several options, which SW we can use for that.

The first and very straightforward method is the commercially available package from ITS. The software provides the user a opportunity to change the shape of the sensor – circular pipe, U channel, line sensors. It is possible to adjust injection currents and many other parameters. Unfortunately it doesn’t support different injection strategies (only the adjacent electrodes) and different sensor shapes.

Another option is using the an open-source EIDORS (http://eidors3d.sourceforge.net). The software allow the user to model various shape of the sensors, select different strategies for current injection and use various methods for evaluation of the results.

Literature

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