Visualization of Flames Using Electrical Capacitance Tomography

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1 Principle of operation

The basic idea behind ECT is to measure the changes in the electrical capacitances between all possible combinations of electrodes that occur when a dielectric material is introduced into the measurement space. These inter-electrode capacitance changes are caused by variations in the permittivity of the material inside the vessel:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d} \tag{1}$$

where: *C – the capacitance;*
A – the area of each plane electrode;
d – the distance between the electrodes;
ε_0 – the permittivity of free space = $8.85 \cdot 10^{-12}$ [s^4A^2/m^3kg]);
ε_r – the dielectric constant or relative permittivity of the insulator used.

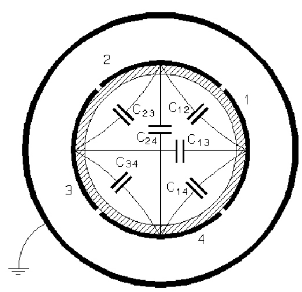

Fig.1. Schematic of the sensor for Electrical Capacitance Tomography (ECT).

At present, the main aim of Capacitance Tomography is to obtain the images of permittivity distribution in gas-flow flow systems, a dense pneumatic conveying system or a bubbling fluidization [1][2][3]. But experimental researches have been carried out showing that this method can be apply to visualization of combustion process [4][5].

2 The measurement concept of Capacitance Tomography

The hardware of Capacitance Tomography consists of a sensors with usually eight, 12 or 16 electrodes, one or more electronic devices for the measurement of capacitances and a computer which controls the measurement, stores the acquired data and reconstructs images from the integral measurements.

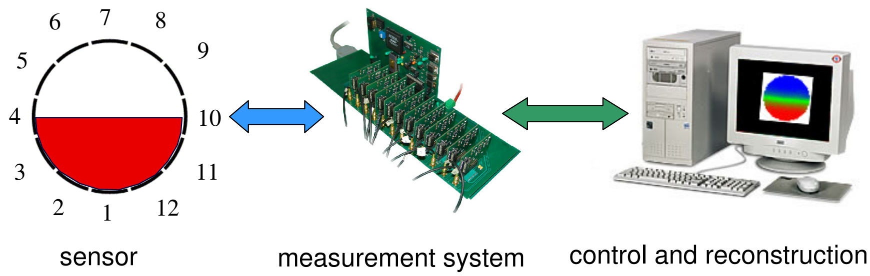

Fig.2. Schematic of Electrical Capacitance Tomography system.

The method normally used to obtain ECT images from capacitance measurements is the Linear Back-Projection (LBP) algorithm, which produces relatively low-accuracy images. For improving the accuracy of LBP images a simple iterative image computation method – ILBP (Iterative Linear Back Projection) is used.

In research an open-ended steel cylinder which was fitted with twelve electrodes, as shown in figure 3 was used. The cylinder is 150 mm in diameter and 200 mm high. The electrodes are 100 mm long and are located centrally along the cylinder. The electrodes are made from brass, which is electrically insulated from the cylinder wall with a thin sheet of PTFE.

Fig.3. Model combustion can

3 Research of the reconstruction of stationary flame.

When fuel is burning, a large number of charged particles are generated. These will modify both the permittivity and conductivity of the reaction zone. So, signal level depends on the concentrations of the various kinds of charged particles present during combustions. Possible carriers are electrons and positive and negative ions. These charged particles may be formed as a result of chemical reactions, which are called chemi-ionization and thermal ionization. The measurements are made in the combustion chamber equipped with specially designed electrodes. The flame distribution (shape) in the cross-section between the electrodes is reconstructed from the measurement of electrical signals (output on electrodes).

The first test consisted of inserting the flame from a Bunsen burner inside the can. The flame was moved around inside the can and the reconstructed image displayed in pseudo-colour on a monitor. The images tracked the flame movements in real-time in a satisfactory manner. An image sequence of combustion process is shown on Fig. 4.

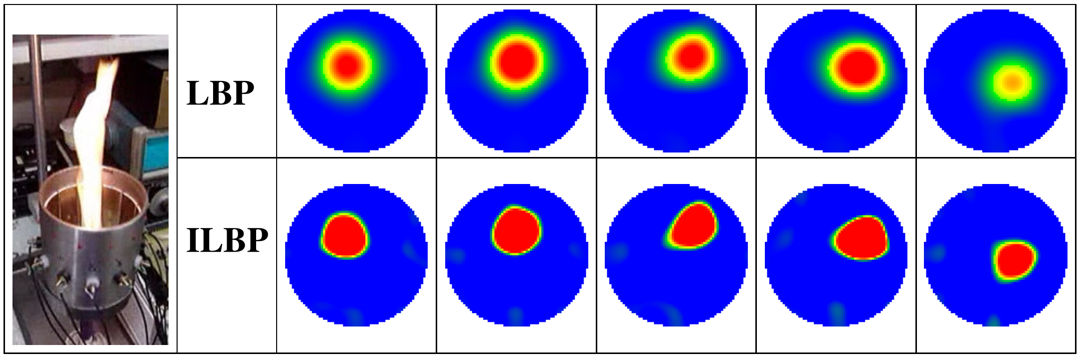

Fig. 4. Reconstructed images of single flame inside the model cylinder can.

In this case, “object” (flame) is only one and size of flame proportion to size of sensor was considerable. Therefore, there was no problem with reconstruction but it is necessary to check if the system will be able to reconstruct more flames of smaller size. For that purpose, it was prepared a special experimental stand, which consist of two parts: plane with holes and miniature burners (Fig.5).

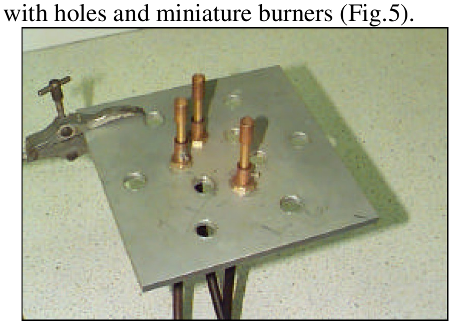

Fig. 5. Three burner array

Aluminum plate was able to any way resolve location of burners in measurement space. To reconstruction was used the some configuration of position of two and three burners.

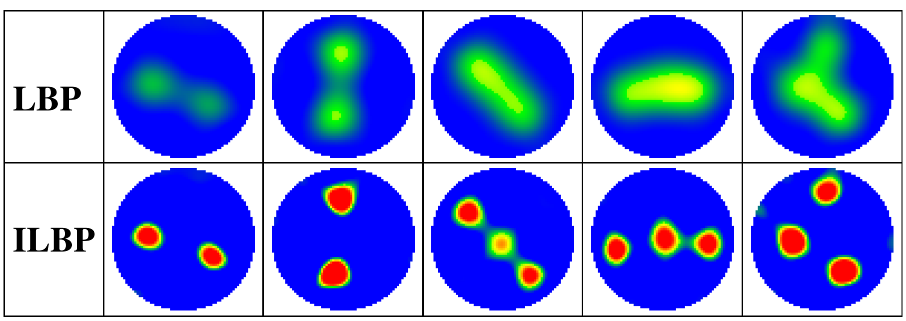

Fig. 6. Two and three burner reconstructed image

From the description of the LBP method, it is clear that images produced by this method will always be approximate. The method spreads the true image over the whole of the sensor area and consequently produces very blurred images. This case we don’t know how many burners were used. With application of the ILBP techniques of signal processing correctly define position and number of flames can be reconstructed, so the resolution of the system is significantly better.

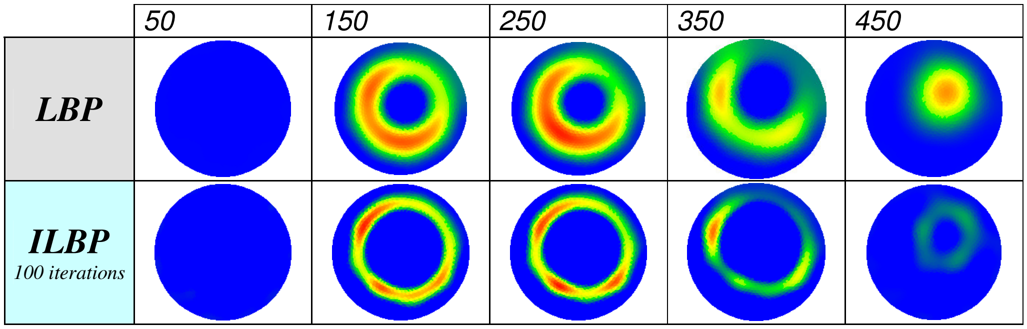

Fig.7 Reconstruction of stationary diffusion flame

On Fig. 7 reconstruction of stationary diffusion Flame is presented. From comparison of the two different methods of signal processing one can find that the ILBP (Iterative Linear Back Projection) is superior over LBP algorithm of signal processing. Results of the experimental investigation of signal properties as a function of flame parameters will be presented in a full version of the paper.

4 Conclusion

The ECT system has the major advantage over optical visualization systems since it does not require optical access and use passive, non-invasive electrodes. The sensors are incorporated into the combustion chamber, burners, etc., in such a way that it could be developed for routine commercial use.

Obviously, there are many parameters affecting the concentrations of the ions. For example: the temperature has a strong influence density of ionization but currently, the link between flame temperature and ECT output has not been jet fully investigated.

It's seems that in a not to distinct future it will be possible to monitor basic flame structure inside the turbojet combustion chamber or industrial burners.

By introducing the possibility of on line monitoring of combustion in a closed system it will be not only possible to increase the safety, but also it could allow control of combustion processes and improve efficiency of the system. It will be also a very good tool for research propose, especially in development of a new combustion chamber operated at very high pressure, where installation of optical windows is very difficult and many time not possible. It will be also possible to introduce multi-row electrode system. At that time, three-dimensional images of the flame structure will be obtained. Its, however, will need further extensive study of this new and very promising techniques.

References

[1] Plaskowski A, Beck M S, Byars M, Dykowski T, He R., Wang S J, Waterfall R C and Yang W Q (1996). Industrial application of electrical capacitance Tomography. Pomiary Automatyka Kontrola 5, pp. 113-115

[2] Yang W Q, Stott A L, Beck M S and Xie C G (1995). Development of capacitance tomographic imaging systems for oil pipeline measurements. Review of Scientific Instriments, 66 (8), pp. 4326-4332

[3] Huang S M, Plaskowski A, Xie C G and Beck M S (1989). Tomographics imaging of two-component flow using capacitance sensors. Meas. Sci. Technol., No. 22, pp.173-177

[4] Waterfall R C, He R, White N B and Beck C M (1996). Combustion imaging form electrical impedance measurements. Meas. Sci. Technol., No. 7, pp.369-374

[5] Gut Z, Wolanski P, He R, Waterfall R C (1997). Application of Electrical Tomography to Combustion Studies. 16th ICDERS, Kraków