PTL

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TFL R5000 PERFORMANCE OVERVIEW

All ECT measurement systems are not the same! When comparing the **TFL R5000** with nominally similar systems from other suppliers, please make sure you consider carefully the performance parameters which are relevant to your proposed application. ECT can offer measurements which are either impossible or very difficult to make with other measurement technologies and we don't want you to be disappointed with results generated by inferior equipment. In this document, we have highlighted some of the essential features of ECT that need to be considered if your application requires usable quantitative data and not just qualitative images!

TFL R5000 Development History

The **TFL R5000** is a spin-off from a recent collaborative industrial research project carried out by Tomoflow and two major industrial partners to develop a 2-phase Tomographic flow meter for use with solid/air mixtures. This development has resulted in a step change in the performance of ECT technology over the last 5 years and the **TFL R5000**, which is targetted at laboratory or pilot plant applications, out-performs all other commercially-available ECT systems. The **TFL R5000** instrument incorporates modern electronic design principles and contains an internal Digital Signal Processor (DSP) and two Field Programmable Gate Arrays (FPGA) for electrode control, excitation, sequencing and capacitance measurements. The user interface is a standard laptop PC, which controls the unit via an ethernet link, displays the measured data. and is also used to update the DSP and FPGA firmware, ensuring that an upgrade path is available for implementing future developments and improvements to the **TFL R5000** as they become available.

Operation and use

When used with a suitable multi-electrode ECT capacitance sensor, the **TFL R5000** can be used for a wide range of ECT-based measurements, including the concentration, velocity and flow distribution of a mixture of 2 dielectric materials over the vessel cross-section. All of the measurement parameters within the **TFL R5000** unit can be configured and set in software on the Control PC via a standard ethernet link. This allows the measurement system to be operated in a wide range of operating and data capture modes and environments and ensures future-proof operation and upgrade capability. The use of Ethernet as the data link means that there can be long runs between the capacitance measurement unit and the control computer (100m per segment for cable, more with fibre optic versions) compared with 5m total for systems which use USB data links. Remote operation is even possible over compatible fast internet or local network links and data capture can be synchronised to the operation of other equipment via an external trigger port.

Measurement channels

The **TFL R5000** can operate in single-plane mode for use with capacitance sensors having up to 16 measurement and 16 driven guard electrodes at a single measurement plane, or in twin-plane mode wth sensors having up to 8 measurement and 8 driven guard electrodes at each of two measurement planes. Single-electrode excitation is the normal mode of operation, but additional options allow combinations of 2 or more electrodes to be excited simultaneously to further improve measurement sensitivity if required.

Capacitance measurement

A differential capacitance measurement method must be used in ECT systems to eliminate the high standing capacitances to ground which exist in all practical ECT systems and sensors, including the sensor connecting cables. The method used in the **TFL R5000** is based on the use of an excitation signal in the form of a 15V p-p square wave with a frequency which can be set within the range 1 to 10 MHz, together with a synchronous demodulator. The phasing of the demodulator can be optimised to measure either the capacitive (loss-free) component or the conductive (lossy) component of the sensor contents. In general, higher speed and lower noise operation are possible at the higher excitation frequencies, although at a cost of some increase in the overall power consumption. The charge/discharge capacitance measurement technology has been extensively developed and refined by ourselves over the last 15 years and is the fastest and lowest noise capacitance measurement technique currently available in any ECT measurement system.

Driven axial guard channels

The **TFL R5000** has a full set of driven guard excitation channels (one for each capacitance measurement channel). The use of driven axial guard electrodes ensures that an axially-uniform electric field is maintained over the capacitance sensor cross-section and allows the lengths of the measurement electrodes to be minimised, which optimises the axial resolution of the ECT sensor. The use of driven guard electrodes is essential for sensors where the sensor diameter exceeds around 50mm, otherwise the axial resolution and capacitances measured across the sensor will be severely degraded, leading to higher measurement noise and drift and lower measurement sensitivity. ECT sensors with measurement electrodes as short as 3cm for use on vessel diameters up to 50cm have been successfully constructed and operated by TFL using effective driven guarding techniques.

Measurement resolution and range

The measurement resolution determines the abilility of the ECT system to measure small changes in permittivity or concentration. The **TFL R5000** uses 16 bit ADCs (Analogue to Digital Converters) and has a capacitance measurement resolution of 1 part in 65,000. The use of a further 3 bits of gain switching on each measurement channel gives an effective measurement range of 19 bits (500,000:1) allowing capacitance measurements to be made over the nominal range from 0 to 2000fF with a measurement resolution of approximately 0.005fF, which can be further improved at lower frame rates. Note that the measurement resolution is very important for calculating accurate voidages (or concentrations) in 2-phase systems. A typical ECT sensor will have a capacitance of 10fF between opposite electrodes. If the resolution of the measurement system is only 0.1fF, this produces a best concentration measurement resolution of 1%, which is inadequate for many solids flow measurement applications.

Data capture rate and measurement skew

When used with an 8-electrode sensor and an excitation frequency of 10MHz, the **TFL R5000** has a maximum capture rate of 5000 frames per second in twin-plane mode. The use of one ADC per measurement channel allows all data within one electrode excitation projection to be captured simultaneously, avoiding any measurement skew within an electrode projection. The high data frame capture rate also means that any measurement skew between sets (frames) of sequential electrode excitation projections is minimised. This is an important consideration when imaging fast changes. The very fast frame capture rate also means that very low measurement noise levels can be achieved by converting this high-speed data to lower frame rates by the use of down-sampling, as described in the next section.

Measurement noise

The measurement noise level of an ECT system is important because it determines a number of measurement parameters. These include the minimum axial length of capacitance electrode that can be used with the measurement system, the overall measurement resolution and the precision of iterative or regularised techniques used to reconstruct ECT images. The **TFL R5000** has a typical measurement noise level of 0.02fF rms at an excitation frequency of 5MHz and a down-converted frame rate of 500 fps (using a down-sampling factor of 5). At slower frame rates (eg at 100fps with a downsampling factor of 25), this reduces to 0.01fF or less. For a typical opposite electrode capacitance measurement (10fF), this corresponds to a signal-to-noise ratio of approximately 60dB. This performance allows capacitance sensor electrodes as short as 15mm (or even less in some cases) to be used (together with suitable driven axial guard electrodes) in an 8-electrode sensor.

Temperature stability

Because of their high measurement sensitivity, ECT systems can be prone to measurement drift with temperature, often resulting in DC offset errors. Unless recalibration of the low permittivity point can be carried out easily with a clean empty sensor, any measurement drift can become a serious problem. For example, a 1fF drift on a 10fF measurement (typical of the capacitance between opposite sensor electrodes) results in an approximately 10% error in the measurement of concentration or volume ratio. The **TFL R5000** is internally compensated for changes in operating temperature and has a residual capacitance measurement stability better than 0.005fF per degree C. A stable capacitance measurement system is also essential to allow an effective sensor model (see next section) to be generated and used.

Sensor Linearisation and concentration modeling

Most ECT sensors are inherently non-linear, both in the relationship between the measured capacitances and the permittivity of the sensor contents and also in the relationship between the concentration of a 2-phase mixture and its effective permittivity. These effects must be linearised using an appropriate model for the sensor and its contents if accurate concentration measurements are required. Our experience of developing ECT for use in high-speed flow measurement applications over the last 5 years has resulted in the development of detailed sensor model algorithms which dramatically improve the accuracy of concentration measurements and images. These algorithms are applied to the measurements before any images are reconstructed.

Software

A comprehensive range of custom software is available for use with the **TFL R5000** system, including software for data capture and replay, capacitance measurement and analysis, sensitivity matrix generation, 2 and 3-D image reconstruction, data logging to Excel-compatible (.csv) files and 2-phase flow measurement and analysis. All of the data file formats used are open, allowing user or third party software to be used for data analysis in addition to the supplied software. Utilities are also supplied to convert all binary data to ASCII format and a range of custom Matlab utilties are also available for Matlab users.

Image Reconstruction algorithms

The software supplied with the equipment allows permittivity/concentration images to be constructed using a range of algorithms, including LBP (Linear-Back-Projection) Landweber, Tikhonov and iterative techniques.

Multi-electrode capacitance sensor design and manufacture

The design of ECT sensors is a complex art and involves optimising the sensor to achieve maximum sensitivity to changes in the sensor contents while minimising the standing capacitances between electrode-pairs, electrode-planes and ground. Sensor impedance matching, calibration and linearisation must also be optimised if accurate results are to be obtained. Comprehensive software is supplied with all TFL ECT sensors to ensure that these tasks can be carried out effectively. TFL has over 15 years' experience in the design and manufacture of effective and robust custom ECT sensors for vessel diameters from 50 to 500mm.

Instrument Dimensions and power consumption

The **TFL R5000** is housed in a compact instrument case having dimensions 400x370x200 mm (excluding handle) and weighs 9Kg. The Power Consumption varies between approximately 20 watts in standy mode to 35 Watts when operating at 10MHz.

Operation in Intrinsic safety environments

For use in ATEX environments, custom integrated sensor versions can be supplied where the measurement electronic assemblies are mounted directly on the sensor tube inside certified ATEX enclosures. In this case, the only connections that need to be taken through the ATEX enclosure are the ethernet and power (24V DC) leads. This form of construction allows the use of stripline connections to be used between the measurement electronics and the sensor electrodes, which results in further improvements in measurement stability and repeatability. The use of ethernet as the communications link allows the control PC to be located in a remote and safe location, well away from the measurement equipment and experimental rig.

Company profiles

Tomoflow (TFL) and its associate company Process Tomography (PTL) have been designing, making and supplying ECT technology, including capacitance measurement systems, custom ECT sensors, tomographic flow measurement systems and custom software for over 15 years. We are world-leaders in this technology and are happy to discuss with and advise prospective customers about the suitability of our equipment for use in any proposed applications. **We will not sell you a system unless we are confident it will meet your requirements.**

For further information or advice, please contact us at: enquiries@tomography.com

Note that all specifications are based on measurements carried out on a prototype versionf the **TFL R5000** and may change in accordance with technical developments and improvements.

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