2. TOKAMAK ISTTOK

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2.1. INTRODUCTION

ISTTOK is a small-size (R=46 cm, a=8.5 cm), large-aspect-ratio, low magnetic field (0.46 T) limiter tokamak with an iron core transformer (flux swing of 0.22 Vs), equipped with a distributed VME control and data acquisition system. Its low temperature (150 eV) low density ($8x10^{18}$ m^{-3}) plasmas are diagnosed by electric and magnetic probes, a microwave interferometer, a heavy ion beam diagnostic, a Thomson Scattering system and spectroscopic diagnostics.

The main objectives of this project are: (i) the development of new diagnostic and control and data acquisition systems; (ii) testing of new operation scenarios (liquid metal limiter and alternating plasma current); (iii) study of the influence of external applied signals on the plasma confinement and stability; and (iv) education and training on tokamak physics and engineering.

This project included in 2004 work in the following research lines:

- Testing of the liquid metal limiter concept;
- Diagnostics;
- Control and data acquisition;
- Plasma physics studies.

2.2. TESTING OF THE LIQUID METAL LIMITER CONCEPT

IST/CFN has proceeded with the collaboration with the Association EURATOM/University of Latvia on the testing of the liquid metal limiter concept.

The liquid metal loop experimental rig has been commissioned in the ISTTOK Laboratory. Tests of this experimental apparatus have begun. A controlled heating system, using a Dallas DS80-C400 microprocessor with Ethernet connection and Java based technology, has been designed, implemented and tested, intended to ensure a 60 ºC stable temperature in the main liquid metal loop. A device to introduce oxide-free Gallium in the main loop for compatibility with UHV operation has been implemented and tested (Figure 2.1). The Gallium cleaning system has been tested. A heating backup system designed to keep Ga in the lower part of the loop always above the melting point has been implemented. A free expansion tank, where Gallium could be stored for long periods, has been designed, implemented and tested (Figure 2.2).

One Portuguese Researcher has participated in Riga in an experimental campaign, aiming at testing a new fast frame camera and studying the jet stability with several diameter nozzles (1.5, 1.8, 2.1 and 2.4 mm).

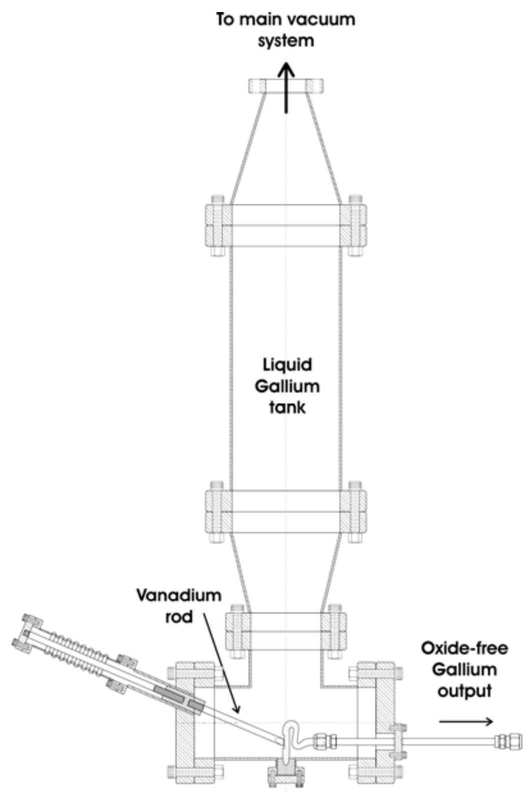

Figure 2.1 - System designed to introduce oxide-free Gallium in the main reservoir.

2.3. DIAGNOSTICS

2.3.1. Introduction

A new diagnostic for magnetohydrodynamic (MHD) studies has been implemented using signals from a set of 12 equally spaced Mirnov coils. A new Gundestrup probe for flow measurements has been developed, giving particular attention to the materials used in its construction. The time-of-flight technique for plasma potential measurements by the heavy ion beam diagnostic with a multiple cell array detector has been optimized. The possibility of using this diagnostic for zonal flows studies has been theoretically evaluated. The design of a soft X-ray tomography diagnostic based on commercial CCD cameras has started. The emissive electrode used in biasing experiments has been optimized, aiming at easy replacement of the emitter material and operation for longer periods.

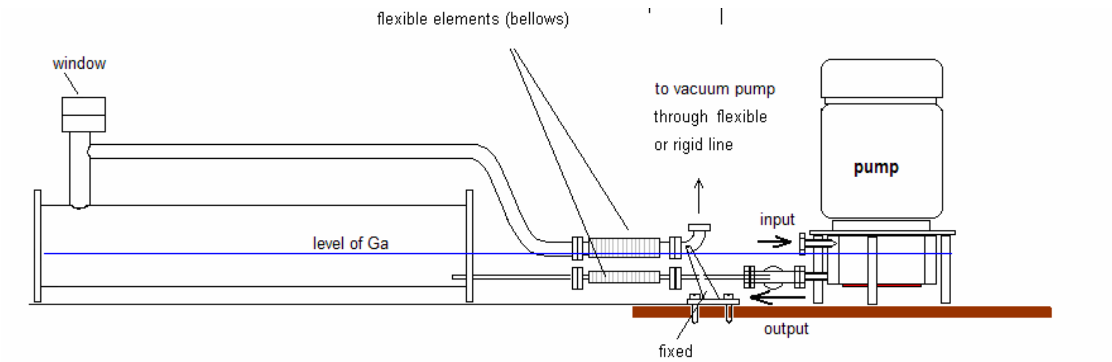

Figure 2.2 - Gallium store tank

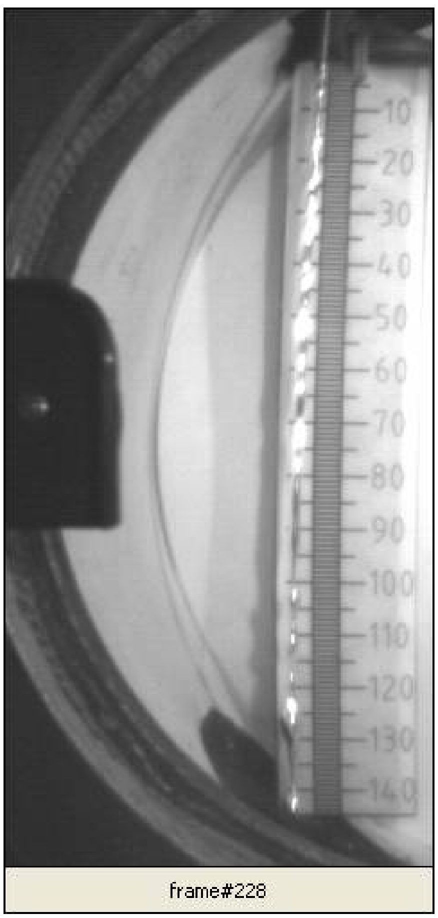

Figure 2.3 - Jet image obtained with the fast frame camera

2.3.2 Diagnostic for MHD studies

This diagnostic uses signals from a set of twelve equally spaced Mirnov coils, originally designed for plasma shape and position equilibrium determination (Figure 2.4). The data acquisition and processing system is based on a locally-developed galvanic isolated, 8 channel, fast PCI transient recorder module, with a 2 MSPS sampling rate, 14 bit resolution and a total memory of 256 MWords. This module includes a Digital Signal Processor (DSP) and a Field Programmable Gate Array (FPGA), allowing real-time determination of MHD modes using advanced identification algorithms, in a sub-millisecond cycle time.

Preliminary data analysis indicates the presence of rotating modes with dominant m=3 poloidal mode number with frequencies of the order of 100 kHz (about 480 times smaller than characteristic toroidal Alfven time).

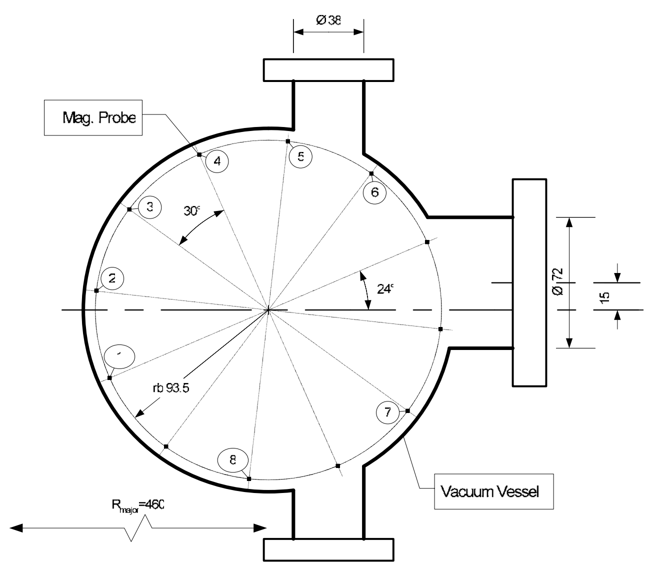

Figure 2.4 - Schematic drawing of the ISTTOK poloidal layout, showing magnetic probe positions.

2.3.3. Gundestrup probe

A new Gundestrup probe has been developed, giving particular attention to the materials used in its construction, aiming at its operation in fusion plasmas. Copper and quartz have been replaced respectively by molybdenum and boron nitride.

The probe has been successfully operated in a large number of ISTTOK discharges without perturbing the plasma behavior. Furthermore, no significant damage in the probe has been found after its removal from the machine, proving that the new probe design is adequate to be used in the edge of tokamak plasmas.

2.3.4. Plasma potential measurements by heavy ion beam diagnostic with time-of-flight energy analyzer

A 4-channel time-of-flight energy analyzer (TOFEA) is being developed for plasma potential profile measurements with the heavy ion beam diagnostic (HIBD). Figure 2.5 presents the picture and schematic illustration of the diagnostic. It is placed inside an auxiliary vacuum chamber attached to a ISTTOK horizontal diagnostic port, and consists of three main parts: (i) a modified multi-channel array detector (MCAD) with TOFEA input slits; (ii) a control module with deflecting cylindrical electrostatic plates and a set of planar alignment electrostatic plates; and (iii) a TOF-path module with "start" and "stop" detectors.

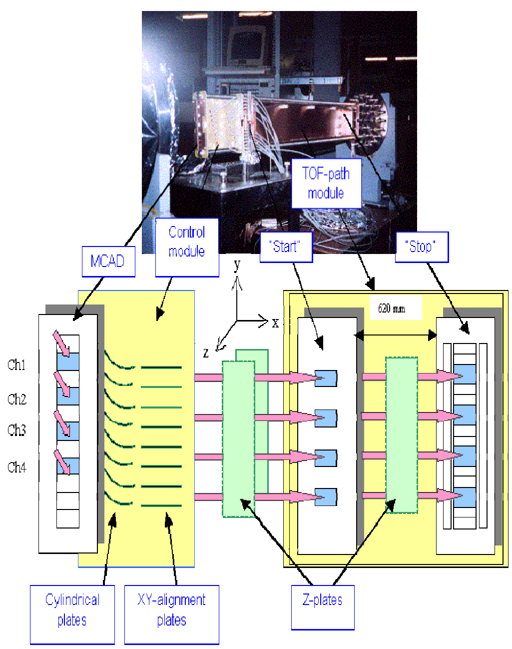

Figure 2.5 - Picture and schematic drawing of the four-channel TOFEA.

One channel of the data acquisition system (DAS) (Figure 2.6) consists of conditioning electronics and a time-to-amplitude converter (TAC). The DAS is used in successive acquisitions of both "start" and "stop" signals, when they are discriminated inside the time-of-flight of the beam pulse along the TOF-path.

Figure 2.7 presents the plasma potential measured in the central region of the ISTTOK plasma by the HIBD and at plasma periphery by electric probes. Although the sign of the core plasma potential agrees with the neoclassical predictions, its absolute value is approximately 1.5-2 times higher (Φ_{neo} ~ - (120-200) V.

The sensitivity of plasma potential measurements by TOFEA has been checked in experiments with limiter biasing.

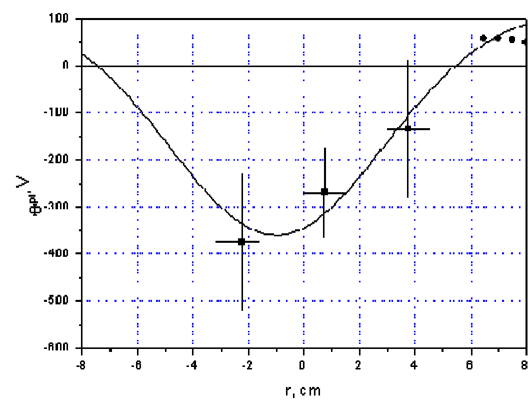

Figure 2.7 - Profile of the plasma potential measured by the TOFEA

2.4. CONTROL AND DATA ACQUISITION

2.4.1. Main activities

Software for shared remote data consulting and analysis has started to be developed, aiming at replacing the existing applications based on DOS and allowing data viewing and analysis by any authorized user, from any personal computer, anywhere in the world. The upgrade of the ISTTOK data acquisition system from the former "dbf" files-based system to an Open Source RDBMS PostgreSQL database has begun, by creating a PostgreSQL data mirror in a Linux server, replicating the original data structure and copying the pulse data on a

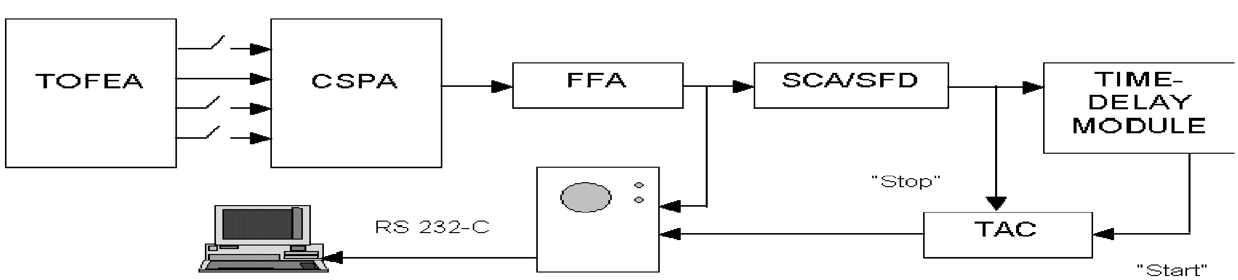

Figure 2.6 – Block diagram of the TOFEA data acquisition system

daily basis to the new relational database, using script codes written in "Python". A modular USB controller for low speed (8 kbytes/s) data acquisition has been developed. The system consists of a small printed circuit board that incorporates 8 I/O lines, 8 open collector lines for power control (500 mA each), I2C bus, as well as 4 analog lines (12 bit of maximum resolution). A library of functions in C language has been also developed to be used with this interface, which allows a quick and simple implementation in slow control and data acquisition systems. A cooperative multi-user program has started to be developed in Java to control and launch the ISTTOK discharges, replacing the present DOS shot launcher program.

2.4.2. Software for shared remote data consulting and analysis "QueryTOK"

A platform, based on standards like CORBA, XML and JAVA, has been developed allowing accessing to data and its analysis in a straight forth way. Several users may be connected simultaneously to the platform and whenever a user launches his configuration query the resulting data is broadcasted to all users, allowing simultaneous analysis and discussion of results between users (Figure 2.8).

Each user has a collection of profiles where he may store the parameters, equations and macros that he usually requests from the database. These profiles can be stored locally or directly in the database and may be shared between users.

The software is plugin-based, allowing addition of new data viewers and data calculation algorithms without the need of rewriting any code. Data is stored in a SQL database and calculations are made locally or by remote computers, which run an application-server routine waiting for a remote procedure call for heavy calculus computation. The application-server routine can be designed on any analysis code built on MatLab, Octave, IDL and others.

The entire platform is fully internationalized. Current available languages are Portuguese and English. The addition of a new language is trivial due to the use of JAVA standard internationalization mechanisms through the insertion of new bundles into the distribution. A built-in chat is also available for users to discuss hardware configuration and data analysis.

The platform is distributed using the JAVA Web-start technology, which greatly simplifies the installation process and version renewing.

2.5. PLASMA PHYSICS STUDIES

Following previous studies on the influence of emissive electrode biasing on the plasma confinement and stability, experiments have been made in 2004 aiming at a better characterization of the modifications introduced by the electrostatic polarization at the plasma edge The evolution of the radial electric field (E_r) profile has been measured. Figure 2.9 presents the radial profiles of the floating potential and radial electric filed, measured by the rake probe. As the biasing is applied, a large electric field is observed for both polarities, reaching a value of around ±12 kV/m in the region near the limiter, associated with a strong E_r shear. Therefore, the velocity shear may be responsible for the observed particle confinement improvement. This is corroborated by probe measurements, which show a decrease of the turbulent particle transport when the bias is applied.

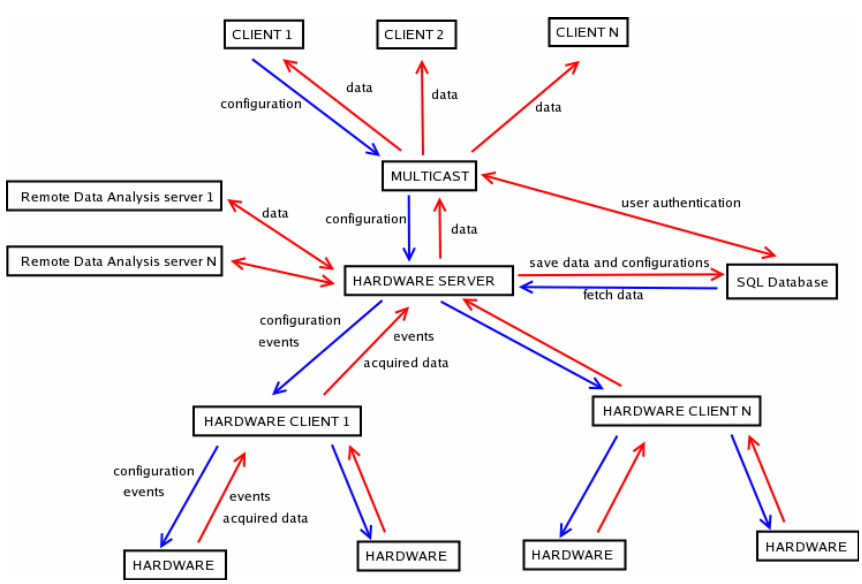

Figure 2.8 - General platform overview showing data flow between the logical entities.

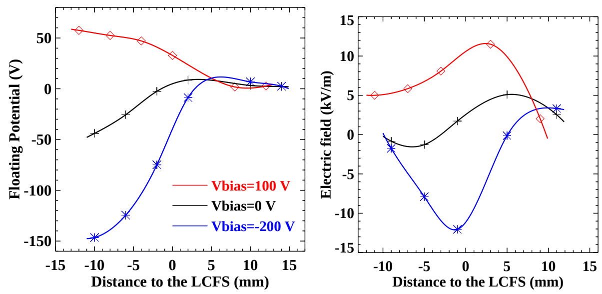

Figure 2.9 - Floating potential and radial electric field radial profiles for positive (V_{bias}=100 V) and negative (V_{bias}=-200 V) emissive electrode biasing. Profiles with no applied voltage are also shown for comparison.

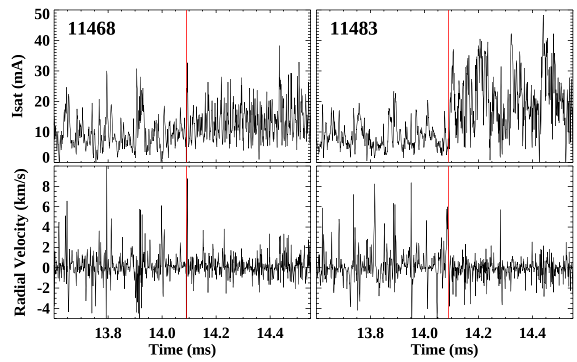

Figure 2.10 - I_{sat} and the effective radial velocity in expanded time scale. The red line indicates the biasing time.

Although the radial electric field induced by emissive electrode biasing is of the same magnitude for both polarities (~12 kV/m), a significant improvement in particle confinement is only observed for negative biasing. In order to understand this different behavior, edge turbulent transport is being investigated. The edge plasma parameters, and in particular the edge density, are characterized by intermittent events (low frequency, large amplitude oscillations). The behaviour of density fluctuations is clearly modified by emissive electrode biasing, being the large-scale transport events reduced for both polarities (Figure 2.10). The different behavior of the particle confinement for positive and negative biasing is possibly related with the large amplitude fluctuations with roughly Gaussian distribution induced by positive biasing. Furthermore, emissive electrode biasing as opposite effects on the low frequency edge fluctuations; at negative bias a reduction is observed for frequency below ~70 kHz, while for positive bias the fluctuations increase in this frequency range.