CONTROL SYSTEM FOR THE DIAGNOSTIC NEUTRAL BEAM INJECTOR FOR THE TCV TOKAMAK

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Abstract

The diagnostic Neutral Beam Injector (DNBI) for the TCV tokamak, Plasma Physics Institute, Lausanne, was developed and commissioned by the BINP team in 1999. The DNBI is capable of providing a beam of hydrogen atoms of 50 kV maximal energy, with an equivalent beam current of up to 1 A. The injector is equipped with all the power supply units needed for operation and for control, including a 50 kV, 2.5 A modulator and 10 kW, 4.6 MHz RF amplifier. The output beam can be extracted continuously over a 2 second period or as an ON/OFF modulated sequence with arbitrary pulse repetition frequency and minimal pulse/pause duration of 2 ms. An increased noise level looks like a normal condition for all subsystem operation. The control system of the DNBI is developed under the pressure of these specific conditions with increased noise. The system includes 8 DAC, up to 64 ADC channels and 64 channels of In/Out digital status control. It operates as a self-sufficient system with minimal data exchange with the global control system of the tokamak, so it becomes flexible to adopt arbitrary external control system.

1 INTRODUCTION

The TCV is a tokamak device built at the Plasma Physics Institute, EPFL, Lausanne, Switzerland. It operates with two-second "shots" with a two-minute repetition rate. A variety of plasma fusion diagnostics, such as Charge Exchange Recombination Spectroscopy, Motional Stark Effect and Beam Emission Spectroscopy are widely used in tokamaks [1]. The typical diagnostics requirement is to have the injected beam of neutral particles (Hydrogen) with energy of 20 kV to 55 kV and equivalent current ~ 1-2A. At times, the spectroscopy methods need to have a continuous beam, at other times a modulation of the diagnostic beam intensity, which enables one to improve the signal to noise ratio because of the synchronous detecting of signals.

2 DNBI MAIN SUBSYSTEMS

The Dignostic Neutral Beam Injector (DNBI) is a device required for these kinds of diagnostics. It comprises the injector ion source, the neutralizer cell, ion bending magnet, residual ion dump, aiming device, two cryo-pumps and thermocouple arrays housed inside a cylindrical vacuum tank. The equipment located in the injector tank provides both regular and repair procedures for injector handling. These procedures include vacuum pumping and pressure monitoring, cryo-pumps refill, ion source aiming, and calorimetric measurements for control of the beam parameters. The injector is equipped with all the power supply and measuring units needed for operation and control.

The major element of DNBI is an ***injector ion source***. It consists of a special assembly of grids with high potentials distributed between them, so it operates like a multi-aperture electrostatic accelerator. A plasma emitter in the ion source is produced by an inductively excited RF discharge in a cylindrical ceramic tube. A special gas valve to puff the hydrogen is installed close to the ion source. A resonant multi-turns RF antenna operates at about 4.6 MHz frequency with up to 5 kW RF-power absorbed in the plasma during the "shot". A non-homogeneous magnetic field is applied into the plasma box to obtain the required homogeneous profile of the ion current density at the plasma grid area. The grids are mounted on the water-cooled flanges enabling the full heat removal from pulse to pulse as well as partial heat removal during the injection pulse. The thickness of the molybdenum electrodes is chosen to be 2mm and 4mm for different grids. As a result, the ion source is very sensitive to the energy dissipated by grids, especially due to breakdowns. Dissipation during one breakdown should be in the level of a few joules. For the DNBI it was specified to allow less than 16 arc breakdowns during one "shot". It is controlled by High Voltage Power Supply (Modulator) that switches OFF the output power within 200 μsec under the local interlock command.

The Modulator is based on the power converter system with switch mode PWM technology [2]. It can provide an output voltage of up to 55 kV with 180 kW of power during of the 2 sec. "shot". The High Voltage (HV) part of the Modulator is placed close to Injector, directly inside the TCV bunker. The Low Voltage (LV) part is placed at the electrical equipment zone, up to 50 m from the Injector. Both HV and LV parts of Modulator consists of six identical cells. Each cell includes an IGBT inverter operating at a frequency of 5 kHz, a high-voltage transformer, a rectifying diode bridge and a capacitor filter. Outputs of the cells are set up in series. The design has small stored energy in transformers and cables that allows reliable protection for the grid system of the Injector. A modulator can perform an ON/OFF amplitude modulation of the output voltage with a rise/fall time of less than 200 μsec. The minimal time intervals of the «OFF» state should be longer than 2 ms, maximal time interval of the «ON» state can be up to 2 sec. To avoid the influence of this modulation on the mains a special dummy load is used inside the Modulator. It works like a 180 kW DAC, accepting the "switched OFF" current of real load during the "OFF" stage of modulation. Of course, the RF power in the antenna is modulated too, but the "low level" of the RF in the antenna is independently regulated.

Beam profile monitor. At the exit of the injector tank there is a retractable target for calorimetric measurement of the beam profile (movable beam dump). The monitor consists of a stack of nested copper rings, which can be installed co-axially with the beam, and a water-cooled tube to which the stack is welded from inside. There is also a thermocouple array, which is used to measure the temperature rise of the rings impinged by the beam particles. When not in use, the beam dump is normally stored in the radial cavity adjacent to the beam duct. A pivoting suspension driven by electric motor is used to traverse it between the storage location and the duct.

Other subsystems of the DNBI: Vacuum system with two cryogenic pumps; RF-system; some power supplies for grids, for bending magnet, driving electronics for Gas Valves and for Ignition. The systems are distributed at the DNBI Tank, at the High Voltage Tank and at six racks with dimensions close to Euromechanics standard.

3 CONTROL SYSTEM

3.1 Specific requirements

A number of specific requirements have been made for the control system of the DNBI during the developing stage. Some of them are:
1) The Control System should be highly resistant to the noise and interference, especially to arc breakdowns at the injector ion source. It should accept without errors and breaks the failures of the power subsystems. ***2) The Control system should have*** a number of protections and interlocks at the hardware level with obligatory computer control of their status. In addition, all the safety functions necessary for safe DNBI system operation should be included in the TCV control system to prevent system operation in the event of possible danger. ***3) The Control system should be*** as autonomous as possible. DNBI can be operated in Test mode and TCV mode with the ability of its control system to be able to safely distinguish these two modes [3]. ***4) No galvanic connections*** between the DNBI system and "external world" (TCV) is allowed. "Hot" cables and signals must be separated from "cold" cables and signals.

All of these specific requirements were satisfied during the development of the control system and DNBI as a whole.

3.2 Control System Hardware Specification and Configuration

The Control System provides control and measurement of Injector Equipment, Distribution unit, High Voltage Cabinet, Low Voltage Cabinet, Vacuum system, Water Cooling system and Gas supplying system. As a result of analysis of configuration of the DNBI subsystems and of the necessity to check their status or to look for their signals before, during and after "shot" we had found that the control system should have the following computer controlled functions (Table 1):

Table 1: The set of computer-controlled channels.

Function	Number of channels, up to
ON/OFF setting	32
ON/OFF checking	32
DAC	6
Slow ADC	35
Fast ADC	12
Timing	14

Of course, these binary status-channels, analog channels for measurement and for control, belongs to the different subsystems of the DNBI. They are placed in different racks, different rooms and halls and, as a result, they have different potentials relative to the "ground", especially due to high voltage breakdowns. From the other side, it is desirable to use multi-channel DAC, ADC, IN/OUT digital Registers and Timer for these kinds of systems. In the case of TCV we applied the CAMAC standard for the control Modules. Connections of all required analogous input/output and digital (status) signals between CAMAC and DNBI subsystems are implemented at the Low Voltage cabinet through a special Cross-Panel Module and system of low-pass filter Modules: Thermocouple Filters Module, Injector Equipment Filters Module and Modulator Interface Module.

The Cross-Panel Module has the function to connect DNBI subsystems via Filters directly with CAMAC Modules. This solution allows us to have minimal noise influence. List of CAMAC Modules of the DNBI Control system includes the IN/OUT registers, 16-channel DAC (0.01%), "Slow" ADC with Analog multiplexers for 64 channel, three "Fast" ADC with 4 channels each and 16-channel Computer Controlled Timer.

All the IN/OUT Digital Signals are organized with TTL compatible current sources. The precise "Slow" ADC is applied for the system because it is a double-integrating device, practically insensitive to the oscillating short-term noise and interference. The "Fast" ADC with programmable sampling period is applied to organize the oscilloscopic mode of DNBI subsystems observing. We can check up to 12 channels with this ADC and simultaneously view up to four of them at the PC monitor.

4 EXPERIMENTAL RESULTS

The DNBI has been designed, tested and successfully installed at the TCV tokamak at the Plasma Physics Institute two years ago [4]. The DNBI control system is operated from an IBM PC compatible computer. It works under Windows 95 using the Java 1.1x environment. A PPI adapter card connects the Crate Controller to the PC. The system accepts all shot-to-shot operation commands from the TCV Control System and follows the clear and simple specification of the "Start of Day" and "End of Day" procedures for safe and reliable DNBI operation. A typical screenshot of DNBI test results displaying status and oscilloscopic information from the HVM is presented in Fig.1.

Fig.1 Typical operation of DNBI subsystem during test "shot"

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