NUKLEONIKA 2001;46(Supplement 1):S89–S91

Technical solutions for the control and command system of a Plasma Focus device

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Abstract The paper presents the technical problems related to the electrical control and command system (ECC system) for the plasma focus installation IPF-4/5A having the following main parameters: 1 MA plasma current and 40 kJ energy stored at 20 kV charging voltage. The ECC system applies 23 interlocked logical commands, acquires and processes 28 logical states, acquires, processes and displays continuously the main slow-varying signals coming from IPF-4/5A subassemblies. All the plasma focus installation operational sequences are governed by strict hard and soft interlocking using in parallel two control and command systems: one based on PC-control methods and another based on classical control techniques.

Key words control system • electromagnetic transients • galvanic separation • plasma focus

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Received: 23 October 2000, Accepted: 15 February 2001

Introduction

An electrical control and command system (ECC system), was designed for the IPF-4/5A plasma focusing installation, the fifth installation of this type designed and built in Romania [1-3]. The main parameters of IPF-4/5A are: a capacitor bank charging voltage of 14–20 kV, 45 kJ maximum stored energy, 1 MA peak plasma current, and a working gas (deuterium) pressure of 1–5 Torr (approximately 1.3×10^2 – 6.6×10^2 Pa). The main sub-systems of IPF-4/5A are described below.

The discharge chamber consists of a coaxial plasma accelerator connected to a pulsed power supply plasma focus driver by means of a disk shaped current collector. The coaxial accelerator uses stainless steel electrodes, with the central electrode having a heavy alloy insert. The high voltage capacitor bank has a modular structure and uses high current spark gap switches of the CIT-10/20 type [3]. Energy transfer from the HV capacitors to the discharge chamber collector is done by means of 150 low inductance coaxial HV cables. The measurement and acquisition system consists of 12 devices for the detection of the electromagnetic, optical and nuclear phenomena. Signals generated by various transducers are simultaneously transmitted over 30 acquisition channels with a bandwidth of ~200 MHz.

IPF-4/5A has mainly been used for fusion studies such as investigation of plasma focus neutron generation. Neutron yields of up to 5×10^9 neutrons/pulse have been produced [2].

Methods

Due to the complexity of IPF-4/5A and the specific conditions under which it operates, the ECC system has been designed to allow both classical automation techniques and modern on-line computer control, either simultaneously or alternately. The main functions of the ECC system are:

- Protection of personnel and sensitive apparatus against dangerous events through centralized control of all protection devices (e.g. interlocks and warning signals enabled under program control during experimental runs);
- Prevention of IPF-4/5A malfunction and reduction of device misfire, as well as control of fusion device operation in a preselected time sequence;
- Protection against electromagnetic interference.

Results and discussion

System configuration and working principles of the ECC system

A block diagram of the ECC system and the main subassemblies of IPF-4/5A are shown in Fig. 1. The ECC system allows the main IPF-4/5A subassemblies, Condenser Bank Charging and Discharging System (CDS), Spark Gap Switch Triggering System (SGS-TS), and Vacuum and Gas Filling System (VGFS) to individually be centrally operated, at the same priority control level, in a hierarchy-like structure. Moreover, the main IPF-4/5A subassemblies may be controlled from their local control panels as well as from the corresponding modules in the Central Control Panel (CCP). In order to prevent any electromagnetic coupling between high power components of the fusion installation and the control system, the latter is separated by a galvanic separation barrier consisting of optical fiber cable assemblies (for analogue signals) and of low stray-capacitance transformers (for logical commands and states).

The slow time-varying signals (e.g. working gas pressure in the discharge chamber, switch triggering system charging voltage and condenser bank charging voltage) are transmitted to ECC system via measurement chains consisting of transducer, voltage to frequency converter, infrared emitter, optical fiber cable, optical pulse detector and frequency to voltage converter. The measurement chains deliver voltages proportional to the input value (within a precision of 2%). The operator both by means of classical instruments on the control panel and by means of the computer control system surveys the evolution of the slow time-varying signals. Digital commands and statuses are transmitted via high voltage and low stray capacitance separation transformers (24 Va.c./24 Va.c., 0.022 pF – measured stray capacitance). The ECC system units and the HV components of IPF-4/5A are coupled to the main a.c. supply via separation transformers of various powers from 500 VA to 6 kVA (0.025 pF measured stray capacitance). Fig. 2 shows some parts of the galvanic separation barrier. The high voltage on the Condenser Banks (CB) modules is detected by five HV dividers and transmitted to the operator via five optical chains, each ending with an LED on the central control panel. The closing of the spark gap switches is detected by five Rogowski coils (measuring the discharge currents) whose signals are transformed into five 30 second optical signals. The information provided by the HV dividers and the Rogowski coils is used to locate certain post-discharge

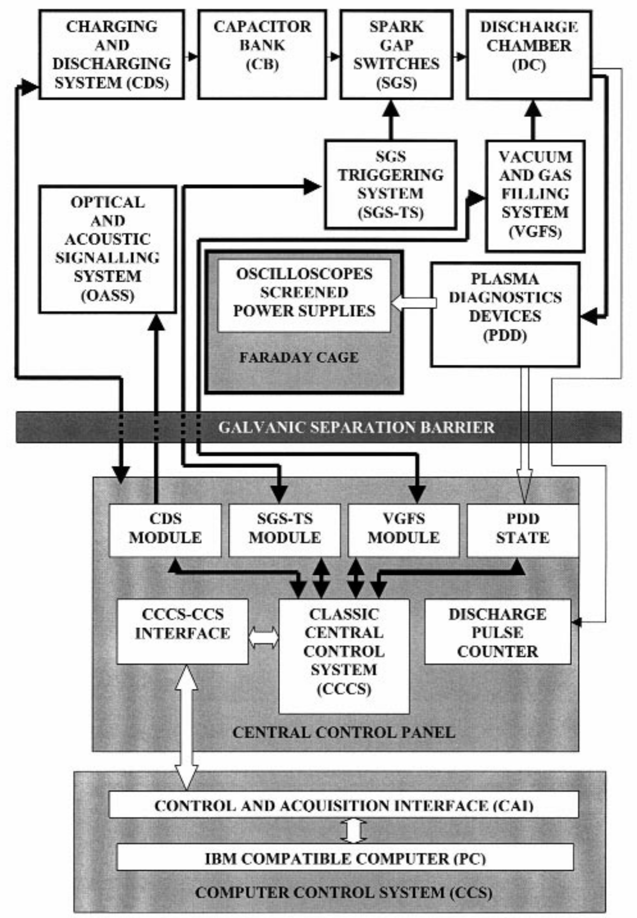

Fig. 1. Block diagram of the EEC system and IPF-4/5A main subassemblies.

failure effects within the experimental installation. The current through the discharge chamber is detected by a magnetic probe, which gives a short signal with fast rise time. It is transmitted via a high voltage, high frequency separation transformer and lengthened to a few seconds before being supplied to the disscharge pulse counter (DPC). The DPC delivers a delayed command to activate both the high current switch gas purging device and the neutron activation counter.

The Computer Control System (CCS) is used both as an operator interface and as an input-output controller. The latter function is based on a general-purpose Control and Acquisition Interface (CAI) mounted in an IBM-compatible PC, as shown in Fig. 1. The Classic Central Control System (CCCS) is interfaced to the CCS by a dedicated module, which provides appropriately scaled signals. It transfers logical commands and states over the digital I/O bus of the CAI and the CCCS as well as analogue signals.

The CCS provides the following functions:

- Generation of 23 interlock signals to be supplied to the IPF-4/5A subassemblies;
- Acquisition and processing of 28 logical states from the installation subassemblies;
- Acquisition, processing and display of three slowly varying signals: condenser bank high voltage, switch triggering system high voltage and discharge chamber pressure.

Certain precautions have been taken in order to protect the personnel working at the installation. These take into

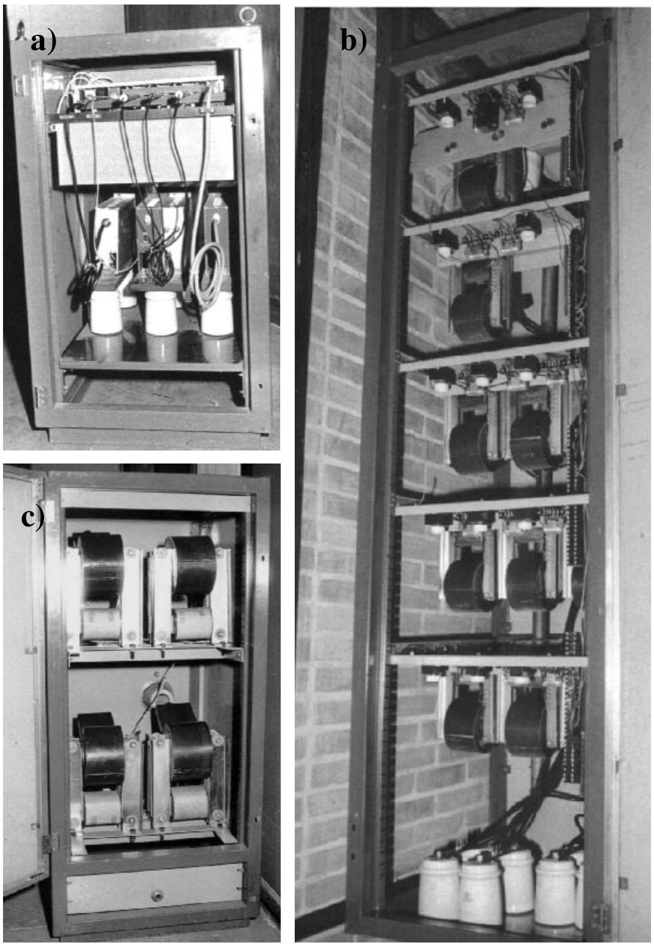

Fig. 2. Some parts of the galvanic separation barrier: (a) The optical fiber cable assemblies; (b) 24 VA high voltage low stray capacitance separation transformers; (c) 500 VA high voltage low stray capacitance separation transformers.

account the presence of high voltage, intense nuclear radiation and electromagnetic interference during the experiment. Classical and software interlock solutions were implemented:

- Controlled access to the experimental area is interlocked with the condenser bank charging system;
- Announcements indicating charging of the condenser bank are made using both optical and acoustical methods;
- Discharging of the condenser bank is delayed by a few seconds from the operator "START PULSE" command;
- Hardware and software interlocking in order to eliminate the risk of any operation error govern IPF-4/5A operation sequences.

Computer-controlled operating mode

Before the start of an experiment the operator specifies the experimental parameters and either the completely automated or sequential operating mode via a user-friendly interface.

In the completely automated operating mode, the operator starts the experiment, the system operation being controlled by software and hardware afterwards. The evolution of the experiment is continuously presented on the computer display. Each experimental phase provides the operator with a set of commands, which can be used in case of system malfunction. In the sequential mode, the operator commands both the starts of the experiment as well as the evolution from one phase to the next from the system keyboard. The system displays each phase of the experiment continuously, including measured values of the main device parameters, as well as a set of commands for operator intervention in case of malfunction.

Both operating modes provide the operator with the possibility of interrupting the experiment at a certain phase ("decision phase") in order to change the experimental parameters that have been previously introduced. At the end of experiment, the operator decides whether the experimental data are to be stored on the PC in experimental data files. Software development occurred using MS-WINDOWS. It is therefore in close proximity to the analysis, modelling and office tools available on the PC. Application programs were developed using the Borland C/C++ compiler. The software package's modular structure allows the implementation of new functionality as the demands for changes and additions appear.

The operator interface software is simple, menu driven and has been optimized for minimum operator interaction in the completely automated operating mode. The software guarantees:

- Interaction between the operator and the system;
- Selection of operating mode;
- Interruption of the experiment using dedicated commands;
- Remote control of the whole experimental runs;
- Delivery of alarm messages;
- Guidance for troubleshooting in case of operational problems;
- Machine and personnel sequence interlocks to prevent unsafe conditions;
- Acquisition and pre-processing of relevant parameters;
- Presentation of data as tables and charts;
- Transfer of the experimental data to the PC;
- Archiving.

The software consists of a set of applications for execution of control algorithms, data acquisition, initial pre-processing of data for protection of equipment and interlocks, transfer of information to the PC.

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