A NEW CONTROL UNIT FOR PROBING ION BEAM FORMING IN HIBP DIAGNOSTIC SYSTEMS

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This paper describes the new version of electronic control unit for ion beam forming in the Heavy Ion Beam Probing (HIBP) diagnostics. This improved unit was developed, manufactured, installed and tested on HIBP system for Uragan-2M torsatron. Some new schematic solutions that are implemented in this unit were created as the result of long-term work with various types of injector power supplies and their control systems, installed on HIBP diagnostics for different fusion devices. The new advanced and highly efficient electronic control block has been constructed. It provides all the necessary functions for adjusting the parameters of the ion beam as well as handy and stable operation of the injector in the experiments on Uragan-2M torsatron.

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INTRODUCTION

A typical HIBP injector system is placed at high electrical potential of the accelerating tube. This circumstance requires the high voltage galvanic insulation of power source and modules that control and measure the injector system parameters. The most practical solution for powering the injector system is to place the charged batteries along with control system in electrostatic screen at high voltage potential. For controlling and measuring the injector parameters the insulated fiber-optical cables should be used.

During its operation, the solid-state thermo-emitter typically requires from 60 to 150 W of heating power [1]. Such wide power range is necessary in order to obtain high values of the primary ion current (50…350 μA). The second reason is decreasing of ion emission caused by depletion of the alkaline (in our case Cs) atoms in the emitter material. The general idea of this work was to design, create and test the compact, reliable and easily maintained control block of the injector with highly efficient power conversion and low standby power consumption.

HIBP INJECTOR CONTROL UNIT ON URAGAN-2M

General view of the power supply system for the injector and the accelerating tube of HIBP diagnostics on U2-M torsatron are shown on Fig. 1 [2]. The whole injector power and control units are placed in a metal electrostatic screen on the insulated support. It prevents corona discharge as the entire system is under high accelerator voltage. The schematics of the installed injector system and accelerating tube are illustrated on Fig. 2. The extractor electrode in the injector block together with the first three accelerating tube rings forms the 3-electrode electrostatic focusing system.

The injector control box provides the full remote operation of the primary beam injector. The main advantages of the new control block are its possibilities to independently control and measure the emitter heating power, extracting and focusing voltages and HV output currents, the battery voltage and current consumption.

Fig. 1. 1 – Injector control block; 2 – Focusing power supply; 3 – Extracting power supply; 4 – Set of batteries; 5 – Accelerator high voltage power supply, 6 – Electrostatic screen for the emitter-extractor unit

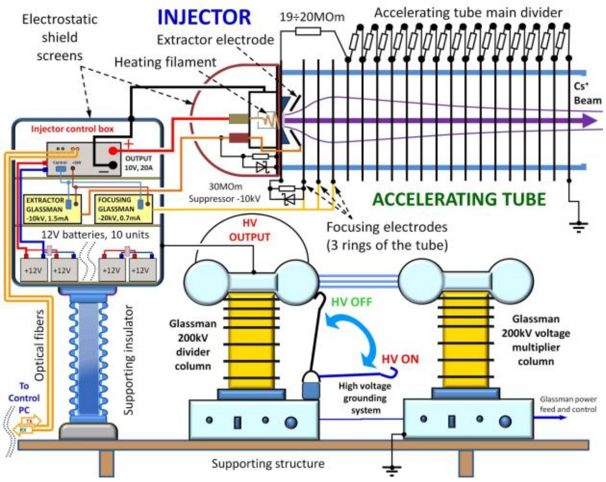

Fig. 2. Schematics of the injector system and accelerating tube

Independent regulation of the extracting and focusing voltages gives the ability to vary focal length of primary probing beam without changing its intensity. The same beam current and focus distance could be archived using different emitter heating powers. This extremely important feature provides both good spatial resolution and large secondary beam current in the experiments. Inability to adjust the parameters of primary beam makes the problem of plasma density profile reconstruction from the secondary beam signal intensity almost irresolvable.

The method of beam profile measurements by using new control unit system for different injector parameters, as well as preliminary obtained signals are shown on Fig. 3.

For scanning the primary beam we used 2 kV 50 Hz AC transformer. Its output voltage is applied to the bottom α1 (vertical) electrostatic deflecting plate. The primary beam profile signals were registered by 2 sets of wire grid detectors, #1 (with the distance between wires is 30 mm) and #2 (35 mm). As the electric field of deflecting plates α1 caused some beam distortion, the beam diameters were calculated as the mean of beam full width at half maximum (FWHM) from both wires of each grid detectors.

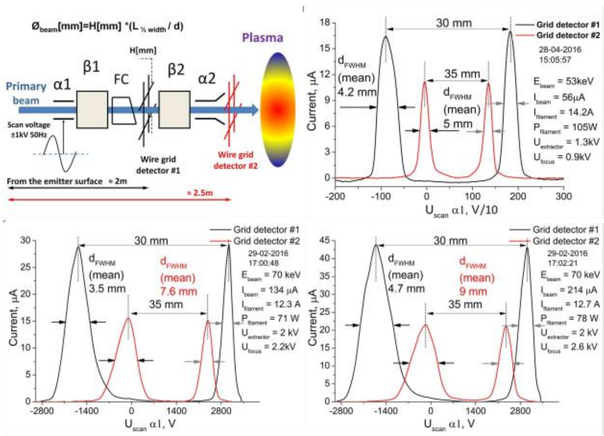

Fig. 3. Beam profile measurements using the new injector control block

The electrical parts and the printed circuit boards (PCB) of the control unit are mounted in the small single module, which controls all functionality of the ion injector (Fig. 4). The input voltage range of the module is 10…15 V, as the battery voltage decreases during its discharge. This unit has a battery protection circuit that turns off the device when the battery is deeply discharged.

The filament of a thermo-ionic emitter is heated by the switching mode power supply. It is based on pulse width modulated (PWM) synchronous buck converter and allows controlling the output current and voltage (0…20 A, 0…10 V). A typical tungsten filament resistance is 0.3…0.5 Ω, depending on its temperature and specific filament type. Accordingly, the direct input voltage from the battery to the buck converter (11…13 V) is enough to provide the full range of necessary heating power (60…150 W). The high switching frequency of the converter (~100 kHz) allows to use the low-inductance (10 μH) and small-sized output choke to provide low ripples of output current and voltage. The output power stage on IRF1104 MOSFETs with very low on-state resistance (9 mΩ) is controlled by the low and high side driver IC (IR2184). It ensures low voltage drop at output currents up to 20 A. Measurement and stabilization of the output current is made by the Hall-effect LCA-050 current sensor IC. A similar sensor measures the current consumption from the battery. Regulation and stabilization of the output current and voltage is controlled by the PWM IC (TL494).

To power the external HV "Glassman" extractor and focusing power supplies, another isolated +36 V push-pull step-up converter is used, based on the same type PWM controller IC (TL494). It is located together with the filament converter on the same single power circuit board (Fig. 5). Its maximum output power is about 50 W.

To control and to measure the output parameters of the heating unit as well as the high-voltage power supplies parameters the ATMEL, ATMEGA32 microcontroller is used. For its operation, the program that provides the whole cycle of data acquisition and control algorithm was written and uploaded. Therefore, the digital connection and control packets transmission from low voltage side (PC USB port and USB to optical converter) to microcontroller is done by universal asynchronous protocol interface via two single mode optical fibers with ST connectors. In turn, the microcontroller is connected via SPI internal interface to 2 units of 12 bit 2-channel DAC IC (MCP4822) and one 12 bit 8-channel ADC IC (MCP3208). To match the levels of output and input voltages with the control and measurement channels the set of TL074 operational amplifiers are used. All input and output circuit channels of the injector control block are bypassed with quick suppressors protecting the device against overvoltage. All these components are mounted on the second PCB (see Fig. 5).

Fig. 4. New injector control block without top cover

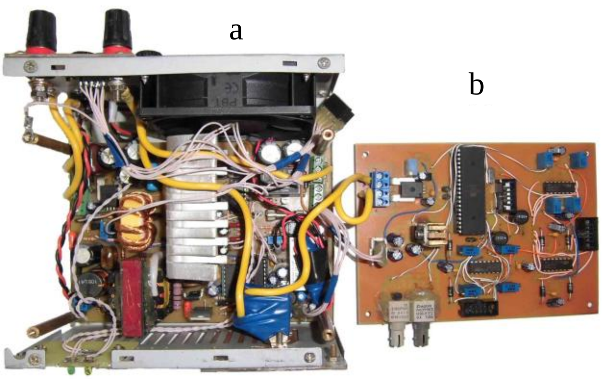

Fig. 5. Layout of the main components in the injector control block. Power board (a), control board (b)

As the source of energy the set of lead-acid batteries are used. Capacity of these batteries has been chosen based on the time required for continuous diagnostic operation during the whole experimental day.

In our case, the power bank was made of 10 sealed lead-acid AGM (12 V, 7 Ah) batteries, connected in parallel. During its operation, the injector control unit continuously monitors battery voltage and consumed current. Under ideal conditions, overall capacity of power bank should be 70 Ah, however the actual measured batteries capacity is always less than that. This is partly due to the effect of "aging" and sulfating of the batteries plates that happens during long downtimes between experimental campaigns at the U2-M torsatron.

In contrast to many other facilities with magnetic plasma confinement, during the operation of Uragan-2M torsatron, the plasma shots come with quite high repetition rate. The typical time between shots is about one minute. Therefore, due to thermal inertia of the heating filament and solid-state thermionic emitter in the injector, the power supply heating system have to operate continuously at a high output current values throughout most part of the experimental time during operational days. The measured parameters of the injector during one of the experimental day are illustrated on Fig. 6.

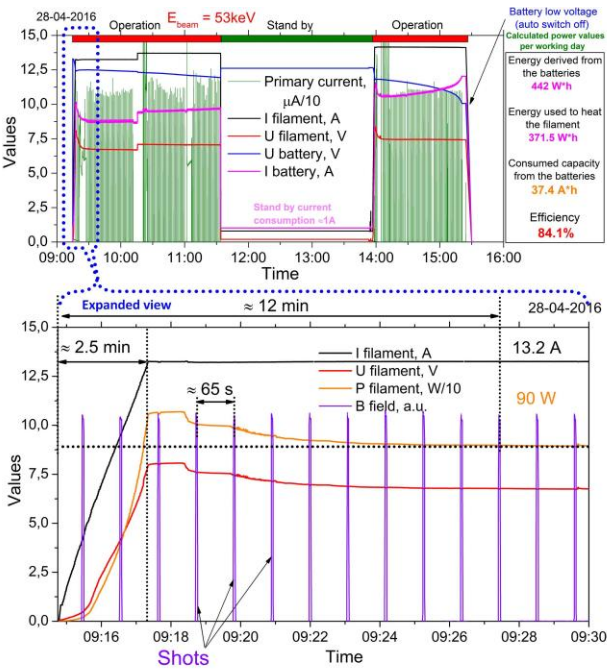

Fig. 6. Injector power supply block efficiency measurement and heating power temporal behavior

The total calculated efficiency of the injector control block during one of the experimental days is about 84 %. The idle current of the unit (about 1 A) is mostly caused by 12 to 36 V DC-DC converter, which is connected to secondary extractor and focusing HV power supplies (“Glassman”) and control board self current consumption. On the cold start-up, the thermal equilibrium of the injector block is reached after 12 minutes, even if the filament current is raised up to the necessary operating values (10…15 A) for as long as 90 seconds by the software.

INJECTORS CONTROL SYSTEMS FOR THE DUO-HIBP DIAGNOSTICS ON TJ-II STELLARATOR

Fig. 7. Exterior view of the injector control and power supply systems for the HIBP1 and HIBP2 diagnostics on the TJ-II stellarator

On TJ-II stellarator it is impossible to place the HIBP1 and HIBP2 injectors control systems near accelerating tubes. Therefore, they are located together in the HV safety cage equipped with the door for maintenance (Fig. 7). Connections with the accelerating tubes are made with long cables with HV insulation.

All elements of each HIBPs injector control and power supply systems are placed in electrostatic shield boxes on HV insulators.

The injector control systems circuits for the HIBP1 and HIBP2 are identical (Fig. 8).

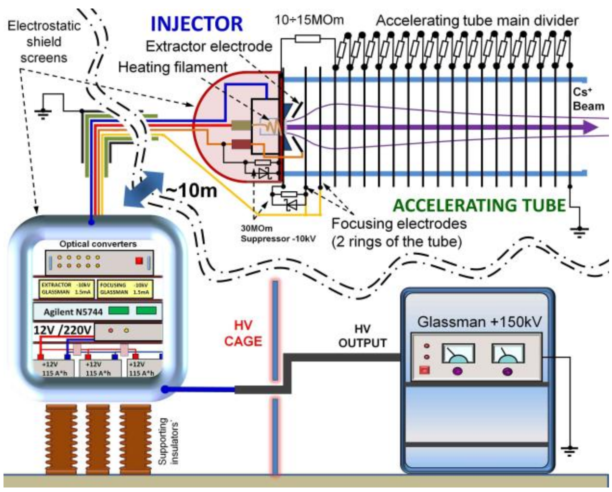

Fig. 8. Schematics of the HIBP injector system and acceleration tube on TJ-II stellarator

Each system includes 3 sealed lead-acid AGM 12 V 115 Ah lead-acid batteries, connected in parallel, as power source. 12 to 220 V DC-AC 1500 W voltage invertor is used to feed all the devices that are intended for 220 V AC. Agilent N5744 (20 V, 38 A, 760 W) power supply is used for filament heating.

Also, system includes “Glassman” extractor and focusing HV power supplies (-10 kV, 1.5 mA), frequency modulation fiber-optical analog input and output modules, twisted pair to fiber-optical Ethernet LAN convertor and some other auxiliary equipment.

All systems are controlled through a number of fiber-optical cables from low voltage side.

The HIBPs TJ-II injector control systems are based on the commercial power supplies, converters etc. This circumstance as well as the scheme, used for the injector power control, has some disadvantages. It is quite expensive and it caused some problems during operation. Since heating filament must be fed with low voltage (below 10 V) but high current ratings (10…15 A), this fact leads to high power losses in double voltage conversion (12 to 220 V and 220 to 0…10 V). Also it results in the high idle current consumption from the batteries (~9 A). All these negative factors highly reduce the time of continuous operation.

CONCLUSIONS

The new advanced version of electronic control unit for ion beam forming was developed, manufactured, installed and tested on HIBP system for Uragan-2M torsatron.

The system of filament current regulation is based on efficient synchronous buck converter with direct supply from 12 V batteries. It leads to high overall injector control block efficiency (up to 85 %) in the wide range of output currents (up to 20 A) and results in low idle current consumption (~1 A).

The new injector control block provides all the necessary functions for adjusting the parameters of the ion beam as well as for handy and stable operation of the injector in the experiments on torsatron U-2M.

The control of the unit is performed by a common USB computer port through two galvanic insulated fiber-optical cables. The complete unit is rather small (of the size of the standard PC power supply box). It can be easily placed inside any types of electrostatic screens under high voltage potential. These features make it easy to implement the control unit of this type with other various HIBP systems.

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НОВЫЙ БЛОК УПРАВЛЕНИЯ ДЛЯ ФОРМИРОВАНИЯ ЗОНДИРУЮЩЕГО ИОННОГО ПУЧКА В ДИАГНОСТИЧЕСКИХ СИСТЕМАХ ЗЗПТИ

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Описывается новая версия блока управления формированием ионного пучка для диагностики зондирования плазмы пучком тяжёлых ионов (ЗППТИ). Этот улучшенный блок был разработан, изготовлен, установлен и протестирован на системе ЗППТИ для торсатрона Ураган-2М. В этой системе были реализованы некоторые новые схемные решения, которые были созданы на основе длительной работы с различными типами блоков питания инжекторов и их систем управления ЗППТИ для различных установок по изучению управляемого термоядерного синтеза. В результате был создан усовершенствованный тип электронного блока управления с высоким коэффициентом полезного действия. Он обеспечивает все необходимые функции как для настройки параметров ионного пучка, так и для удобной и стабильной работы инжектора в экспериментах на торсатроне Ураган-2М.

НОВИЙ БЛОК КЕРУВАННЯ ДЛЯ ФОРМУВАННЯ ЗОНДУЮЧОГО ІОННОГО ПУЧКА У ДІАГНОСТИЧНИХ СИСТЕМАХ ЗППВІ

О.І. Жежера, О.О. Чмига, Г.М. Дешко, О.С. Козачок, О.Д. Комаров, Л.І. Крупнік, С.М. Хребтов

Описується нова версія блоку керування формуванням іонного пучка для діагностики за допомогою зондування плазми пучком важких іонів (ЗППВІ). Цей електронний блок був розроблений, виготовлений, встановлений і протестований на системі ЗППВІ для торсатрону Ураган-2М. У цій системі були реалізовані деякі нові схемні рішення, які створені на основі тривалої роботи з різними типами блоків живлення інжекторів та їх систем керування ЗППВІ для різних установок з вивчення керованого термоядерного синтезу. У результаті був створений вдосконалений тип електронного блоку управління з високим коефіцієнтом корисної дії. Він забезпечує всі необхідні функції як для настройки параметрів іонного пучка, так і для зручної і стабільної роботи інжектора в експериментах на торсатроні Ураган-2М.