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ORIGINAL RESEARCH

Electrical Parameter Measurement System of the Ion Source for EAST Neutral Beam Injector

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Abstract Neutral beam injection (NBI) is recognized as one of the most effective means of plasma heating. A virtual instrument (VI) has been designed to provide electrical parameter measurement for the ion source of EAST-NBI. The VI is written using the National Instruments LabVIEW graphical programming language. All data acquisition (DAQ) is accomplished using ADLINK DAQ hardware interface and Task-oriented DAQ Driver. The VI can measure filament voltage, filament current, arc voltage, arc current and accelerating voltage etc. The data obtained from the VI are feedback of the ion source operation state and helpful to direct the operation parameter optimization of the ion source.

Keywords Neutral beam injection · Virtual instruments · Electrical parameter measurement · High voltage

Introduction

High energetic neutral beam injection (NBI) is one of most important methods for auxiliary heating and non-inductive current drive of plasma in nuclear fusion devices [1–3]. A neutral beam injection system (NBIS) for EAST has been constructed, whose target values are beam energy 50–80 keV, beam power 2–4 MW, beam pulse width 10–100 s,beam current up to 70 A [4–8]. Highly stability and highly repeatability of NBIS is very important to the experiment operation of EAST. To obtain an uniform plasma, ion source power supply of NBIS requires flat-top pulse, good repeatability, small ripple and high stability. A real time PCI extension for instrumentation (PXI)-based virtual instrument (VI) system has been built for measuring electrical parameter of ion source. This system has been developed using LabVIEW graphical software package and data acquisition (DAQ) cards (ADLINK).Experimental data obtained from this measurement system give feedback to the ion source power supply operation state. Analyzing the experimental waveforms, we can understand the carrying capacity and the key working state of the arc and filament power supply, the loss of line, and beam power loss.

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Measurement Systems

For EAST-NBI, a high voltage air-insulated platform (named High Voltage Deck, HVD) has been installed to host the ion source, accelerating grids, power supply of filament and arc and associated diagnostic system. The filament and arc power supplies are referenced to the accelerating voltage that is up to 100 kV. As shown in the Fig. 1, the ion source is connected with power supply through cable in which there are voltage losses, so the electrical parameters of the ion source is not equal to which of power supply. In order to protect ion source and make it work in a good state, the electrical parameter measurement system of the ion source is important.

The hardware of the whole measuring system includes voltage divider circuits, over-voltage protection circuits, signal conditioning circuits, PXI system and other accessories preventing from disturbing, such as fiber optic transmission. The block diagram of the measurement system is shown in Fig. 2, which also has data storage and

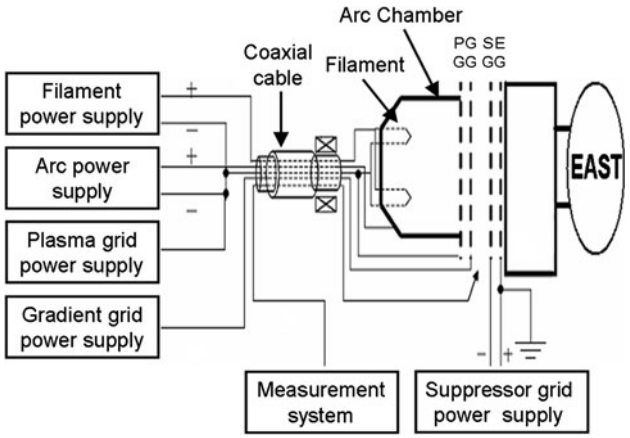

Fig. 1 Power supply system of EAST NBI ion source

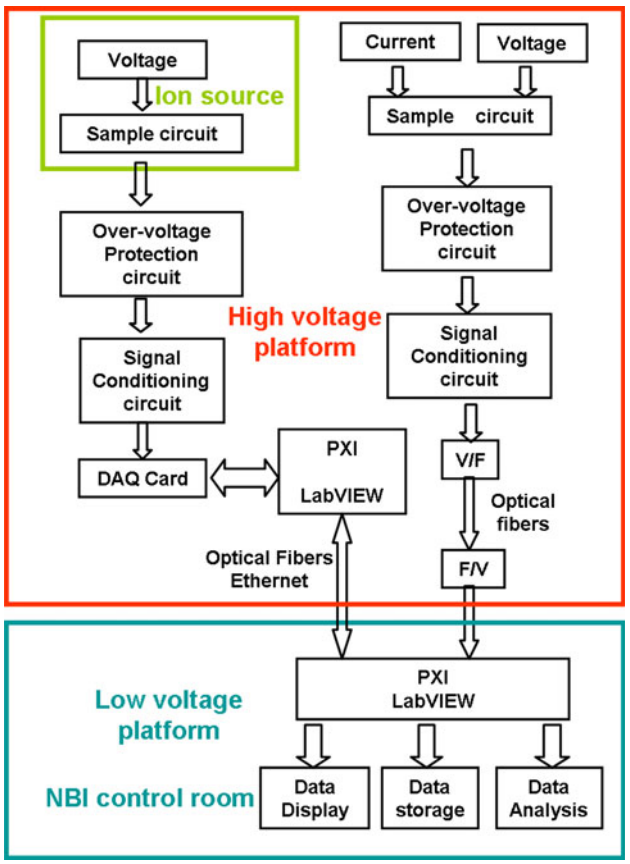

Fig. 2 The block diagram of the measurement system

data display function PXI system (Adlink Technology Inc. products) includes the eight-slot chassis (PXIS2630), CPU (PXI3950), PXI DAQ cards. In this system, the high-speed DAQ cards play an important role. PXI system has the following advantages: (1) high scalability and compatibility, (2) the entire graphical system design platform, (3) fast and flexible data storage options. According to the Nyquist sampling theorem, as some of power supply of the ion

Table 1 Main parameters of ion source power supplies

Supply	Voltage (V)	Current (A)	Operation mode
Filament	0–20	0–5,500	Steady state falling time 1–2 s, rising time 1–3
Arc	0–200	0–3,000	Steady state falling time <10 μs, rising time <20 μs
Accelerating	0–100,000	0–60	Steady state falling time <10 μs, rising time <20μs

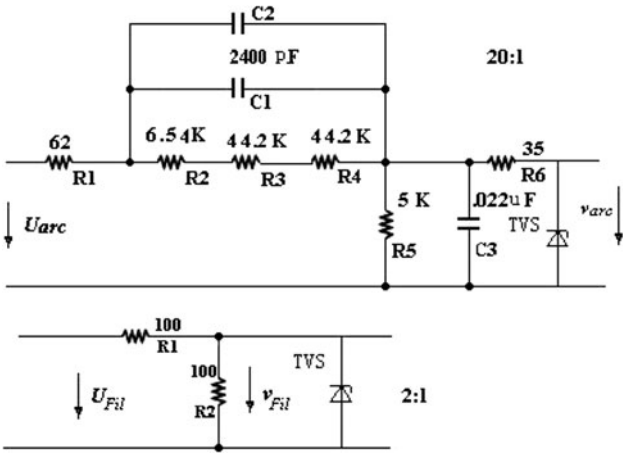

Fig. 3 The voltage divider circuits of filament power supply and arc power supply

source rising and falling time is short, such as the arc power supply rising time <20 μs and the falling time <10 μs, in order to achieve the variation characteristics of the ion source in the process of breakdown and ignition transient, DAQ card PXI-2010(ADLINK Technology Inc.) has been adopted, which is 4-ch, 14/16-bit, up to 2MS/s simultaneous-sampling multi-function PXI modules.

Typical operating ranges for power supplies of the Neutral Beam Injector are listed in Table 1. For the filament and arc power supplies are referenced to the accelerating voltage, and their output voltages ranges are 0–20 and 0–200 V respectively, but the maximum acquisition voltage of data acquisition card is 10 V,in order to work properly, the measurement system should adopt voltage divider circuits. There are two voltage divider circuits shown in the Fig. 3, in which the arc voltage divider ratio is 20:1, and filament voltage divider ratio is 2:1. As the rise and fall time of filament voltage is far more than 1 s, common resistor divider circuit can meet measurement requirements. But the arc voltage rising and falling time is too short (as shown in Fig. 3), the existence of stray capacitance on the voltage divider circuit would bring time delay between input and output of the arc voltage divider circuit. The RC potentiometer circuit has been used to

reduce the transient response time. When the time constant of the RC potentiometer output is equal to that of input (i.e. $R_iC_i = R_oC_o$), the circuit does not exist transient response process. In order to enhance the anti-interference ability of the measurement system, the voltage divider circuits should be hosted inside a metallic box.

Since the ion source works on a HVD, it will produce strong electromagnetic interference, and the large-capacity, high intensity vertical and poloidal electromagnetic field of EAST will also produce strong space electromagnetic interference. All these interference will not only influence the accuracy of the measurement system, particularly the accuracy of the voltage transient characteristics, but also endanger the safety of the operator. In order to prevent high voltage from damaging the measurement system and guarantee the correct signal transmission, the inputs and outputs of the measurement system should be electrically isolated. As shown in Fig. 2, arc current and electrical parameter of power supply are acquired on the HVD and then transmitted to low voltage control system through V/F circuit and optical fiber. But for the filament and arc voltage of the ion source, they are acquired using the PXI and then transmitted to low voltage control system through network. This method doesn't adopt V/F conversion (F/V conversion) chips, which increase output signal accuracy, and reduces the time delay. Agilent HFBR-0400 family devices are selected as optical transmitting and receiving devices.

National Instruments LabVIEW graphical program language and ADLINK Task-oriented DAQ Driver (DAQPilot) were selected for their ability to allow the user to create a front panel user interface. Graphical programming languages allow the designer to select objects (icons) to perform required functions. DAQPilot provides Express VI and Polymorphic VI libraries to guide development of LabVIEW applications without the need for the complex configuration of ADLINK DAQ cards. LabVIEW and DAQPilot allow hardware configuration, output display, and data acquisition to be implemented in a short time period.

Table 2 Steady state experimental data

Measurement point	Arc voltage (V)	Filament voltage (V)	Arc current (A)	Filament current (A)
Ion source	85	6.5	520	3000
Power supply	90	11	520	3000

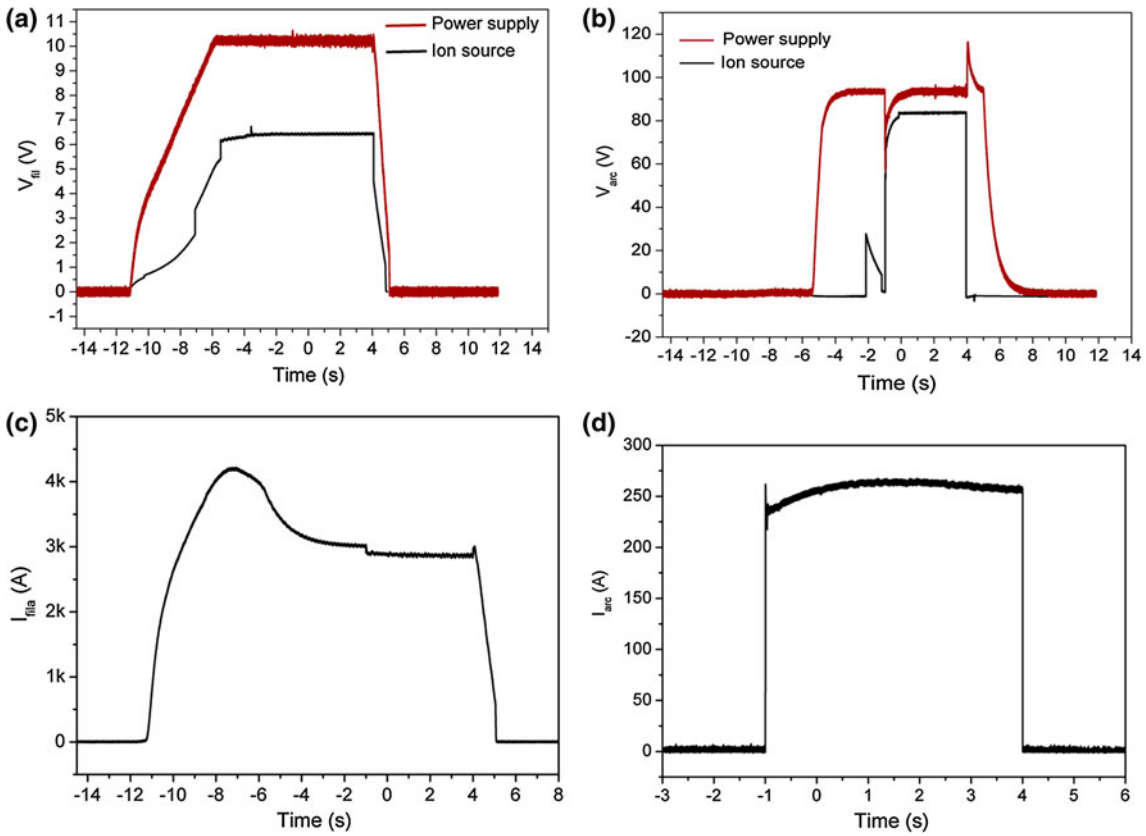

Fig. 4 Arc and filament waveforms measured on the power supply side and ion source side: **a** filament voltage, **b** arc voltage, **c** filament current, **d** arc current

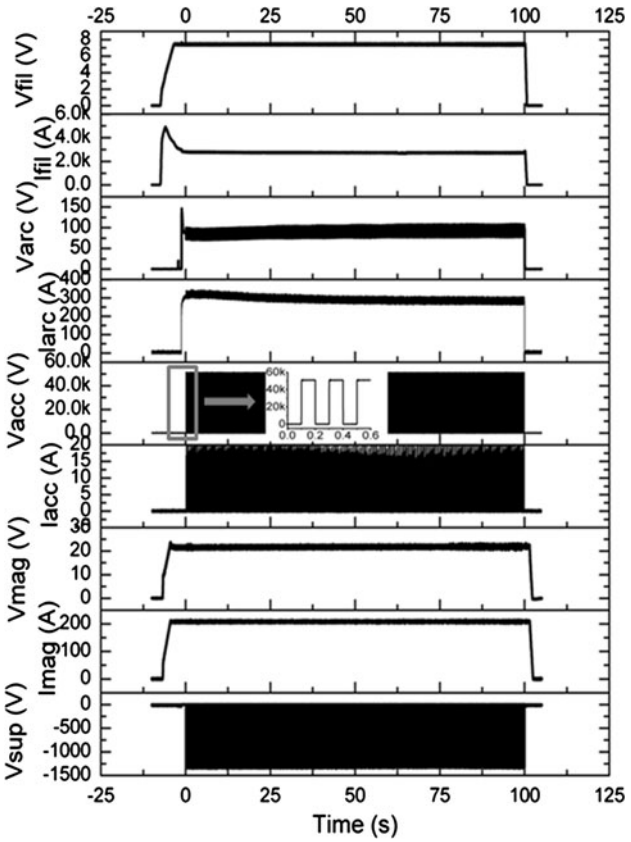

Fig. 5 Waveform of 100 s long pulse beam extraction (50 keV, 16 A, modulating)

Experimental Results and Discussions

After the commissioning test of ion source power supply system, the result of the experiment is acceptable. The filament power supply: output approx 10 V, 3000 A, pulse width 10 s and arc power supply: output 10–50 kW, arc discharging approx 3–5 s. The experimental data have been achieved as shown in Table 2 and Fig. 4. Figure 4a is the filament voltage waveform measured on the power supply side and ion source side, Fig. 4(b) is the arc voltage waveform measured on the power supply side and ion source side and Fig. 4c, d are the current waveform of filament and arc respectively. As shown in Fig. 4, there are a few differences between the values measured on the power supply side and the values measured on the ion source side.

The possible reasons are existence of line loss or the power carrying capacity is not strong enough. In addition, Fig. 4 also shows that arc current rises with the arc voltage increasing. According to the arc efficiency formula

$$\eta_{eff} = \frac{I_{acc}}{P_{arc}} = \frac{I_{acc}}{V_{arc} \bullet I_{arc}}$$

here, η_{eff} is arc efficiency, I_{acc} is beam current, V_{arc} is arc voltage and I_{arc} is arc current. Constant current power supply will help improve arc efficiency. As shown in Fig. 4, the filament current keeps increasing during the pre heating phase. In order to prevent the filaments burning out, some protective measures should be taken. In short, according to Fig. 4, we can find that accurate arc discharge process and specific parameters can be achieved, which can direct the operation parameter optimization of the ion source.

Based on this measuring system, EAST-NBI obtains 100 s long pulse modulating beam extraction (as shown in Fig. 5). The results show that: (1) electrical parameter measurement system of the ion source can work properly; (2) EAST-NBI has ability of long pulse beam extraction.

According to the speed of electrical parameters, fast and slow measurement systems can be designed. The next step is to improve the measurement accuracy of the system and broaden the measurement function.

Conclusion

EAST-NBI ion source electrical parameter measuring system based on National Instruments LabVIEW and ADLINK Task-oriented DAQ Driver (DAQPilot) can provide a solution of high compatibility, flexible expansibility and anti-electromagnetic interference. Experimental results show that the system is stable, reliable, and meet the experimental requirements fully.

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