60 KEV 30 KW ELECTRON BEAM FACILITY FOR ELECTRON BEAM TECHNOLOGY

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Abstract

At the Budker Institute of Nuclear Physics, Novosibirsk, the 60 keV 30 kW electron beam facility for electron beam technology has been developed. The electron gun provides continuous or modulated beam within the current range from 1 mA up to 500 mA. The optical system allows both static and dynamic focusing of the electron beam within the 50÷500 mm range of distance from the gun outlet, the beam scanning and its parallel displacement from the optical axis. The electron gun facility is controlled by the computer via the CAN interface. This paper presents the general description of the facility, its block diagram and main parameters.

INTRODUCTION

Since 2003 at the Budker Institute of Nuclear Physics the 60 keV 30 kW electron beam facilities for electron-beam technology developed and produced. The aim of efforts was to satisfy up-to-date constantly growing requirements of aerospace and other branches of industry. In order to provide the procedures of welding, cutting, surface treatment, drilling of holes and melting, the electron beam facility has following operations:

- Continuous regime of the electron beam.
- Modulated electron beam.
- Static focusing of the electron beam.
- Dynamic focusing of the electron beam.
- The beam scanning.
- Parallel displacement of the electron beam from the optical axis.

Main parameters are presented in Table 1.

SCHEME OF THE FACILITY

There are three main parts of the installation:

- Electron-optical system of the beam.
- High voltage unit.
- Block of electron beam control.

A photo of the facility is shown in Fig. 1.
A block diagram of the facility is presented in Fig. 2.

Electron-Optical System of the Beam

The electron gun consists of direct heated cathode with boundary electrode, control electrode, which allows one to set beam current value, screen electrode and the anode. (See Fig. 3). Next to anode where an electron beam has a minimal diameter, a system of beam axe correction is placed.

Then the beam passes through static and dynamic electromagnetic lens gaining required size. At the very exit there is a system of scanning coils enabling one to deflect a beam on a work piece according given parameters. At the device exit there is a protection system that confines electron beam deviation, while systems of video surveillance and the one registering reflected from the work piece electrons to enable to watch closely the welding process.

Table 1: Basic parameters of the facility

Parameters	**Unit**	**Value**
Maximum beam power	kW	30
Energy of electrons	kV	30÷60
Energy stability	%	0.5
Beam current	mA	1÷500
Beam current ripple	%	± 2
Filament current	A	70÷90
Filament current ripple	%	± 1
Power consumption	kW	36

Figure 1: Photo of the facility.

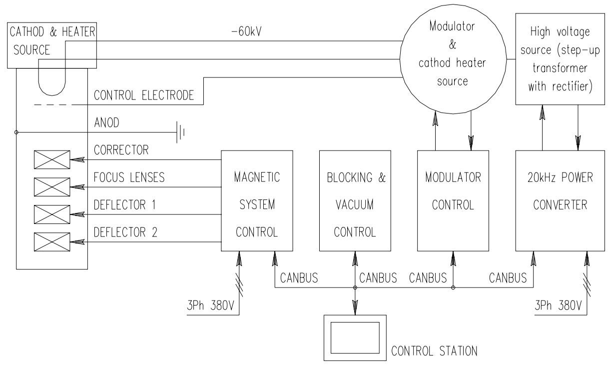

Figure 2: Block-diagram of the facility.

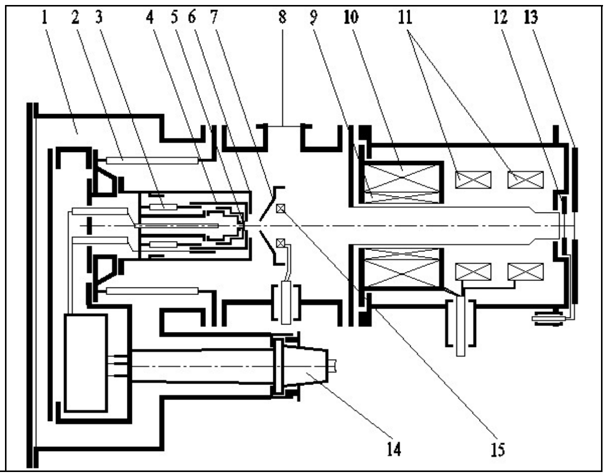

Figure 3: The sketch of electron-optical system of the beam. Legend: 1-oil tank, 2-high voltage insulator, 3-insulator control electrode, 4-control electrode, 5-cathode, 6-screen electrode, 7-anode, 8-pumping, 9-dynamic magnetic lens, 10-main magnetic lens, 11-two coordinates deflected coils, 12-pick-up of beam boundary, 13-pick-up of secondary electrons, 14-high voltage input, 15-trajectory corrector.

The cathode made from tantalum foil 0.1÷0.2 mm of thickness mounted in precisely manufactured and preliminary adjusted cartridge, which simplifies the replacement of the gun and excludes necessity of further beam axe alignment. The life-time of the cathode is about 100 hrs at high parameters but one can prolong it by keeping the gun in stand-by regime (70% of maximal) between welding.

The cathode-anode area is pumped by the turbomolecular pump.

High Voltage Unit

High voltage unit consists of two parts:

- High-voltage source.
- Modulator with cathode heater source.

The high-voltage source was designed for some different BINP internal applications. That was reason for some specific terms like: fast time for rise voltage to 60 kV after high-voltage breakdown, strong reliability to high-voltage breakdown, breakdown energy less than 15 J for 60 kV operation, low voltage ripple for maximal power operation [1]. The design of power part high-voltage source is shown at Fig. 4.

The high-voltage source consists of the 20 kHz power converter with IGBT as switches (part A) and high-voltage sectioned step-up transformer with the rectifier (part B). The design of power converter consists of 3-phase rectifier D1-D6, electromagnetic filter F1, ripple damping filter L1 C1-C4, 20 kHz inverter with IGBT switches Q1-Q4, impedance matching design L2, L3, C5, and isolation transformer T1.Full-bridge inverter Q1-Q4 converts DC 550V voltage to AC voltage with 20 kHz frequency. Inverter working with principle of pulse-width modulation (PWM) with 2 circles: freewheeling when switches Q2, Q4 are switched on (ON) and energy increase when Q1, Q4 or Q2, Q3 are ON. With this conditions the IGBT switches is been in soft switching mode, and the switching transient process and the switching energy loss are minimised.

The power source must work with wide range of loads, from zero current to full load. The matching circuit consists of C5, L2, L3 is used for minimising transient process and for improving efficiently of design. The transient process time is less then 5 ms with transient voltage jump less than 6 kV for 60 kV operations for load switching between 20 mA and 250 mA (full load). The frequency characteristic of high-voltage transformer with matching circuit is characteristic of two coupled resonant circuits: series circuit of matching design C5, L2, L3 and leakage inductance of high-voltage transformer, and parallel circuit, which being obtained from magnetising inductance (for about 100 μH) and parasitic capacitance (for about 1,5 μF recalculated to primary winding) of high-voltage transformer. 20 kHz is located between two peaks on the frequency characteristic and the transfer coefficient at this frequency doesn't depend on load. It's matter that in ideal conditions on 20 kHz frequency this design is a voltage source and the output voltage is constant with wide range of loads. This is the first reason to use matching circuit – minimising effects of big parasitic capacitance and leakage inductance.

The second reason to use this circuit is improving efficiency of power design. Magnetising inductance, parallel parasitic capacitance and the matching circuit organise low-pass filter for all higher harmonics of inverters rectangular alternating voltage. That way, sinusoidal voltage is feed in the high-voltage transformer, because all high harmonics are filtered. In other case, the presence of high harmonics causes power dissipation in the leads because of skin-effect. Also this harmonics can induce the oscillations in the secondary winding of high-voltage transformer. Sectioned high-voltage transformer consists of four step-up high voltage sections. Each section is complete design and it includes winding, half-bridge rectifier and output filter capacitors. Output voltage for section is 15 kV for 60 kV operations. Output filter includes the filters in sections and addition high voltage output capacitor. Output filter capacity is chosen

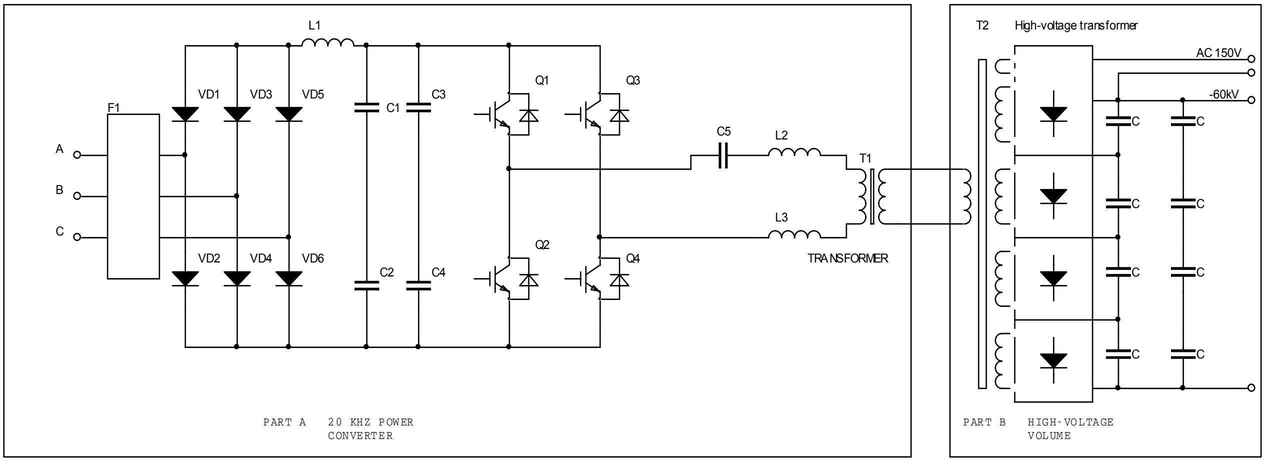

Figure 4: High-voltage source design.

for output voltage 40 kHz ripples less than 0,5% for full load operation. The transformer is designed in oil-filled tank. The silicon oil [2] is used.

The control circuit is with using the digital signal processor (DSP), programming logic matrix array (PLM), and analogue input buffers. The control and analogue grounds are isolated from external signals and grounds and, that way, in control circuit low noise level has obtained. It allows operation at better than 0.1% measuring precision. All the IGBT switches are protected from short circuit and overcurrent. The controller measured 7 analogue channels with 12 bits precision and 50 μsec time period of measuring for all channels. The controller has CAN-bus interface which is used to link with a controlling system. The used data rates are 125, 250 and 500 Kbits/sec. The feedback system includes three loops: main analog feedback loop, connected to the ADC channel of DSP, Digital 300 Hz correction and low-frequency correction loop, increasing of DC frequency gain. Digital corrections are realized in DSP. Breakdown protection controls output current. If this current jumps up to 300 mA or higher the converter switches off (OFF). Switching off time is less then 50 microseconds. For that reason, the breakdown energy less than 15J for 60 kV operations with connected of 10 meters high-voltage cable. The converter tries to switch on after 5 milliseconds.

High-voltage transformer protection measures the temperature of oil in the top part of tank and input current. If the transformer input current rises to 100A, a short circuit in the transformer would result. In this case the converter is OFF. The actuation of protections is shown on front panel indicator.

Modulator with cathode heater source is supplied by the 20 kHz power converter and provides:

- Control electrode of electron gun with high voltage in the range of 0 to 600 V with ripple 0.5% for decreasing of energy spectrum and stabilization of electron beam current.
- Mode of electron beam modulation.
- Cathode heater with stabilized current in the rang of 0 to 100 A electron beam.

Block of Electron Beam Control

High-voltage source, magnetic system, modulator controller, alarm and blocking system are connected to control computer through CAN-bus interface at 250 kbits per second rate [3]. Control computer can control and monitor output voltage, beam current, cathode heat current, magnetic lens and correctors currents, blocking state and other output and input parameters.

RESULTS

The four facilities have been produced and tested with success in BINP. The tests have shown that facilities provide their necessary parameters. At present they have been installed in Scientific Research Technological Institute "Progress", Izevsk, Russia and are under field tests.

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