ELECTRON MINIACCELERATOR ON THE BASE OF TESLA TRANSFORMER FOR THE BEAM OF CHARGED PARTICLES NONDESTRUCTIVE TESTINGS

V.E. Akimov, A.V. Bulatov, P.V. Logatchev, I.V. Kazarezov, A.A. Korepanov, D.A. Maljutin, A.A. Starostenko,
The Budker Institute of Nuclear Physics, Novosibirsk, Russia.

Abstract

The electron miniaccelerator on the base of Tesla-transformer for the beam of charged particles nondestructive testing with operating voltage up to 200 kV, half-wave duration 4 mks and diagnostic beam current within few mA is described. The primary circuit is switched by IGBT-module. The gun control and filament circuit power supply (impregnated cathode with 1.2 mm diameter) are performed through high frequency isolated transformer. The accelerating tube is performed from sectional welded metal ceramics insulator (ceramics 22HS with diameter 95/85 mm). The accelerators test results are presented.

INTRODUCTION

The development of accelerating technology leads to increasing the role of non-destructive diagnostic methods of the electron beams. One of the perspective devices which allows to obtain the spatial charge distribution and not to affect the bunch is a beam monitor. The basic principle of its operations is the interaction of the test low energy electron beam with electro-magnetic fields of the ultrarelativistic charged particles bunch. The bunch desired parameters are determined from the interaction result [1]. Along with accelerators beam intensity increase the necessity of testing beam energy raising is appeared. For this purpose a miniaccelerator with energy up to 200kV and high voltage generator based on Tesla transformer was developed [2,3].

DESIGN AND POWER SUPPLY SYSTEM OF THE ACCELERATOR

The Tesla transformer represents two oscillatory inductive couppled circuits with equal resonance frequencies. The property of the ideal Tesla transformer is full energy transfer from primary circuit to the secondary at fixed magnetic coupling coefficients of the coils equal to 0.6, 0.385, 0.2 etc. The maximum efficiency is obtained at coupling coefficient 0.6 because of dissipation in the circuits. The advantages of the Tesla transformer based generator compared to other types of generators are:

– full energy transfer from the primary circuit to the secondary one at the given point of time;
– good coaxial configuration of the pressure vessel, primary and secondary windings and an accelerating tube simplifies high voltage generation at comparatively low operating gradients and small-scale size of the apparatus and provides shielding against external fields on which the testing beam is sensitive;
– there is no closed magnetic core which fabrication is frequently connected with a lot of technological problems;
– an up-to-date semiconductor basis allows comparatively easily to realize primary circuit switch with recuperation on single module.

The Tesla transformer based accelerator design within the structure of the beam monitor test bench is presented

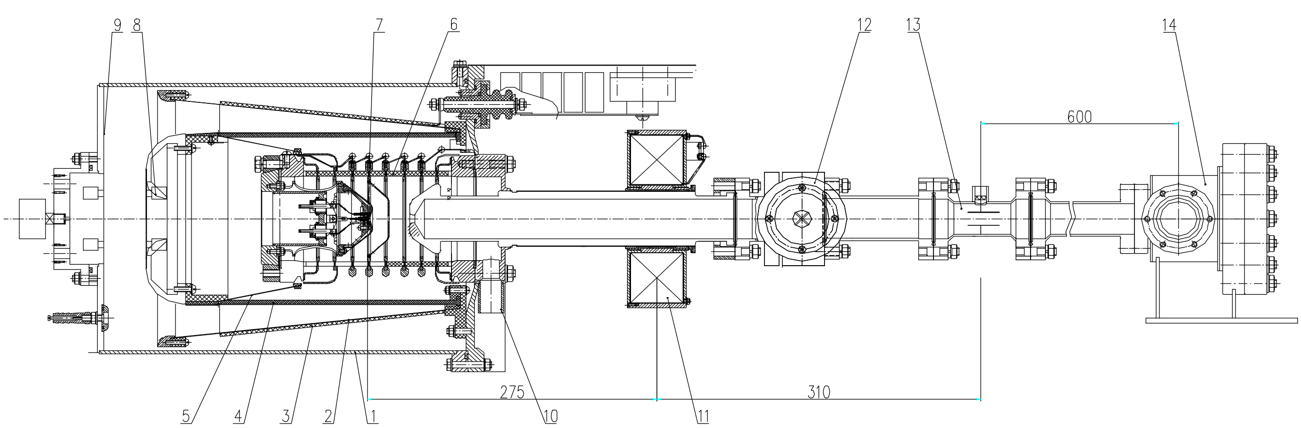

Figure 1: Testing electron miniaccelerator design. 1 – pressure vessel, 2 – primary winding, 3 – ferrite core, 4 – secondary winding, 5 – equipotential shield, 6 – accelerating tube, 7 – electron gun with control electrode, 8 – power transfer transformer, 9 – capacitive divider; 10 – vacuum pumping, 11 – magnetic lense,, 12 – vacuum gate valve, 13 – scanning device, 14 – beam collector.

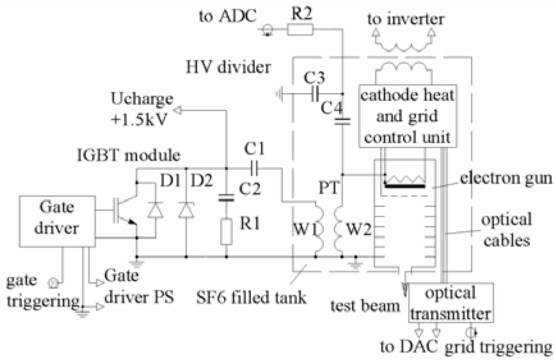

Figure 2: Miniaccelerator power supply simplified circuit.

in Fig.1. The accelerator is placed in SF6 filled vessel 1 at pressure 0.17MPa. For better shielding from external fields the vessel is made of steel st3. The primary circuit 2 is performed out of double layer foil-clad glass-cloth laminate by the printed circuit board technology. The grounded shield is located at the inside of the winding. To be penetrable to magnetic field the shield represents a set of 0.4mm width tracks with 0.4mm spacing between them. To increase the primary winding rigidity it is reinforced by glass tissue and impregnated by epoxy compound at the outside. In the same place a magnetic core 3 made of ferrite bars providing required coupling coefficient 0.6 is assembled. The secondary winding 4 (glass-epoxy skeleton) is winded by lacquer isolated wire 0.21 mm in diameter. To provide the stable operation of the winding isolation at inevitable breakdowns a special protective shield 5 penetrable to magnetic flux is used.

The accelerating tube 6 is made of 22HS ceramics by thermal-compression bonding technology [4]. An impregnated cathode 7 of 1.2mm diameter is used for the gun's emitter. The beam control is realized by a diaphragmatic control electrode ("grid") of 0.6 mm in diameter.

The cathode heat and grid control unit is supplied by the high voltage isolation transformer 8 [5] based on E-shape cores. The unit is controlled using optic fiber cables laying along the accelerating tube. High voltage pulse measurement is realized with use of capacitive divider 9 which is assembled inside the vessel.

The beam focusing is realized by axisymmetric

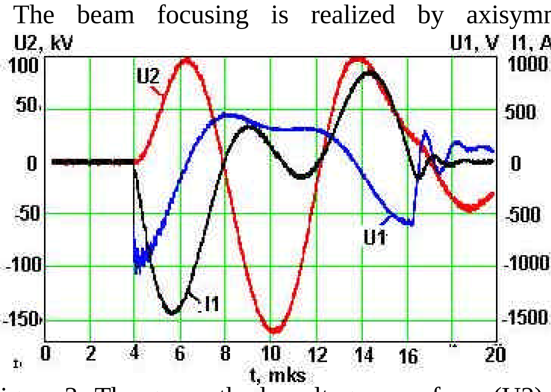

Figure 3: The gun cathode voltage waveform (U2), PT primary voltage waveform (U1), primary circuit current waveform (I1).

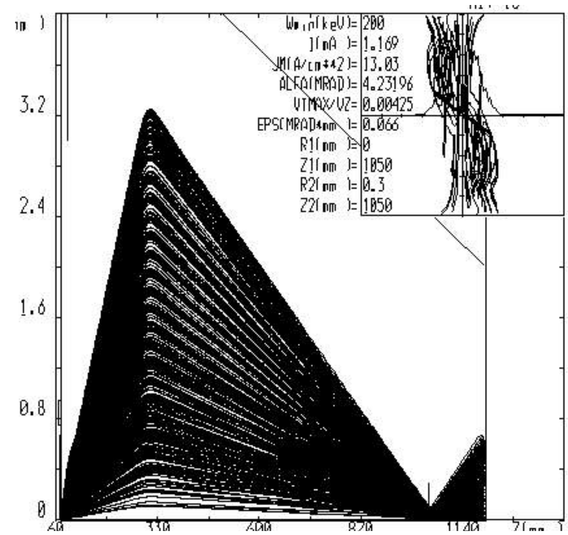

Figure 4: Results of EOS simulation (trajectories of electrons, at the right upper corner – current density distribution and phase portrait of the beam at a distance of 1m from the cathode).

magnetic lens (11). The pulse electrostatic scanning device (13) turns electron beam in the plane of the testing bunch flight and so enables to study the behaviour of train of bunches.

The miniaccelerator simplified circuit of power supply is presented in Fig.2. The primary circuit capacitance consists of 16 polypropylen K78-10 capacitors with rated value 0.15mkF each. Semikron SEMiX 653GB176HD IGBT module is used as a switch. Primary and secondary voltage and current waveforms are shown in Fig.3. The gun control electrode is triggered in a moment when all energy is concentrated in the secondary circuit capacitance. When the pulse of the beam current comes to the end the whole of energy transfers to the primary circuit capacitance through the diode D1 bypassing IGBT. By this time IGBT is switched off and all energy except for energy took off by the beam and disappeared in the circuits concentrates in the capacitance C1.

Simulations made by the computer codes SAM, ULTRASAM [6] taking into account electrons thermal speeds finally allows to obtain electron beam of 0.15 mm in a radius at the distance 1m from the cathode (see Fig.4).

BEAM DIAGNOSTICS

Electron-optical system composed of a microchannel plate (MCP), luminophor and CCD camera is used for beam registration. In this design MCP perfoms two functions: the first one is amplification of the surface charge density and the second one is the role of fast shutter (~40 ns). The first function is necessary for detection of low electron beam density arising when high intensity ultra-relativistic bunch interacts with testing beam. The second – for selection of necessary point of time for the beam under test observation. The tantalum plate loaded on 50 Ohm is utilized for the beam current measurement.

OPERATION RESULTS

Within the source testing the following results was obtained:

1. Operational voltage 200 kV is defined by vacuum isolation electrical strength. The beam current amplitude is regulated by the value of controlled voltage on the cathode iris electrode. At the same time the size of beam focused on screen is changed. The minimum spot size on the phosphor screen is obtained at the beam current ~10 mkA.
2. The beam autographs obtained at the electrons energy 160 kV and 200 kV and at the optimal controlled voltage are presented in figure 5. The spot sizes measured at the half height of the spot's brightness are marked.
3. The phosphor screen aging experiment was carried out at the described test bench. Since irradiation of the phosphor with scanned 75 keV beam (fig.6 left) with integral charge ~10 mkC (0.3 mkC/mm^2) the screen brightness at the beam irradiation area has been decreased by 7 % in comparison with nonirradiated area (more light lines in fig.6 on the right).

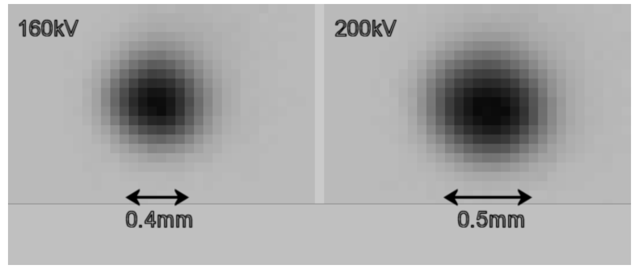

Figure 5: Focused beam image on phosphor screen (beam current ~10 mkA).

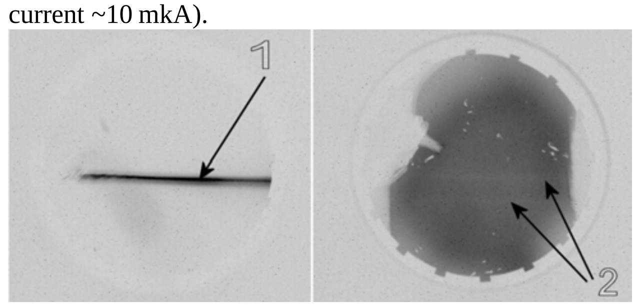

Figure 6: 1 – phosphor screen image of scanned beam (beam width – 1 mm, length – 20 mm), 2 – "aged" regions of the phosphor screen visible at uniform flash of the screen (beam current ~400 mkA).

REFFERENCES

[1] P.V. Logatchov, P.A. Bak, A.A. Starostenko, N.S. Dikansky, Ye.A. Gusev, M.B. Korabelnikov, S.V. Shiyankov "Non-Destructiv Single Pass Monitor Of Longitudinal Charge Distribution", HEACC2001, March 26 - 30, 2001, Epochal Tsukuba International Congress Hall, Tsukuba, Japan.

[2] S.B. Vasserman, Tesla transformer in high voltage charged particles accelerators. – Novosibirsk, 1977, – Preprint / Institute of nuclear physics (in russian).

[3] High voltage pulse electron accelerators of Institute of nuclear physics (Novosibirsk) for industrial and experimental purpose. /S.B. Vasserman, I.V. Kazarezov, V.Ph. Kupenko et al. – In 4th All-Union conference on charged particles accelerators, Moscow, 1974, (in russian).

[4] Ju.D. Valyaev, I.V. Kazarezov, A.M. Kryuchkov. Sectioned high voltage ceramic-metal isolators for accelerator tubes. Novosibirsk, 1988. – (Preprint Institute of nuclear physics, 88–143) (in russian).

[5] Compact high frequency isolation transformer for power supply of the equipment located at the high voltage potential. /Ju.D. Valyaev, I.V. Kazarezov, V.I. Kuznetsov et al. – Novosibirsk, 1989. – (Preprint Institute of nuclear physics, 89–160) (in russian).

[6] Ivanov A.V., Tiunov M.A. ULTRASAM-2D Code for Simulation of Electron Guns with Ultra High Precision. – In Proceedings of the EPAC2002, Paris, 2002, p. 1634 – 1636.