ISSN 1027-4510, Journal of Surface Investigation: X-ray, Synchrotron and Neutron Techniques, 2022, Vol. 16, No. 5, pp. 698–701. © Pleiades Publishing, Ltd., 2022.
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System for Measuring the Spatial Characteristics of Ionizing-Radiation Beams Based on an X-Ray Fluorescent Wire Scanner

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Received November 18, 2021; revised January 22, 2022; accepted January 29, 2022

Abstract—A wire scanner designed to measure the spatial characteristics of beams of relativistic and nonrelativistic charged particles, as well as beams of X-ray and gamma radiation, is proposed. The scanner contains several wires of different materials located along the beam axis and capable of moving across the beam. During scanning, characteristic X-ray radiation is generated in the wires under the action of the beam, the spectra of which are recorded by an energy-dispersive X-ray detector. Determination of the transverse profiles of the studied beam consists in measuring the radiation-intensity dependence on the impact parameter of the wires. Matching of the obtained profiles with specific wires is performed according to the energy of characteristic X-ray radiation. The data obtained during scanning allows determination of the transverse dimensions, shape, trajectory, divergence and emittance of the beam.

Keywords: wire scanner, characteristic X-ray, beam diagnostics, transverse profile, divergence, emittance, trajectory, X-ray detector, energy-dispersive detector, radiation spectrum

DOI: 10.1134/S1027451022050123

INTRODUCTION

One of the main parts of accelerator complexes is a diagnostic system designed to determine the spatial and temporal characteristics of particle beams. At present, there are many methods for the diagnostics of beams based on the use of different physical phenomena [1–4]. For example, scintillating screens [5, 6], as well as screens based on transition [7, 8] and parametric X-ray [9, 10] radiation, which also carry information about the divergence of charged particle beams. To prevent the destructive effect on diagnosed beams, solid-state screens can be replaced by gas curtains (jets) [11–13]. In some high-energy accelerator complexes, the nondestructive monitoring of spatial parameters of the beam is carried out using synchrotron [14–16] or undulator [17, 18] types of radiation.

As a universal tool for diagnostics of the transverse dimensions and shape of low- and high-energy beams, characterized by a simple design and low cost, wire scanners are widely used, which can be made in the form of static wire grids [19] or include movable wires in the design [20–22]. During the operation of such scanners, the intensity of bremsstrahlung or the secondary-emission current generated during the interaction of beam particles with wires is registered. To minimize the destructive effect of high-energy beams, it is possible to use its laser analogue instead of a classical wire scanner [23, 24].

In this paper, we present the design of a wire scanner designed to determine the spatial characteristics (position, transverse dimensions and profiles, divergence, and emittance) of beams of relativistic and nonrelativistic charged particles, as well as photon beams. To obtain transverse profiles, it is proposed to measure the dependence of the intensity of the characteristic X-ray radiation (CXR) on the distance between the beam axis and the scanning element, which is a thin wire. An energy-dispersive detector is used to register CXR spectra, which makes it possible to separate the signals from different scanning elements according to the radiation energy.

DESIGN

The device and appearance of the proposed wire scanner, shown in Fig. 1, is the result of a continuation of works [25–27] devoted to particle-beam diagnostic systems. The scanner contains four scanning elements made in the form of wires with a diameter of about 0.1 mm, bent in the shape of "V." The wires are made of different materials (titanium, copper, molybdenum, and tungsten) and are fixed in fork-shaped aluminum

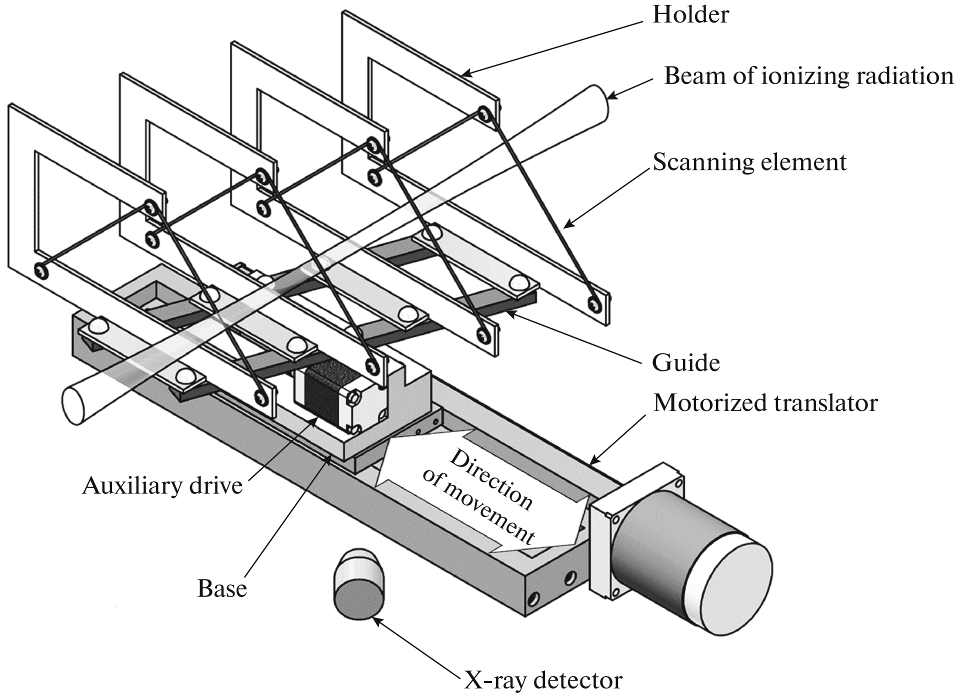

Fig. 1. Appearance of the wire scanner.

holders, the planes of which are always oriented by means of two guides perpendicular to the presumed beam axis. To detect CXR formed in the wires under the action of fast particles, an Amptek XR100SDD semiconductor energy-dispersive silicon detector is used, which makes it possible to measure X-ray spectra with an efficiency close to 100% in the energy range of 2–10 keV. Since CXR propagates isotropically, the detector can be installed at any angle to the beam axis, providing observation of all scanning elements during operation. The simultaneous movement of all scanning elements in the direction perpendicular to the beam axis is carried out using a Standa 8MT175 motorized translator with a minimum step of about 2.5 μm. The distance between the scanning elements, counted along the beam axis, depends on the angle between the beam axis and the guides, which can be changed by means of an auxiliary motorized drive provided in the design.

During scanning, the holders move perpendicular to the beam; each wire crosses the beam twice (Fig. 2). Due to the shape of the wires traditionally used in such devices [28, 29], the beam is crossed in two mutually perpendicular directions, which makes it possible to measure two transverse profiles at once.

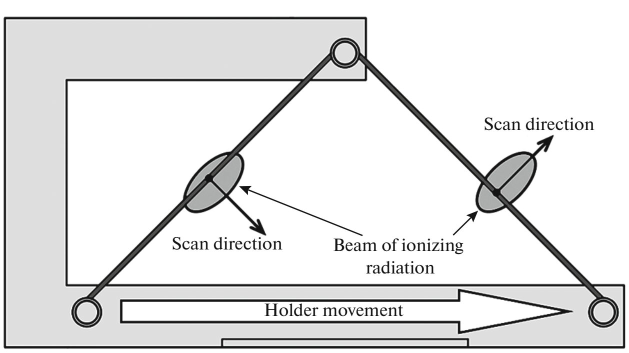

Fig. 2. Scheme for measuring the transverse profiles of the particle beam.

PRINCIPLE OF OPERATION

The interaction of beam particles with the wires is accompanied by the formation of CXR, the intensity of which is proportional to the flux density of the beam particles, and the spectrum contains narrow peaks or lines, the energy of which is determined by the structure of the wire atoms. Figure 3 shows the CXR spectra of the materials used to make the wires. It can be seen that, by measuring the energy of the peak in the spectrum, one can unambiguously determine which wire this peak corresponds to.

To obtain information about the transverse profiles of the particle beam at the location of a particular wire, it is necessary to measure the dependence of the intensity of the corresponding CXR line on the value of the scanner shift as a whole. In the general case, such a

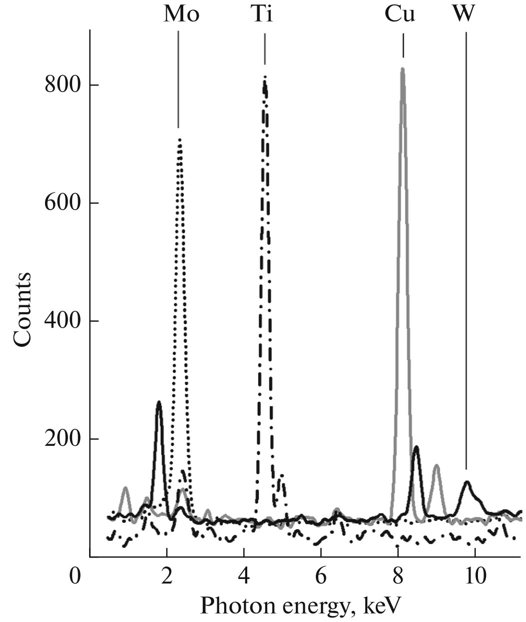

Fig. 3. Spectra of characteristic X-ray radiation measured during scanner operation.

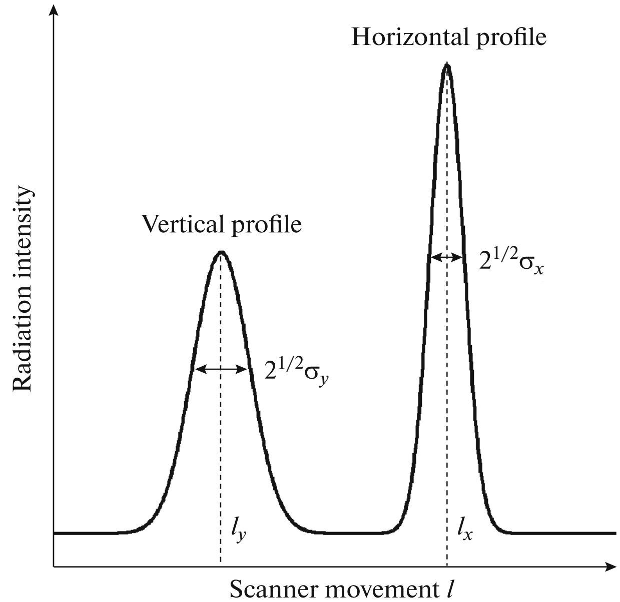

Fig. 4. Example of measured transverse profiles.

dependence (Fig. 4) will have two peaks, the shapes of which correspond to vertical and horizontal beam profiles and contain information about its dimensions σ_x and σ_y, and the positions of the peaks l_x and l_y allow us to calculate the beam coordinates: $x = l_x/2^{1/2} + x_0$, $y = l_y/2^{1/2} + y_0$ (where x_0 and y_0 are constants determined during scanner calibration).

Based on the transverse profiles measured at the locations of the wires, it is possible to determine how the transverse dimensions of the beam depend on the coordinate along the axis z: $(\sigma_i)^2 = A_i(z - z_0)^2 + (\sigma_{i,\,\min})^2$, where $\sigma_{i,\,\min}$ are the minimum beam dimensions, A_i and z_0 are the fitting parameters, and $i = xy$ (Fig. 5). Based on the fitting results, it is possible to estimate the corresponding values of the emittance $\varepsilon_i = \sigma_{i,\,\min}(A_i)^{1/2}$ and divergences $\theta_i = 2\arctan(\varepsilon_i/\sigma_{i,\,\min})$.

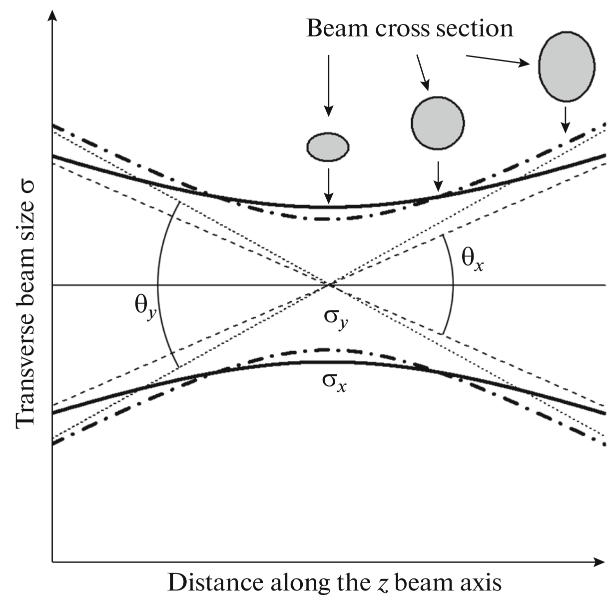

Fig. 5. Spatial characteristics of the beam.

CONCLUSIONS

A wire scanner of the described design was used at the experimental setup of the National Research University BelSU to determine the spatial characteristics of electron beams with energies from 10 to 50 keV, a current of about 1 μA, and a size of about 1 mm. It should be noted that as the energy of charged particles increases, the ionization cross section of atomic shells [30] does not change significantly, which makes it possible to use the developed scanner, among other things, for the diagnostics of ultrarelativistic particle beams both at atmospheric pressure and under high vacuum conditions.

FUNDING

The work was financially supported by a Program of the Ministry of Education and Science of the Russian Federation for higher education establishments (project no. FZWG-2020-0032 (2019-1569)).

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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