Three-dimension tracing on the electron beam in micro-focus and nano-focus X-ray sources

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X-ray radiation has been widely used for imaging since its discovery[1] as its large penetration depth and nondestructive testing. The development of X-ray imaging calls for continual improvement in the micro-focus X-ray source and the newly invented nano-focus X-ray source[2]. Smaller electron beam spot with high current density has been achieved in X-ray tube[2-4] in recent years. Expected X-ray focal spot size, X-ray intensity, X-ray stability fail to be obtained although more attention has been paid on the design and optimization of the transmission target and reflection target[3-5]. Parameters of the incident electron beam are limited to energy, current, and spot size at the target instead of velocity of every electron. Furthermore, ideal Gauss distribution is assumed in simulating the electron bombardment, which is not suitable for all x-ray tubes with different energy and current density. In this paper, three-dimension electron beam current density distribution is obtained through N-body Monte Carlo method and practical 3D incident electron parameters are achieved.

Firstly, the principle of N-body Monte Carlo simulation on all aberrations was researched. Bunches of electrons are created near the 90keV Tungsten gun[6] with random initial positions, directions, kinetic energies and distributions as listed in Tab.1. Secondly, 3D electron trajectory is simulated by solving the Newton-Lorentz equations, where the electric field can include Coulomb interactions among electrons. The spatial field of the lenses is got by second order finite element method and Hermite interpolation[7]. Finally, electrons in a micro-focus source[6] are traced by fifth-order Runge-Kutta algorithm to get 3D current density distribution(Fig.1) and incident beam parameters. In Fig.2, the beam spot is about 1μm under 50μA. Our micro-focus source has a resolution below 4μm(Fig.3) now and will be better with the new 3D incident beam parameters. Also, Coulomb interactions in X-ray source can be obtained by adjusting N when needed.

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Tab. 1 Original parameters of 1mA Tungsten electron gun

Class	Tungsten electron gun
Diameter	15μm with Gaussian intensity distribution
Energy spread	3.528eV, Gaussian distribution
Angular current density	961.3mA/sr, Uniform distribution

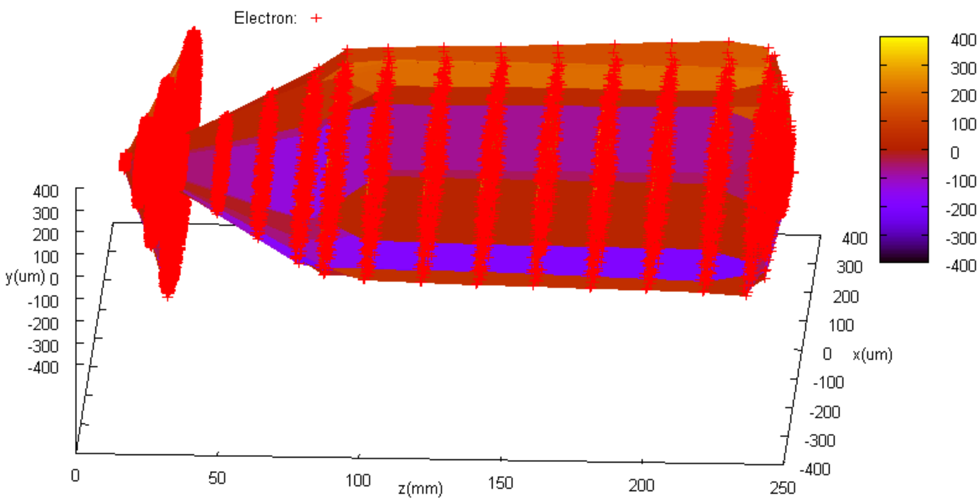

Fig.1 3D beam current density distribution of the micro-focus X-ray source

Tab. 2 Optical parameters of the micro-focus X-ray source

Class	Electron source	Aperture	Lens1	Lens2	Upper surface of Target
Coordinate(mm)	10.859	30.859	85	240.000	247.000

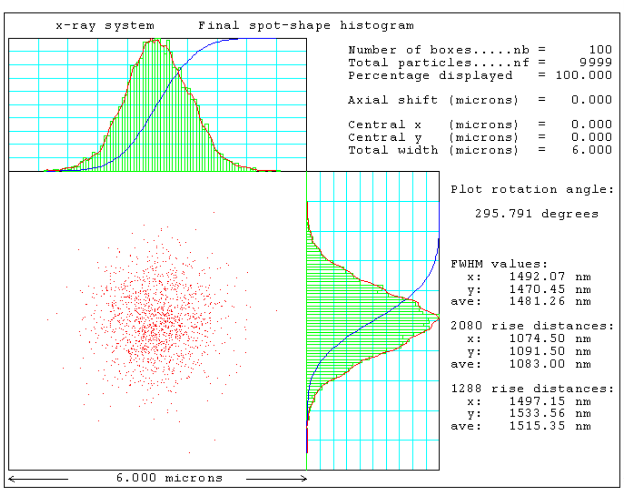

Fig.2 Electron beam current distribution at Target

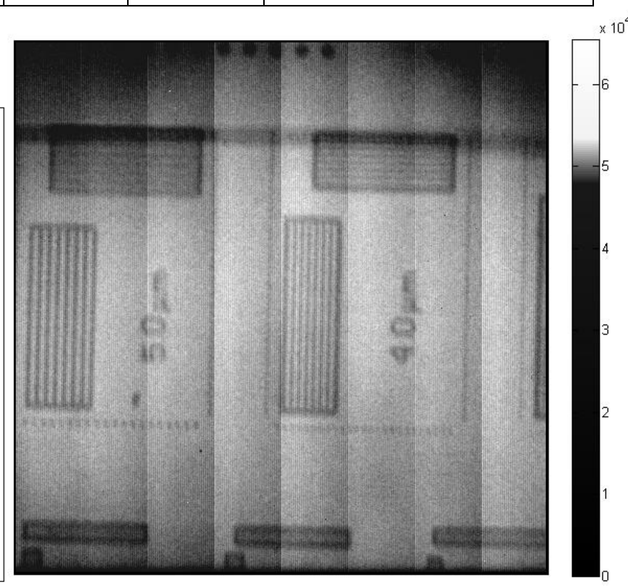

Fig.3 X-ray imaging with a transmission target