Nuclear Instruments and Methods in Physics Research A 802 (2015) 5–9

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Technical Notes

Combined optic system based on polycapillary X-ray optics and single-bounce monocapillary optics for focusing X-rays from a conventional laboratory X-ray source

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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form
25 July 2015
Accepted 18 August 2015
Available online 29 August 2015

Keywords:
Combined optic system
Polycapillary X-ray optics
Single-bounce monocapillary optics
X-ray focusing

ABSTRACT

Two combined optic systems based on polycapillary X-ray optics and single-bounce monocapillary optics (SBMO) were designed for focusing the X-rays from a conventional laboratory X-ray source. One was based on a polycapillary focusing X-ray lens (PFXRL) and a single-bounce ellipsoidal capillary (SBEC), in which the output focal spot with the size of tens of micrometers of the PFXRL was used as the “virtual” X-ray source for the SBEC. The other system was based on a polycapillary parallel X-ray lens (PPXRL) and a single-bounce parabolic capillary (SBPC), in which the PPXRL transformed the divergent X-ray beam from an X-ray source into a quasi-parallel X-ray beam with the divergence of sever milliradians as the incident illumination of the SBPC. The experiment results showed that the combined optic systems based on PFXRL and SBEC with a Mo rotating anode X-ray generator with the focal spot with a diameter of 300 μm could obtain a focal spot with the total gain of 14,300 and focal spot size of 37.4 μm, and the combined optic systems based on PPXRL and SBPC with the same X-ray source mentioned above could acquire a focal spot with the total gain of 580 and focal spot size of 58.3 μm, respectively. The two combined optic systems have potential applications in micro X-ray diffraction, micro X-ray fluorescence, micro X-ray absorption near edge structure, full field X-ray microscopes and so on.

1. Introduction

Single-bounce monocapillary optics (SBMO) mainly include parabolic and elliptical hollow glass tubes which can focus all of the parallel or divergent X-rays satisfying the total reflection condition to the same focal spot position. Moreover, SBMO not only have a large focal distance and high reflectivity, but can be used to obtain a small spot size down to 250 nm by illuminating a still smaller area of the capillary surface with a prefocused beam by a Fresnel zone plate [1]. Based on the positive attributes mentioned above, SBMO have many applications in recent years, such as high resolution micro X-ray diffraction, micro X-ray fluorescence, micro X-ray absorption near edge structure, confocal X-ray fluorescence and micro small angle X-ray scattering [2–6]. Furthermore, SBMO, which provides a hollow-cone type incident beam for the Fresnel zone plate, can be used as condensers for full field X-ray microscopes [7]. However, the ideal incident illumination for ellipsoidal and parabolic glass capillaries is the parallel beam and the divergent beam emitting from the ideal point source, respectively. Therefore, at present, the ellipsoidal and parabolic glass capillaries were mainly used in synchrotron or conventional X-ray source with a micro focus. However, synchrotron radiation facility is so large and expensive that it is not available for conventional laboratory, and conventional X-ray source with a micro focus not only is expensive, but also has a low power, which limits its application ranges.

In order to apply the SBMO in the common X-ray source with both high power and large source spot size, we designed two combined optic systems: one was based on a polycapillary focusing X-ray lens (PFXRL) and SBEC, and the other was based on a polycapillary parallel X-ray lens (PPXRL) and SBPC. Such polycapillary X-ray optics, which works on total external reflection and has also been named the Kumakhov lens, has now been widely used in many fields such as confocal X-ray fluorescence, X-ray diffraction, X-ray absorption fine structure and X-ray imaging [8–16]. Compared with the Fresnel zone plate used in the similar method proposed

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http://dx.doi.org/10.1016/j.nima.2015.08.043
0168-9002/

by Snigirev in 2007, the polycapillary X-ray optics not only have much higher gain and efficiency, but also have more wide bandwidth which given the designed set up the ability to perform Laue micro X-ray diffraction [17]. Moreover, the polycapillary X-ray optics, which was used to combine with SBMO, could be manufactured according to the X-ray source size, focus properties and spectral transmission requirements. So it could be used for different laboratory X-ray sources. In this paper, the properties of the designed combined optic systems based on the polycapillary X-ray optics and the SBMO with the common laboratory X-ray source were studied.

2. Experiment and results

2.1. Experimental setup

Fig. 1 shows the schematic diagrams of the designed two combined optic systems for focusing X-rays based on conventional laboratory X-ray source. Fig. 1(a) was the designed X-ray focusing setup based on the combined optic system of PFXRL and SBEC. In this configuration, the divergent X-ray beam, which was from the X-ray source (S) positioned at an input focal distance L_1 away from the input of the PFXRL, was focused into an output focal spot at output focal distance L_2 away from the output of the PFXRL. The SBEC was placed collinearly to the PFXRL. The output focal spot of the PFXRL worked as a “virtual X-ray source” for the SBEC and was situated in the one focal spot of the SBEC. Fig. 1(b) was the designed X-ray focusing setup based on the combined optic system of PPXRL and SBPC. In this configuration, the divergent X-ray beam from the X-ray source positioned at an input focal distance L_3 away from the input of the PPXRL was focused into a quasi-parallel X-ray beam with the divergence of sever milliradians which was replaced the quasi parallel X-ray beam emitting from the synchrotron radiation as the incident illumination for SBPC. The SBPC was placed 5 cm (L_4) away from the PPXRL. In order to acquire a confined incident illumination, a beam stop with a diameter of 200 μm and a pinhole with a diameter of 400 μm were placed between the X-ray source and the SBMO.

In this experiment, the X-ray source (S) was a Mo rotating anode X-ray generator (RIGAKU RU-200, 60 kV to 200 mA) whose spot size is 300 μm in diameter and the working condition of the X-ray source was 20 kV, 10 mA. Besides, a Cu-target X-ray tube with a source-spot with a diameter of 50 μm was used to compare the performance of the combined optic system of SBEC and PFXRL in laboratory large focus X-ray source with the SBEC single used in conventional laboratory microfocus X-ray source. In order to use the Mo rotating anode X-ray generator to simulate a Cu target X-ray source with a large focal spot, a Cu film was placed between the Mo rotating anode X-ray source and the polycapillary X-ray optics to filter the high energy X-rays. The PFXRL, PPXRL, SBEC, SBPC, pinhole and bean stop were adjusted by the five-dimensional stage with mini step size of 1 μm, respectively. An X-ray HAMAMATSU CCD camera with 6.5 μm pixel size was positioned beyond the capillary used to align the optic and to observe the far-field pattern of radiation of the lens. In order to quantitatively measure the focal spot size, transmission efficiency and gain in power density of the lens, a detector with the energy resolution of 155 eV at 5.9 keV was used in the experiment. The designed parameters of the PFXRL and PPXRL were shown in Table 1. Table 2 showed the designed parameters of the SBEC and SBPC.

2.2. Performance of the PFXRL and the PPXRL for the combined optic systems

2.2.1. PFXRL

The energy dependence of the gain in power density and output focal spot size of the PFXRL is shown in Fig. 2. By placing the CCD camera at the entrance aperture of the SBEC, the cross section image

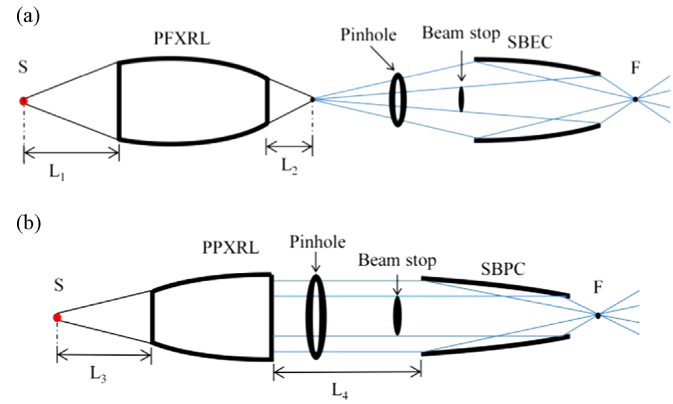

Fig. 1. Schematic diagrams of the two designed combined optic system used in conventional laboratory X-ray source.

Table 1
Designed parameters of PFXRL and PPXRL.

Parameter	PFXRL	PPXRL
Length/mm	65.3	43.7
Input diameter/mm	4.7	3.6
Output diameter/mm	2.1	4.8
Input focal distance/mm	72.3	75.6
Output focal distance/mm	28.7	–

Table 2
Designed parameters of SBEC and SBPC.

Parameter	SBEC	SBPC
Length/mm	30.1	30
Input diameter/μm	400	400
Output diameter/μm	346.4	282.8
Output focal distance/mm	29.9	30

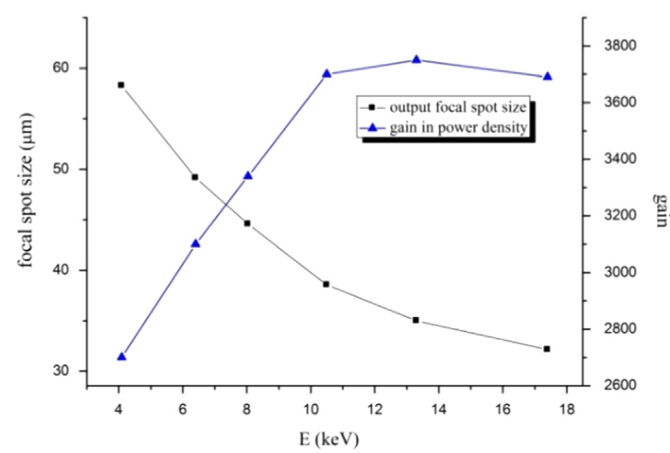

Fig. 2. Energy dependence of output focal spot size and gain in power density for PFXRL.

(Fig. 3) of the X-ray beam emitting from the “virtual” point X-ray source can be acquired. As shown in Fig. 3, a hexagon facula with a brighter center was consisted by many small hexagon faculae. The cause of the formation of such faculae is that the polycapillary was drawing by the compound polycapillaries [18]. There are gaps between the compound polycapillaries, which results in the intensity gap (black sideline of the small hexagon facula in Fig. 3) where X-ray was very weak as the red line shown in Fig. 3. This influences the performance of the SBEC. Considering this factor, when designed the SBEC used in this study, the light blue annulus region in Fig. 3 located in the black sideline should be avoided.