DESIGN OF MULTICHORD SOFT X-RAY DETECTION ARRAYS FOR THE URAGAN-2M STELLARATOR

M.B. Dreval

Institute of Plasma Physics NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine

Two miniature pinhole camera arrays for spatially and temporally resolved measurements of soft X-ray emission have been designed for the URAGAN-2M stellarator. The power of soft X-ray filtered by different filters has been calculated numerically in order to optimize applicability of two foils temperature measurement technique. In the initial operation, a *Be* foil with a thickness of 10 µm and *Al* filter of 3 µm have been chosen to test signal strength and to test two foils temperature measurement technique. SXR photodiodes photocurrent amplifiers with bandwidth up to 5MHz have been designed for signal amplification. Digitizers with 12 bit resolution and sampling rate up to 8 MS/s have been tested for SXR data acquisition.

PACS: 52.55.Hc; 52.70.La

1. INTRODUCTION

In the URAGAN-2M torsatron *R*= 1.7 m, *a* = 0.24 m, $B_t \le 1$ T, two type of RF discharges with low $n_e < 10^{12}$ cm^{-3}, and high densities are induced by frame and strap RF antennas. An application of Thomson scattering (TS) diagnostics is limited in the low density plasmas. Electron cyclotron emission (ECE) diagnostics applications limited by ECE cut-off in the high density case. A multichord soft x-ray (SXR) diagnostics is a robust tool for the plasma profile evolution monitoring and plasma fluctuations studies in wide plasma conditions range. There are no cutoff problems due to the plasma itself, i.e., plasma is optically thin in the range of soft x-rays. The SXR channels have a fast digitizing rate and consequently a high time resolution, crucial for prompt detection of rapidly developing phenomena. Soft x-ray (SXR) arrays provide a line-integrated x-ray emissivity or brightness on a number of viewing chords. It allows reconstruct plasma profile with high special resolution. Relative simplicity and low cost of the SXR diagnostics (to ECE, TS) in addition to its high performance determine its wide application in tokamaks, stellarators, reverse field pinches, etc [1-3]. In addition it is also widely used to evaluate the electron temperature (T_e) by the absorber foil method via soft x ray energy region above 2 keV, where the majority of the soft x-ray radiation comes from the bremmstralung contribution [4-5]. Thick foils (in the 50µm range and higher) are used for such a range. High performance of SXR detector and preamplifiers is required for its application in low temperature and density plasmas. An applicability of thin foils is limited due to strong influence of the spectral lines radiation, however SXR diagnostics based on 0.9/6.15 µm foils can be used for row temperature estimation in a moderate impurities concentration case[4]. Optimization of foils thickness as well as preamplifiers for the URAGAN-2M stellarator is described in present work. In order to increase SXR signal strength and remain its appropriate spatial resolution SXR pinhole camera design optimization for URAGAN-2M stellarator geometry in condition of non-circular rotated in toroidal direction magnetic surfaces has been performed in the present work.

2. ADAPTATIONS OF TWO FOIL TECHNIQUE

The x-ray continuum radiation emissivity by the bremsstrahlung formula for a Maxwellian plasma:

$$\frac{dW}{dE} \propto n_e(r) n_i(r) Z_{eff}^2(r) T_e^{-0.5}(r) e^{-\frac{E}{T_e(r)}} ,$$

where *dW* is the radiation power emitted in the photon energy interval *dE* and n_e, n_i, Z_{eff}, and T_e are electron and ion density, effective plasma charge and electron temperature, respectively. The SXR intensity in a detector defined by integrated along line of sight *l* and photon energies *E* of x-ray continuum emitted by plasma filtered by a foil is given by :

$$I \propto \int_l \frac{n_e^2(l)}{\sqrt{T_e(l)}} \int_E \exp\left[-\frac{E}{T_e(l)}\right] \exp\left[-\frac{\mu}{\rho}(E)\rho \cdot t\right] dE dl,$$

where µ/ρ is the mass energy absorption coefficients of a foil. A dependence of µ/ρ of aluminum (*Al*) and beryllium (*Be*) on the photon energy is not monotonic in a low energy range 10…100 eV [6] as shown in Fig. 1.

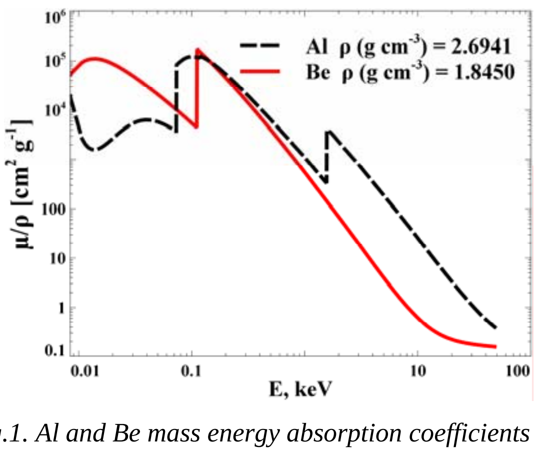
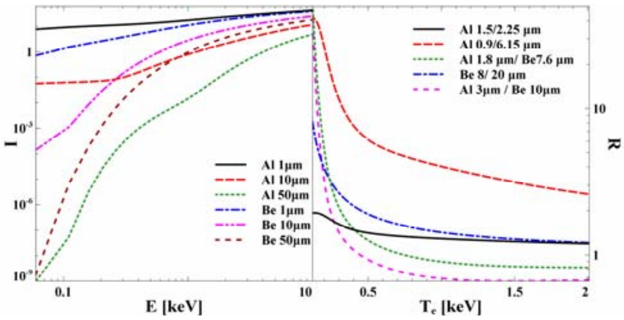


Fig.1. Al and Be mass energy absorption coefficients [6]

The aluminum absorption also has a peculiarity in 1keV range. These peculiarities limit two foils T_e measurement technique for thin foils due to significant impact of the low energy photos. Soft X-ray emission in the plasma includes free-bound recombination radiation, bound-bound line radiation are also introduce photons in the low energy range and affect considered T_e measurement technique.

The x-ray continuum radiation has been calculated numerically using absorption coefficients from Fig. 1 and parabolic and constant densities and temperatures radial profiles. According to the numerical calculations, in a case of 50 μm Be foil filter, sensitivity to the photons below 1keV is considerably suppressed (Fig. 2, a).



a *b*

Fig.2. SXR intensities passed from Al and Be foils (a); ratio of the intensities from different foil combinations(b)

The beryllium filter introduces the energy response closer to the exponential function. Its applications are preferable in that point of view. The energy dependence of SXR intensities ratios from different foils combination are shown in Fig. 2,b. However thin aluminum foils is more common and produces significantly higher signal intensity (lower requirement to the SXR detector and preamplifiers) combination of 1.5/2.25 μm Al foils is not allowed to determine T_e. A higher difference of the foil thickness is required for considerable dependence of intensities ratio R on the electron temperature. The 0.9/6.15 μm Al foils combination considered in [4] allows T_e estimation in moderate impurities concentration case, however influence of spectral linens the 1…200 eV range is high in 0.9 μm Al foil case. The 3μm Al / 10 μm Be foils combination introduces considerable R dependence on T_e in 0.1…1 keV range. Such a combination is proposed for initial SXR signals testing on the URAGAN-2M torsatron. Such foils thickness maintain significant SXR signals form AXUV-20EL[7] detector and 10^5 V/A preamplifier in the case of average electron temperature $T_e \approx 200$ eV and average electron density $n_e \approx 5 \cdot 10^{12}$ cm^{-3}[1].

3. GEOMETRICAL DESIGN

Each miniature SXR camera system is designed so as be inserted through a small, round port with an inner diameter of 4 cm. Each SXR camera array consists of a 20 channel photodiode linear array IRD AXUV-20EL[7] and a pinhole. Figure 3 shows design of the detector head. The front cover consists of two circular disks having pinholes in the middle. Be or Al foil is clamped between the disks. The pinhole and filter assembly can be taken apart from the main camera head, facilitating change in filter thickness or pinhole size. The size of the pinhole and its location relative to the diode array are optimized to cover the whole poloidal cross section and to achieve a good spatial resolution with minimum overlap with nearby channels. Each array consists of 20 fanlike lines of sight.

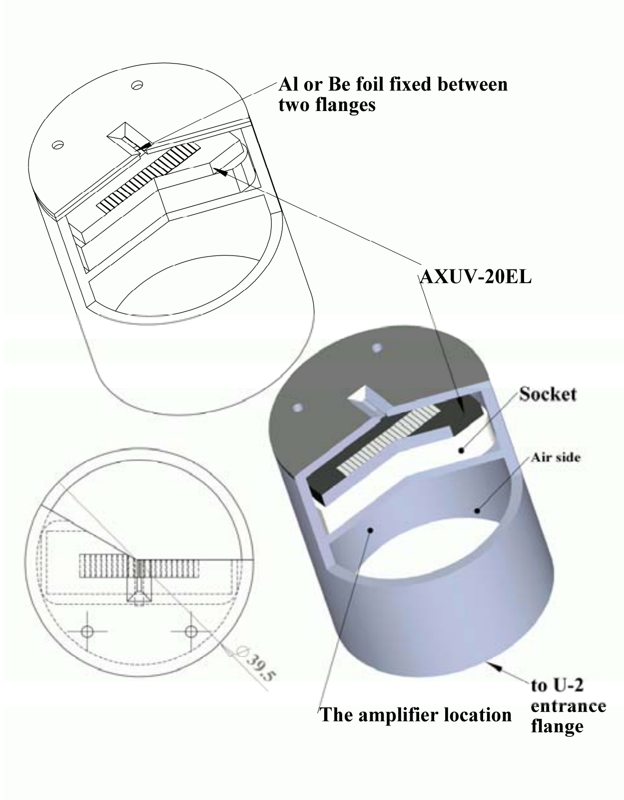


Fig.3. Design of SXR camera head

Fig. 4 shows the lines of sight of two arrays viewing horizontally and vertically across the plasma cross section through two ports separated by 90° the poloidal direction. Each IRD AXUV-20EL array contains 20 rectangular photodiodes, each having a sensitive area of 0.75x4 mm and an active thickness of 35 μm.

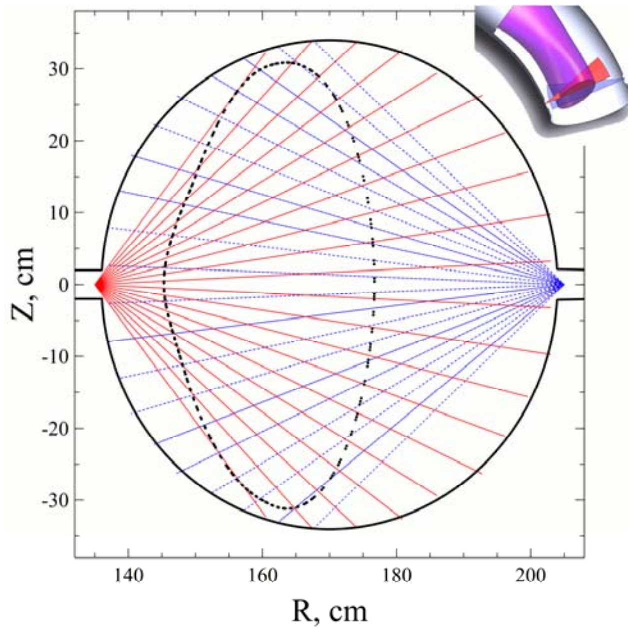


Fig. 4. Lines of sight of the SXR detector arrays across a URAGAN-2M cross section

4. PREAMPLIFIERS AND DATA AQUISITION DESIGN

AXUV-20EL photodiodes have flat response over a wide range from visible light to x-ray and are therefore also suitable for bolometric measurements. High responsivity of 0.275 A/W, low noise and 200 ns risetime allow AXUV-20EL applications in high speed SXR systems. Precision, low noise, 10 MHz bandwidth, small size operational amplifier AD8606 has been selected for SXR diode current preamplifiers. Designed 5 MHz, 10^6 V/A preamplifier has been tested on photomultiplier as a current source on the charge exchange neutral particles diagnostics (CX) and on spectral lines diagnostics on U-3M trorsatron. An example of the testing waveform obtained using the preamplifier is shown in the Fig.5.

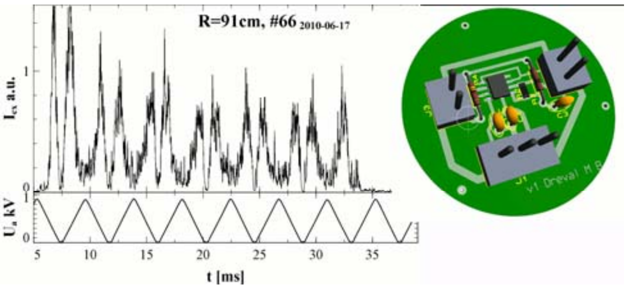


Fig. 5. Preamplifier testing waveform (photomultiplier signal source on charge exchange diagnostics, U-3M torsatron); and its design

The photomultiplier signal (upper Fig. 5) is linked to the CX analyzer sweeping voltage (lower Fig. 5). In the considered design the AXUV diodes are connected in a biased common anode configuration as in [1]. The preamplifiers are placed near the diode assembly, in a air side of a feedthrough connector. Low coast, 12 bit resolution, 16 channels, up to 8 MS/s sampling rate, 1MS/channel on board memory TEREX ET-1255 ADC board [8] have been chosen and tested for the SXR diagnostics.

ACKNOWLEDGEMENT

This work is supported by the STSU project 4216.

REFERENCES

1. C. Xiao,T. Niu, et al.//*Rev. Sci. Instrum.* 2008, v. 79, p. 10E926.
2. S. Ohdachi, K. Toi, et al.//*Rev.Sci. Instrum.* 2003, v. 74, p. 2136.
3. P. Franz, L. Marrelli, et al.//*Phys. Rev. Lett*. 2004, v. 92, p. 125001.
4. S. Morimoto, S. Okamoto, et al.//*Japanese Journal of Applied Physics*. 1986, v. 25, p. 120.
5. Z Xiangju, , H. Liqun, et al.// *Plasma Science & Technology*. 2006, v. 8, N 2, p. 147.
6. http://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html.
7. http://www.ird-inc.com/.
8. http://terex.kiev.ua/.

Article received 28.09.10

РАЗРАБОТКА МНОГОХОРДОВОГО НАБОРА ДЕТЕКТОРОВ МЯГКОГО РЕНТГЕНА ДЛЯ СТЕЛЛАРАТОРА УРАГАН-2М

М.Б. Древаль

Два миниатюрных датчика для измерения временного поведения и пространственного распределения излучения мягкого рентгена были спроектированы для стелларатора УРАГАН-2М. Мощность мягкого рентгена, проходящего через различные фильтры, была рассчитана численно с целью оптимизации применимости техники измерения температуры плазмы, базирующейся на двух фольгах. В начальных экспериментах для тестирования величины сигнала мягкого рентгена и проверки техники двух фольг были выбраны 10 мкм-бериллиевая и 3 мкм-алюминиевая фольги. Были разработаны усилители фототока фотодиода мягкого рентгена с частотной полосой до 5 МГц. Аналогово-цифровые преобразователи с разрешением 12 бит и частотой оцифровки до 8 МГц были протестированы для их применения в диагностике мягкого рентгена.

РОЗРОБКА БАГАТОХОРДОВОГО НАБОРУ ДЕТЕКТОРІВ М'ЯКОГО РЕНТГЕНА ДЛЯ СТЕЛЛАРАТОРА УРАГАН-2М

М.Б. Древаль

Два мініатюрних датчики для виміру тимчасового поводження й просторового розподілу випромінювання м'якого рентгена були спроектовані для стелларатора УРАГАН-2М. Потужність м'якого рентгена, що проходить через різні фільтри, була розрахована чисельно з метою оптимізації застосовності техніки виміру температури плазми, базованої на двох фольгах. У початкових експериментах для тестування величини сигналу м'якого рентгена й перевірки техніки двох фольг було обрано 10 мкм-берилієву і 3 мкм-алюмінієву фольги. Було розроблено підсилювачі фотоструму фотодіода м'якого рентгена із частотною смугою до 5 МГц. Аналогово-цифрові перетворювачі з розділенням 12 біт і частотою оцифровки до 8 МГц були протестовані для їхнього застосування в діагностиці м'якого рентгена.