§9. Imaging of Soft X-ray by Using Soft X-ray CCD Camera

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The soft X-ray CCD camera system has been installed to the tangential port on Compact Helical System (CHS) to measure soft X-ray image with energy resolution. This system consists of pinhole, Be filters, and soft X-ray CCD camera.

The soft X-ray CCD camera is made by Princeton Instruments (model number SX-TE/CCD-1024S) with TEK 1024x1024D frame transfer Back illumination CCD detector (the imaging is 512 x 1024 pixels). To reduce dark current the CCD detector is cooled up to -40 °C using multistage Peltier devices.

The intensity of each pixel is proportional to the energy of X-ray photon, when the flux of the soft X-ray is low enough to the level of one photon per pixel per frame (photon counting mode). The energy resolution of each pixel is calibrated to be 16eV/count using soft x-ray source. The full image is divided to 16x8 sections and one energy spectrum is derived from each section(64x64 pixels). The integration time of CCD is ~1.4s with 100kHz A/D rate. Since CHS discharge length is ~150ms, x-ray photons of whole discharge are integrated in one frame and there is no time resolution. When the soft X-ray flux is much higher than the level of photon counting mode, the intensity of each pixel is proportional to the total X-ray energy (photon energy x number of photons). By assuming the total X-ray energy is constant on magnetic flux surface, the shape of magnetic flux can be reconstructed from the soft X-ray image.

There are four sets of pinhole with different diameter of 0.03mm, 0.1mm, 0.3mm and 1.0mm, respectively, to adjust the flux of soft X-ray. These pinhole disks are made of Tungsten with thickness of 0.5mm. Since the pinhole disk is too thin to stop the hard X-ray (>30keV), 12-mm-thick Tantalum mask (V-shape hole) with pinhole diameter of 0.5mm had been installed in front of the pin hole disk. The spatial resolution is determined by the size of pinhole, and it is 7.5 mm at the plasma for the 0.3mm pinhole (The spatial resolution of CCD itself is 0.6 mm in the plasma).

Between the pinhole and the CCD surface, six Be filters, of different thickness of 10μm, 30μm, 70μm, 140μm, 300μm and 800μm, respectively, are mounted on the rotating filter disk. The X-ray flux is adjusted to the level good for the imaging mode or the photon counting mode by choosing various combinations of pinhole and absorber foils.

The contour plot of soft x-ray imaging of CHS plasma with vacuum magnetic axis of 92.1cm and the magnetic field of 1.7T is shown in Fig. 1. The diameter of pinhole and the thickness of Be filter are 0.3mm and 70μm, respectively. The target plasma for NBI is produced by ECH for t=15-45ms and NBI is injected from t=35ms to 185ms. The central electron temperature measured with YAG Thomson scattering is 0.69keV and the line averaged electron density measured with FIR is ~$1.5\times10^{19}m^{-3}$ at 60ms. Steep gradient of x-ray intensity at R=80cm indicates the shadow of inner wall, which gives the excellent reference for the position.

The soft X-ray energy spectrum measured with soft x-ray CCD camera near the center of CHS plasma (indicated square box in Fig.1.) is shown in Fig. 2. The target plasma is produced by ECH for t=20-30ms, then NBI and ECH are injected from t=35ms to 185ms and from t=50ms to 110ms, respectively. The spectrum was averaged through 6 reproducible shots with 0.3-mm-diameter pinhole and 800-μm-thick Be filter. The strength of magnetic field is ~0.9T, the vacuum magnetic axis is 92.1cm, the central electron temperature measured with YAG Thomson scattering is 0.92keV and the line averaged electron density measured with FIR is ~$0.6\times10^{19}m^{-3}$ at 110ms. The peak at ~4.5 keV show the titanium kα line.

This diagnostic system provides a useful tool to measure the 2-D soft X-ray intensity, electron temperature and information of high energy tail with good spatial resolution.

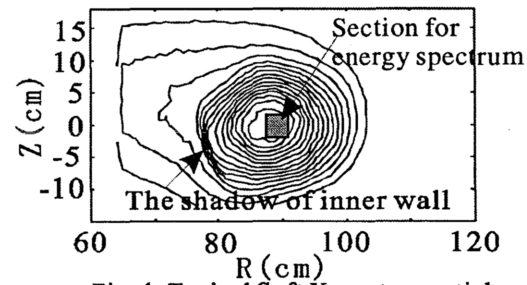

Fig. 1. Typical Soft X-ray tangential image of CHS plasma

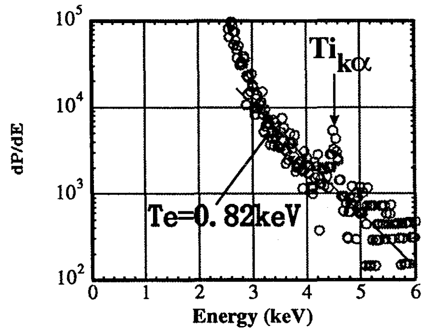

Fig. 2. Typical Soft X-ray energy spectrum of CHS plasma along the center chord.