II. 4.  Beam Diagnosis System of the Beam Line for the Francium Production

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The preparation of the experiment on the search for an Electric Dipole Moment (EDM) of the francium (Fr) atom is now in progress at CIRIC. The key point of the successful experiment is to construct a high intensity Fr source (surface ionizer) with a production rate more than $10^6$ particles/s to realize the high accuracy measurement. The Fr is produced by the nuclear fusion reaction of $^{18}$O+$^{197}$Au $\rightarrow ^{210}$Fr+5n, and the beam transport of the primary beam $^{18}$O with high transmission efficiency is quite important to utilize the full beam for the Fr production. Also we need to measure the beam energy spread and beam profile on the target to estimate the Fr extraction efficiency at the surface ionizer. The 34 course at the target room 3 is now upgraded for the EDM experimental project.

To fulfill the requirements mentioned above, two kinds of beam optics are designed as follows. The ion optics calculations have been done by the computer code TRANSPORT.

1. Achromatic mode: In this mode, the beam is doubly focused at the focal plane, where the target of the surface ionizer is installed. The beam size should be less than 5 mm, which is the effective hole size of the high temperature oven of which the target is located in the middle. The beam size also has to be adjusted by the small elements of the quadrupole magnets in the beam line. The ion optics is shown in the Fig. 1.

2. Dispersive mode: The beam energy spread is measured with this mode. To monitor the energy resolution of the extracted beam, this beam line is utilized as a high resolution monochromator with a maximum dispersion of 1100 mm and the horizontal and vertical magnification of about 1 at the focal plane. The beam viewer with ZnS is placed there and the beam profile is measured with the combination of the CCD camera and frame grabber.
module described below. The ion optics is shown in the Fig. 2. Not only the focal plane at the target position, but also the point in the beam line shown as ALM-J becomes the focal plane with the dispersion of about 600 mm. The ion optics can be checked with the measurement of the horizontal length of the beam profile at the ALM-J and the target position.

In these two modes, we do not have to change the polarity of all the quadrupole magnets located in the beam line. The Fr fusion reaction produces many neutrons at about 5 MeV in the target area. At these energies, neutrons pose a significant radiation hazard, and can be quite severe to the detector. In order to realize the neutron free environment, we should move the Fr from target area as an ion and transport it to the trapping room, located away behind a thick concrete wall in the next stage. The beam profiles for the achromatic and the dispersive modes are shown in the Fig. 3. The requested beam optics is achieved based on the ion optics calculation described above. The energy spread was estimated about 0.5 % from the beam profile size in the dispersive mode.

The beam profile monitor using the CCD camera and frame grabber module is prepared for the accurate beam intensity and profile measurement. The beam intensity is measured by the CCD camera with the brightness of the ZnS viewer. The output signal of the CCD camera is transferred to the frame grabber module installed into the PCI bus at the windows computer. The image data has the $512 \times 512$ pixel data with 8 bit depth showing the image intensity. These image data is analyzed in real time to extract the horizontal and vertical beam distribution. To reduce the noise in the obtained image, the background image, which means the image taken at the beam ‘off’ period, is subtracted from the image at the beam ‘on’ period with the first image processing, so that only the beam profile is extracted for the further detailed analysis. The typical image data is shown in the Fig. 4. The length of the horizontal beam profile corresponds to the beam energy spread in the dispersive transport mode. The linearity of the beam intensity to the light output measured with this detector system should be studied in more detail and now in progress with the comparison to measurement by the imaging plate.
Figure 1. The achromatic mode. The beam is doubly focused at the target position.

Figure 2. The dispersive mode. The beam is focused at the target position and also ALM-J.

Figure 3. The beam profile at the target position. The left is for the achromatic mode, and the right is dispersive.

Figure 4. The horizontal and vertical projection image of the beam profile. The left plot shows the focusing beam and the right is the defocusing beam. The beam structure can be seen clearly.