

Fast optical spectrometer for the charge exchange diagnostic on RFX-mod.

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Introduction.

Improved understanding of transport processes in magnetically confined plasmas calls for better space and time resolved measurements of the relevant parameters for comparison with the theoretical predictions. A new diagnostic neutral beam injector (DNBI) [1] has recently been installed on the reversed field pinch RFX [2]. The main purpose is to study the radial distribution of the flow fields, of the ion temperature and of the impurity densities via the analysis of the charge exchange emission lines of intrinsic or deliberately injected impurities. The detection of charge exchange radiation is known to be a challenging exercise when diagnostic beam injectors are involved due to the relatively low ion currents that such sources deliver: around 5-6 A in the case of the RFX DNBI with current density around 200 mA/cm². The spectrometers devoted to the spectral analysis have therefore to feature large apertures to optimize light collection, good imaging quality to allow multiple input fibers and also high spectral resolution when relatively low temperature and flow velocities are to be measured, as is the case of RFX. High speed, little aberration and good spectral resolution are colliding requirements and some compromise has to be accepted.

In the recent literature the last advances in the field, applied to charge exchange measurements or to passive spectroscopy especially at the edge of the plasma, are based on holographic transmission grating spectrometers [3-6]. Such instruments offer excellent performances in terms of resolving power (5000-15000) and apertures (f/3-5) with some limitations depending on the specific solutions.

An alternative solution is represented by spectrometers based on echelle gratings, quite popular in the astronomic field, which also offer high performance in terms of resolving power, with $\lambda/\Delta\lambda > 200000$ [7,8]. In fusion research this solution has permitted to reach a spectral resolution of 0,05 Å, with an aperture f/3 [9].

The spectrograph.

Considering that most of the charge emission lines of interest in our case are emitted in the visible range between 450 and 540 nm, (C VI at 529.5 nm, He II at 468.5 nm, B V at 498.0

nm and H β at 486.0 nm) we have decided to design and build a spectrometer based on a large, high resolution plane reflection grating and a relatively long focal length photographic objective lens. The grating (by TYDEX, St. Petersburg, relatively cheap despite its dimensions) has 3000 g/mm and a clear aperture of 143 x 180 mm². It is placed on a high precision rotating turret equipped with a computer controlled stepper motor. The mount is in the Littrow configuration (incident and reflection angles, α and β respectively, are almost coinciding) so that one single lens is used and the anamorphism factor ($\cos \alpha / \cos \beta$) is optimized. A sketch of the spectrograph layout is given in Fig.1. The main topological problem with the Littrow mounting arises from the fact that the detector and the input slit should lay as close as possible to each other to preserve the aperture of the system as well as its imaging properties that are optimum on the axis of the lens. A miniaturized entrance slit

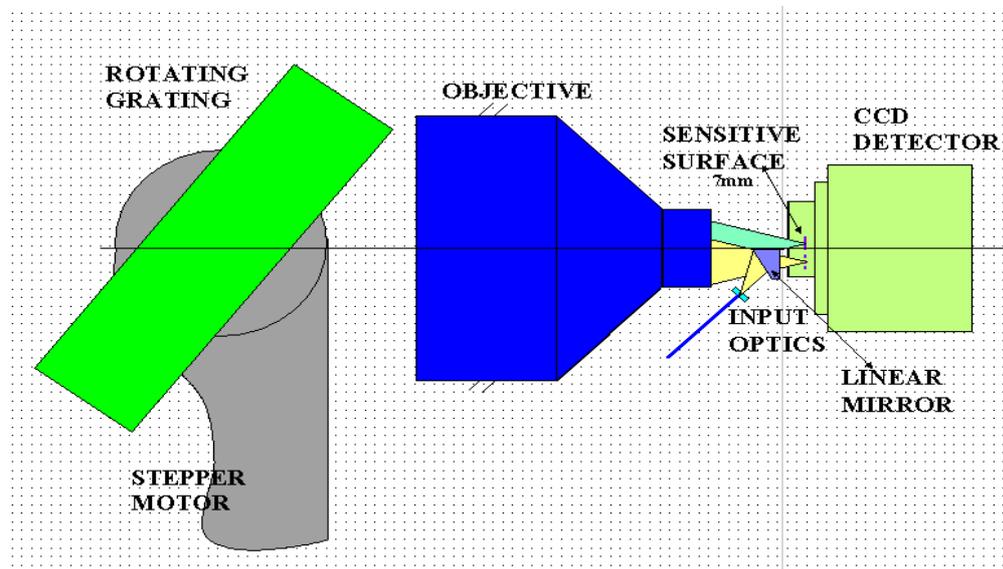


Fig.1 sketch of the spectrometer layout.

aims at the collimating lens through an aluminum-coated deflecting mirror, also miniaturized, to minimize the distance between entrance slit and detector on the focal plane and in such a way as to avoid detector vignetting. The manufacturing characteristics of the mirror lead up to a reflectance of the incidence light higher than 90%. Baffles are placed between slit and deflecting mirror to limit the aperture of the input fibers (approx $f/2$) and match that of the spectrograph ($f/3.1$) to minimize stray light. The objective lens is a commercial 400 mm $f/2.8$ NIKON telephoto lens with high transmission efficiency (at 500 nm). The detector is a two-dimensional back-illuminated Peltier cooled CCD camera (Micromax 512 EBFT-Roper Scientific). The 512 x 512 pixels (with a size of 13 μm^2) give a corresponding 6,7 x 6,7 mm² detector area. Input fibers are now coupled directly to the entrance slit. Telecentric fiber to

spectrograph aperture matching can be easily introduced at the expense of the number of plasma chords that can be monitored. Also, various fiber diameters are available for use and the final choice will depend on the actual signal level that will be found on the experiment. All of the supporting structures are made of black-anodized aluminum. The optics and the detectors are positioned on a standard honeycomb blackened stainless steel optical bench, large enough to accommodate all the elements. Stops are placed in various positions to prevent stray light from various orders reaching the detector after multiple reflections.

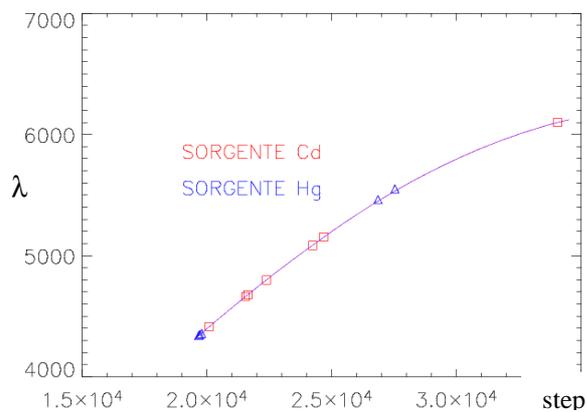


Fig. 2. Relationship between incident angle and selected wavelength for a Littrow mount and a 3000 g/mm grating .

The detector quantum efficiency at 529 nm is about 90%. The ADC conversion of a single pixel is of 1 Mhz and the dynamic range is 14 bit. The sampling rate for input fibers can be as high as 500 Hz, where in any case smearing across the detector is to be taken into account. The use of a high density grooves grating implies that large incident angles are to be used (e.g. 52 ° at 529 nm), which also maximizes the grating efficiency [10]. The resolving power is higher than 8800 at 529.0 nm and with an input slit of 100 microns. The dispersion curve has been found (Fig.2), utilizing two different sources (Cd and Hg). It has been possible to see the lines of the Hg lamp from 4216,74 Å corresponding to an angle $\vartheta=39,28^\circ$ till the line of Cd 6099,142 Å corresponding to $\vartheta=66,32^\circ$. The spectral dispersion

has been calculated equal to 0,08 Å/pixel at the reference line of 4600 Å; this dispersion value ensures the possibility to have a spectral window of about 40 Å with a single CCD image for

Performance.

The effective aperture of the spectrometer in the wavelength range of interest is f/3 at 529 nm and is limited by the grating itself. For some of the viewing chords the aperture is actually limited by the optics on the machine front-end optics, where, due to access geometry, the f/# can be as high as 5. The transmission of the objective lens in the wavelength range of interest has been measured equal to 83%. The grating efficiency at 500 nm is greater than 50%.

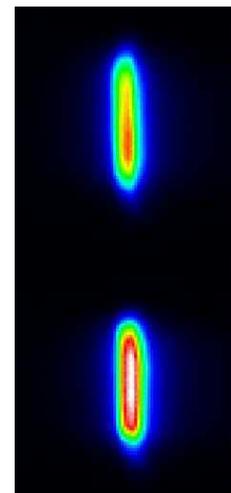


Fig.3 Spectrally resolved CCD image of the two fibers utilized for the test.

those wavelengths. An example of the imaging quality of the system is given in Fig. 3 where the spectrally resolved CCD image of two fibers stacked one on top of the other is shown. The width of the Cd line 5085 \AA captured by means the CCD and calculated with a routine that reconstruct the Gaussian shape of the distribution light, is 8,5 pixels as expected for an input slit of $100 \text{ }\mu\text{m}$. The height of the CCD image is 47 pixels, consistent with the dimension of the fiber diameter ($600 \text{ }\mu\text{m}$). The shape of the spectral line from a Cd source is shown instead in Fig.4. The resolution at the reference Cd line of $5085,822 \text{ \AA}$ is $0,64 \text{ \AA}$. The cross talk between the two fibers is totally negligible. We expect an accuracy in the determination of the position of the Gaussian curve centroid of the order of 0,1 pixel, associated to an uncertainty of $0,008 \text{ \AA}$ at that reference wavelength. This value naturally depends on the optics alignment, not optimized yet and on signal/noise ratio. This uncertainty corresponds to an error in the determination of the velocity flow, calculated with Doppler effect, of $0,5 \text{ km/sec}$ for the elements in the spectral range of interest. These results have been reached with a provisional mounting, so we expect that there will be some improvements with the definitive configuration.

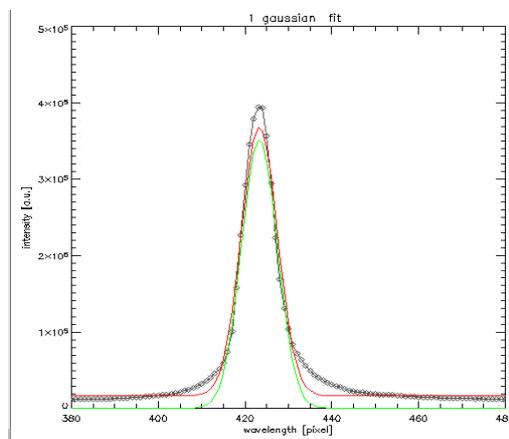


Fig.4. The shape of the spectral line (Cd $5085,822 \text{ \AA}$) obtained with a Gaussian fit.

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