§2. Absolute Electron Density Measurement Based on Nitrogen Gas Rayleigh Scattering Calibration

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In order to deduce the absolute value of electron density (ne) from the Thomson scattered (TS) light signals obtained by injecting an intense laser beam into a plasma, we have to know many involved parameters such as the scattering length, the solid angle of the light collection optics, the transmittance and reflectance of the optics, the sensitivity of photo detector, and so on. It is difficult, if not impossible, to precisely estimate these parameters separately. Moreover, the resulting conversion factor obtained by multiplying these many parameters is hardly precise. This difficulty is usually solved by applying Rayleigh or Raman gas scatterings: Thomson, Rayleigh and Raman scattering signals are proportional to many common parameters. The Rayleigh scattering seems to be better than the Raman scattering since the scattering mechanism is similar to TS and hence the interpretation of the result is simple, but it is very hard to pursue in the presence of intense stray light of laser wavelength; the weak scattered signal is deeply buried in the intense stray light. This is particularly the case in the heavily obliquely back scattering configuration adopted on LHD. The wavelength shifted Raman signals may be detected even in the presence of intense stray light if the spectrum-channel lying closest to the laser wavelength can catch the Raman signals, while rejecting the stray light. This situation depends on the magnitude of the wavelength shift and the blocking power at the laser wavelength of the used interference filter. We tested hydrogen Raman -which has the largest wavelength shift- calibration in CHS, which was a pilot machine of LHD, and obtained a satisfactory result. Based on this result, we designed and constructed 200 polychromators for LHD TS.

After the completion of design and construction of the polychromators, it was suddenly determined without any scientific explanation to inhibit to fill hydrogen gas in the LHD chamber. We were forced to try several alternative methods to do absolute calibration. For several years after the start of the LHD experiment, we tried nitrogen Raman scattering, which has a shorter wavelength shift. Though the Raman scattering signal from each polychromator was linearly proportional to the filling pressure indicating the calibration was well done, the ne profile obtained by using these calibration factors became highly irregular from channel to channel. We guessed that a small part of the nitrogen Raman signals was caught by the #1 color-channel at the right wing, and hence the magnitudes of the measured or the expected signals are very sensitive to the spectrum shape of the #1 color-channel, which is highly subject to environment temperature and the method of wavelength calibration. Thus thinking, we replaced the #1 filter with that with a wider pass band to catch more Raman signals. But, no appreciable improvement was obtained. Next, an idea of using a high-pressure low-laser-energy Rayleigh scattering came to our minds: The Rayleigh scattering signal is proportional to laser energy times gas pressure, while the stray light is proportional to the laser energy; Rayleigh signal surpasses the stray light signal at a higher gas pressure. We had two options: the first is to install a new laser whose wavelength lies on the existing color-channel; the second is to add to each polychromator a new color-channel #6 dedicated to Rayleigh scattering (1064 nm). Thinking the first option is easier, we installed OPO laser, whose wavelength is tunable to fall into any spectrum channel. After two years trial, we found it difficult to make the OPO laser beam transport a long distance and fit it to the YAG laser beam path used for TS in the LHD chamber. Moreover, the OPO laser output was not stable enough. In 2006, we moved to the second option. We installed a new color channel (#6) to ten polychromators as a feasibility test.

Injecting ~1 mJ YAG laser into the LHD chamber filled with several tens of kPa nitrogen gas, we surely observed Rayleigh scattered light, which were proportional to filling pressure. However, the ne profile was not so good. In 2007, we installed the refined #6 color-channel (1064 nm) to 144 polychromators. The necessary 144 APDs were prepared by disassembling 29 unused polychromators, and we newly purchased 1064 nm interference filter in May 2007. The ne profiles, thus first observed, were not of good quality: There were some channel-to-channel irregularities in shape and the right-left asymmetry. Through patiently examining raw data, we found several problems resulting to a poor calibration: one was very intense stray light entering from the side of fibers, which drives the APD circuit almost out of its dynamic range for long time; the second it the pointing stability of the laser beams, which leads to the right-left asymmetric ne profile. Solving these problems year by year, we finally reached a point where we can compare the line integration of ne along the major radius with the interferometer data, giving agreements within 20% discrepancies. An example is shown in Fig.1. The ne profile is sill irregular channel to channel. It seems necessary to further improve the laser beam quality such as the pointing stability, the beam profile and the polarization state.

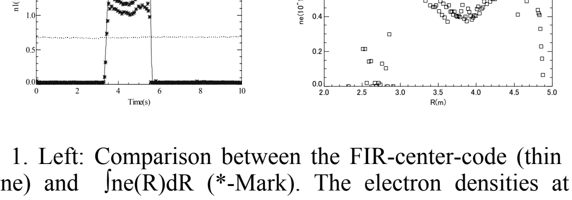

Fig. 1. Left: Comparison between the FIR-center-code (thin solid line) and ∫ne(R)dR (*-Mark). The electron densities at 144 points are absolutely calibrated using Rayleigh scattering. Two laser beams with different energies are injected. The calculated ne-line- integral is systematically larger than the FIR data by 10-20%. Right ne-profile at time= 4s. The left side data points are degraded by the intense stray light.