PFC/JA-96-14

Time-of-Flight Neutral Particle Analyzer for Alcator C-Mod

R.L. Boivin, M. Koltonyuk, C.P. Munson[1], R.M. Mayo[2]

May 1996

[1]Los Alamos National Laboratory, Los Alamos, NM 87545.
[2]North Carolina State University, Raleigh, NC 27695-7909.

Submitted to Review of Scientific Instruments.

This work was supported by the U. S. Department of Energy Contract No. DE-AC02-78ET51013. Reproduction, translation, publication, use and disposal, in whole or in part by or for the United States government is permitted.

A neutral particle analyzer, based on the Time-Of-Flight (TOF) technique is scheduled to be installed on the Alcator C-Mod tokamak. The instrument was originally designed and used in the ZT-40 experiment, and later, briefly used on the CTX experiment at Los Alamos National Laboratory. The design consists of a chopper wheel mounted on a turbomolecular pump, a ~2m long flight tube, a CuBe secondary electron emitting surface and an electron multiplier, which together are used as the neutral particle detector. Among the changes introduced in the system from the original design, of particular interest is the location of the instrument. The instrument is mounted behind a magnetic-type neutral particle analyzer and shares the same line of sight. Both of them can be scanned, poloidally down to the X-point and tangentially to R/R_o=0.7 . This will enable us to compare neutral flux through 2 different techniques with an overlap in energies from ~0.5 - 4 keV, with the instrument capable of detecting neutral particles with energies as low as ~20 eV. This should aid in characterizing neutral and ion behavior at the edge of the tokamak plasma, especially near the X-point. We will also describe changes made to the controls for improved versatility and ease of operation.

I. Introduction

Alcator C-Mod is a compact, diverted tokamak, with high magnetic field, high density and high power density (ohmic and ICRF). One of the key aspects of our program resides in the study of divertor dynamics, including the study of the edge near or at the separatrix. It also has a natural applicability to the study of H modes, which are essentially an edge phenomenon. The measurement of escaping neutral population and its energy dependence is particularly important and can lead to a better understanding of the dynamics of neutrals and ions near the edge. However, the energy range of interest for edge populations (~250 eV and below) cannot be seen by a standard neutral particle analyzer based on a stripping cell technique. At those energies, the stripping efficiency of deuterium or hydrogen on helium is too low to receive appreciable signal for good statistics. Consequently, we are reverting to the well-known technique of time-of-flight spectroscopy[1–4] to extend our neutral particle spectroscopy to lower energies.

The time-of-flight (TOF) technique consists in measuring the particles energy distribution based on their drift time along a known distance. A fast rotating chopper (with an open duty factor of less than 1%) allows neutral particles to pass only during a very short time period. The particles are then allowed to drift along a flight tube and are detected at the other end, usually by an electron multiplier, micro-channel plate or similar instrument. For neutral particles of low energy, the detection efficiency can be quite low and it is usually necessary to go through an intermediary such as forming secondary electrons from a Cu-Be surface. It is also important to restrict the neutral particles to only one species as this technique can not discriminate between different mass particles such as hydrogen and deuterium.

The instrument described here has been developed and used on ZT-40M[5] and CTX,[6] both located at LANL. However, some key features have been modified for its installation on Alcator C-Mod and will be described below.

II. Diagnostic Description

A. Vacuum

This neutral particle analyzer consists mainly of 3 components, a particle chopper, a flight tube and the detector assembly. The chopper is a flat titanium alloy (Ti-6Al-4V) disk, 26.67 cm in diameter and 0.0254 cm thick. The wheel is mounted on a Leybold NT-150 turbomolecular pump, which nominally rotates at approximately 360 rev/sec. The pump controller has been slightly modified to allow for control of the pump speed. The bearings of the pump were also retrofitted with ceramic components, eliminating the need for oil changing, reducing stress on the internal components and allowing the pump to run in any orientation. In principle, the instrument can be mounted at any angle (from horizontal to vertical) but care must be taken that the wheel itself is appropriately supported. Since the maximum inclination of the instrument will be less than 13° from a vertical position (the chopper being nominally vertical), we do not believe that any additional support would be needed in our application. The chopper wheel consists of 16 radial slits (2 cm x 0.0254 cm), located 0.85 cm away from the outer edge. The wheel is placed behind a single stationary slit (2 cm x 0.0254 cm), which acts as a collimator and a vacuum break between the instrument and, in this case, the other diagnostic (or the tokamak vacuum vessel, in normal applications). With the stationary and chopper slits of same sizes, the temporal acceptance is mainly triangular (with very small corrections due to the circular nature of the chopper) with a half opening time of $\sim$ 0.9 μsec. Opposite to the neutrals path, 180° away from the stationary slit, a HeNe laser beam is projected through the chopper slits onto a photodiode (fiber optic receiver HP model HFBR-2402), allowing monitoring of the chopper speed. Originally, this was intended to be used also as the time fiducial, but because of small jitter and precision in alignment, the use of the UV pulse from the plasma through the slits was found to be more reliable (see Section C).

Once the neutral particles passed through the stationary slit and the chopper, they drift down the flight tube ($\sim$ 2 m long), which is 3.5 cm in diameter (inner). Background pressures are kept low ($\gtrsim 10^{-6}$ torr) with the use of a turbomolecular pump (Balzers 510), and with the chopper pump itself, which keeps most of its pumping efficiency, even with the presence of the chopping wheel. The low pressure is needed for good neutral transmission and for arc prevention in the detector. The pressure is monitored near the detector with a Granville Philipps nude gauge, interlocked with the High Voltage circuitry to protect the detector against arcing.

Since neutrals with energies as low as 20 eV are difficult to detect, we use a Cu-Be plate (3.81 cm diameter) to generate secondary electrons which are then accelerated towards a 20 stage electron multiplier (Johnston Labs

MM-1). The copper plate is tilted approximately 10° from the flight tube axis (see Fig. 1), and is mounted directly above the electron multiplier whose axis is perpendicular to the flight tube.

B. Mechanical support

One of the key features of this diagnostic will be its mounting in "parallel" with a magnetic-type (E||B) neutral particle analyzer (see Fig. 2). The existing high-energy neutral particle analyzer[7] is mounted on a cradle which allows the line of sight to be scanned between shots poloidally from the midplane down to near the X-point, and toroidally from perpendicular to a tangential view of R/R_o=0.7. This analyzer has a built-in port in the back which views through the beamline and the stripping cell, which is sometimes used for measuring unstripped particles. In our case we are planning to attach the time-of-flight on that open port. In principle, we should be able to measure the neutral particle spectrum, from 20 eV, to up to 300 keV, on one line of sight. Since their energy range overlaps between 0.5 to 4 keV, it should also be possible to cross-calibrate the analyzers, obtaining a better handle of the escaping neutral particle flux and power. However, it may be necessary to decrease the stripping cell pressure in order to limit attenuation of the low energy particle. Since the pressure is remotely controlled, it would be a relatively easy operation to switch from one instrument to the other.

C. Electronics

The TOF detector is nominally configured for current mode, where the anode is at ground and the first stage typically biased between -1.7 kV and -2.5 kV, although designed to go as "high" as -3.5 kV. A 5 kV negative power supply (Bertan model 502C rated at 2 mA) is used for both Cu-Be plate and multiplier. The multiplier signal is processed through a pre-amplifier (fast current to voltage converter at 6 MHz) and directed to a fast CAMAC transient digitizer (TRANSIAC 2008 with 256 kB or LeCroy 8818 with 2 MB of memory). Since the detector assembly has a direct line of sight with the plasma, care must be taken that the electron multiplier does not saturate due to the brief pulse of UV light during slit alignment. Since the multiplier has a relatively long saturation recovery time ($\sim$ 100 μsec), the Cu-Be bias is reversed from the normal negative -300V (with respect to the multiplier first stage) to positive 100V during the expected UV pulse. The switching is done, using high speed, high voltage transistor (model STI-70) with a time constant of $\sim$ 0.2 μsec. Despite care taken to gate the detector and avoid saturation on the UV pulse, some UV light signal is still evident and can be utilized for several purposes. Firstly, it serves as the time fiducial ($t = 0$) for the particle drift times, and provides the triggering for the high-voltage circuitry based on the rising edge of the pulse. Finally, it can be used (at low gain) to verify the acceptance function of the slit assembly by looking at the time dependence of the UV signal.

Since we are mostly interested in the lower part of the energy spectrum ($\sim$ 250 eV or less), it may be necessary to increase the gain (i.e. HV) on the multiplier. However, the multiplier may now saturate on the neutral signal as well (see Fig. 3) originating from the "bunched" high energy end of the spectrum. Consequently, we modified the HV circuitry to allow for an external output determining the delay in the HV switching from the nominal t=2-3 μsec, to as high as t=100 μsec. Naturally, the maximum time allowed should still be lower than the maximum particle drift period, which is around 175 μsec, as determined by the chopper wheel rotation speed and the number of slits. The lower limit in time delays also defines the maximum detectable energy, which is approximately 4 keV for deuterium in the nominal setting.

III. Expected signal levels

The calculations leading to the signal levels for the analyzer involve many parameters, of which some are not very well known, such as the neutral density profile inside the plasma. Coupled to uncertainties in ion density and temperature profiles, the uncertainties in escaping neutral flux, both in magnitude and in the spectral shapes are rather high, potentially up to a few orders of magnitudes. However, we dispose of a few measurements, one with the TOF instrument on CTX, and with the high energy analyzer on Alcator C-Mod. If necessary, we can increase the signal levels by increasing the slit dimensions, reducing the chopper speed, plasma-chopper distance, but usually at the expense of resolution, mainly in particle energy.[8] However, the most powerful knob resides in the electron multiplier gain, adjusted by the HV bias, which has a range from unity up to 10^7. For example, with a bias of $\sim$ -2kV, the multiplier has a nominal gain of $\sim 10^5$. Shown in Fig. 3 is a simulated signal as seen by the electron multiplier for the following plasma conditions: edge neutral density n_{oa}=1x10^{16} m^{-3}, central electron density n_{e0}=1x10^{20} m^{-3}, and central ion temperature T_{i0}= 2 keV. Included in the calculations are the collection fraction of secondary electrons from the CuBe plate ($\sim$ 0.5-0.8), the secondary electron emission coefficient[3] η(E) (taken to be $\sim$9.7 x 10^{-4} (E(eV) - 14.6)) and G, the gain of the electron multiplier set nominally at 10^5. Since the majority of Alcator C-Mod plasmas have a hydrogen content of less than 1%, no significant "contamination" is expected in the deuterium spectrum. Care must be taken that the multiplier current does not significantly exceed 1-2 μA. Consequently, the simulations indicate that reasonable signal levels are expected, although large uncertainties still exist in the neutral density profile and that adequate alignment can be performed.

IV. Acknowledgments

We would like to acknowledge the help of H. Alvestad, K. Schoenberg, both at LANL, C. Fiore, W. Burke, W. Parkin at MIT, and the support of C. W. Barnes and G. Wurden (LANL). Supported by US DOE Contract No. DE-AC02-78ET51013 and No. W-7405-ENG-36.

References

[1] D. E. Voss, *Low Energy Neutral Atom Emission and Plasma Recycling in the PLT Tokamak*, PhD thesis, Princeton University, Princeton, NJ, 1980.

[2] D. E. Voss and S. A. Cohen, *Rev. Sci. Instrum.*, **53**, 1696 (1982).

[3] H. Verbeek, *J. Phys. E*, **19**, 964 (1986).

[4] Y. Miura and F. Okano, *Rev. Sci. Instrum.*, **61**, 3581 (1990).

[5] G. A. Wurden et al., Ion Heating Studies in the ZT-40M Reversed Field Pinch, in *Controlled Fusion and Plasma Physics,*(Proc. of the 15$^{\text{th}}$ European Conf., Dubrovnik,1988), Vol 12B, pages 533–536, Geneva, 1988, European Physical Society.

[6] R. M. Mayo et al., *Nucl. Fusion*, **31**, 2087 (1991).

[7] C. Kurz and C. L. Fiore, *Rev. Sci. Instrum.*, **61**, 3119 (1990).

[8] W. van Toledo, R. van Buuren, A. J. H. Donné, and H. de Kluiver, *Rev. Sci. Instrum.*, **63**, 2223 (1992).

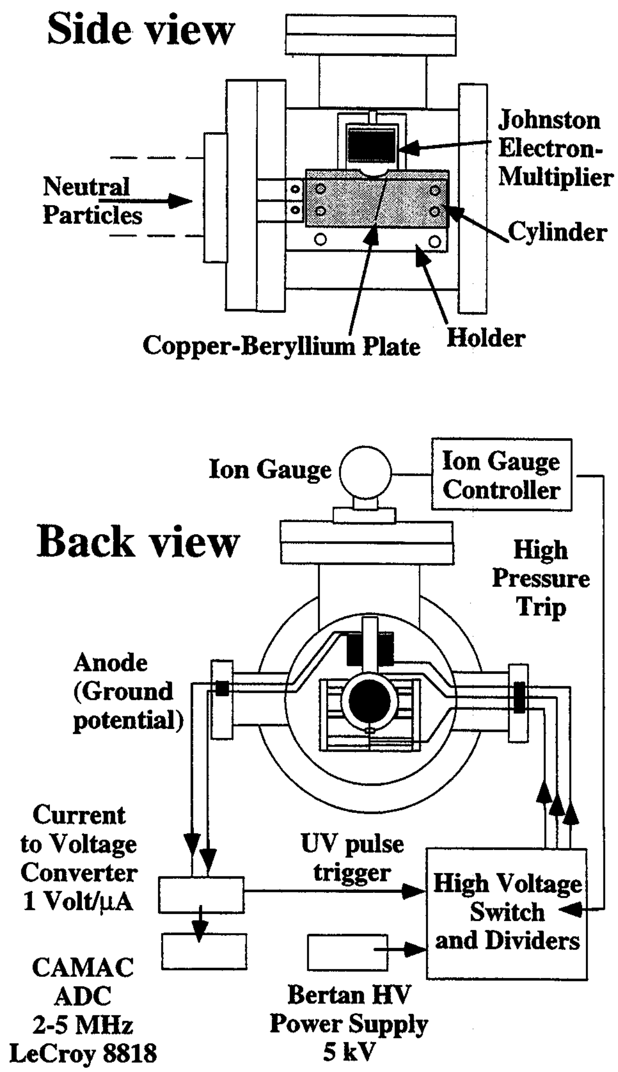

Fig. 1: Details of the detector assembly and the associated electronics components.

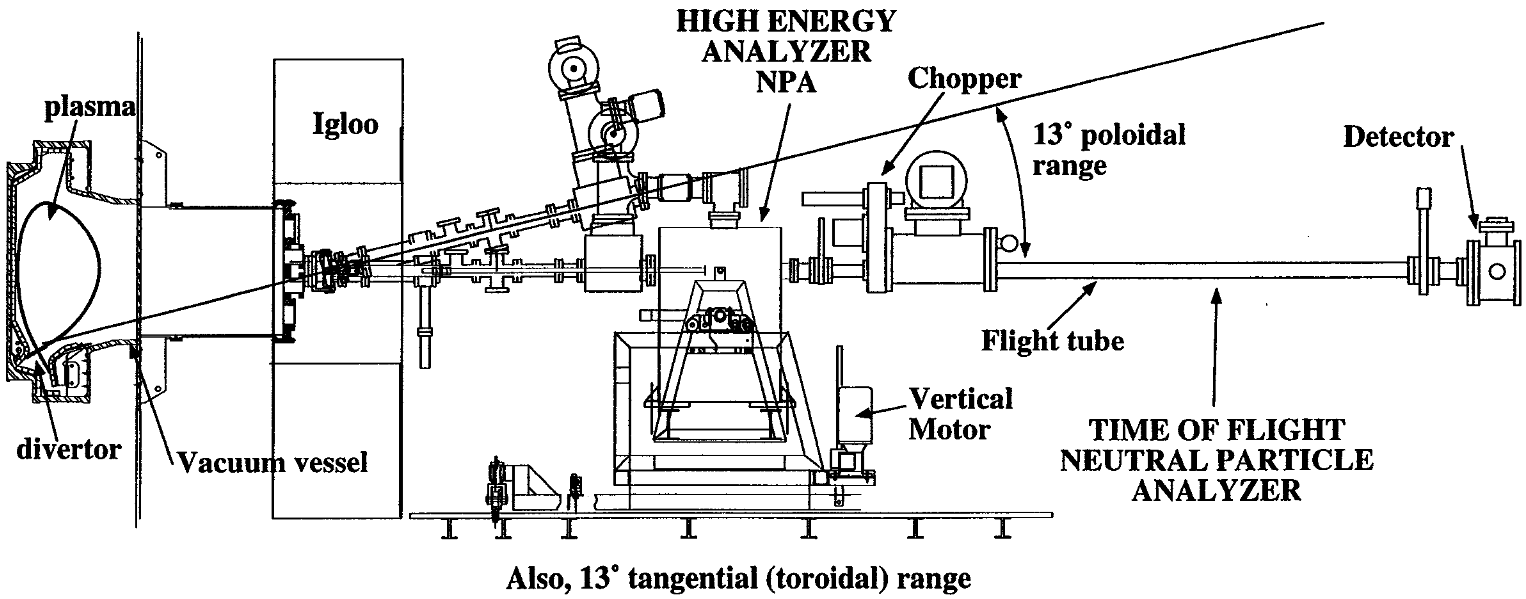

Fig. 2: Schematic side view of the time-of-flight installation with the high energy neutral particle analyzer (left) on Alcator C-Mod.

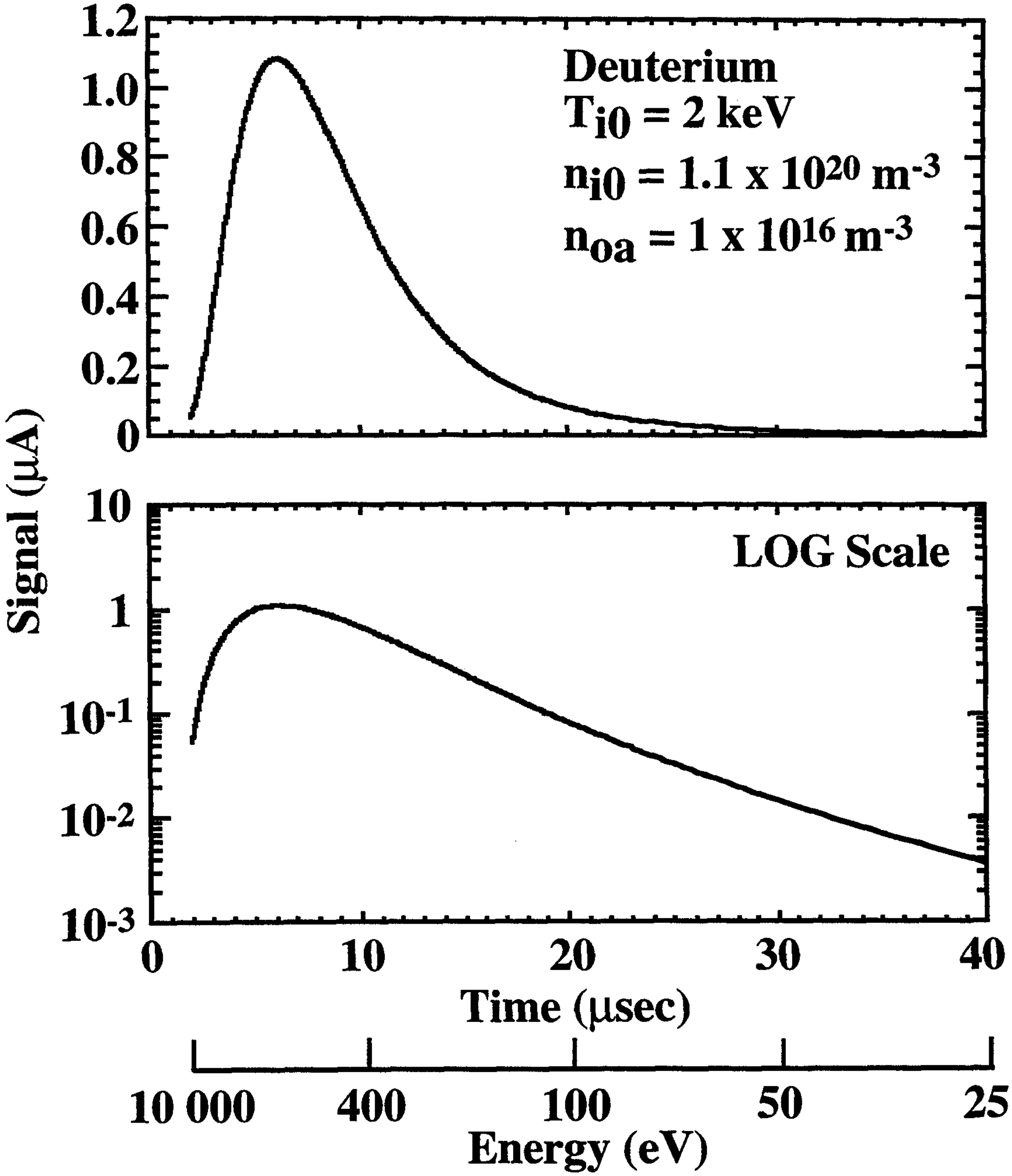

Fig. 3: Expected count rate, in linear and log scale, as a function of arrival time, and equivalently, of particle energy.