EFDA–JET–CP(10)03/02

I.S. Nedzelskiy, A. Korotkov, M. Brix, P. Morgan, J. Vince
and JET EFDA contributors

# Characterization of the Li Beam Probe with a Beam Profile Monitor on JET

# Characterization of the Li Beam Probe with a Beam Profile Monitor on JET

I.S. Nedzelskiy[1], A. Korotkov[2], M. Brix[2], P. Morgan[2], J. Vince[2]
and JET EFDA contributors*

***JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK***

[1] *Associação EURATOM/IST, Instituto de Plasma e Fusão Nuclear, Instituto Superior Técnico,*
*1049-001 Lisboa, PORTUGAL*
[2] *JET-EFDA, EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*
** See annex of F. Romanelli et al, "Overview of JET Results",*
*(Proc. 22 nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

Preprint of Paper to be submitted for publication in Proceedings of the
18th High Temperature Plasma Diagnostics, Wildwood, New Jersey, USA.
(16th May 2010 - 20th May 2010)

## ABSTRACT.

The Lithium Beam Probe (LBP) is widely used for measurements of the electron density in the edge plasma of magnetically confined fusion experiments. The quality of LBP data strongly depends on the stability and profile shape of the beam. The main beam parameters are: beam energy, beam intensity, beam profile, beam divergence and the neutralization efficiency. For improved monitoring of the beam parameters, a Beam Profile Monitor (BPM) from the National Electrostatic Corporation (NEC) has been installed in the Li beam line at JET. In the NEC BPM, a single grounded wire, formed into a $45^o$ segment of a helix, is rotated by a motor about the axis of the helix. During each full revolution, the wire sweeps twice across the beam to give X and Y profiles. In this paper we will describe the properties of the JET Li beam as measured with the BPM and demonstrate that it facilitates rapid optimization of the gun performance.

## 1. INTRODUCTION

The Lithium Beam Probe (LBP) is widely used for the measurements of the electron density in the edge plasma of magnetically confined fusion experiments. The quality of LBP data strongly depends on the quality of the beam formed in the injector part of the diagnostic. The main beam parameters are: beam intensity, beam profile and dimensions, beam position, and neutralization efficiency. The beam parameters are controlled by adjusting the temperature of the thermionic emitter and neutralization cell and by adjusting the extraction, acceleration and deflection voltages of the ion gun. Obviously, monitoring and control of the beam parameters are essential. One common beam diagnostic tool used in all LBPs is the Faraday cup. However, it does not allow real-time monitoring, and the measurements are time consuming. As shown in this paper, practically real-time monitoring, control and optimization of the main beam parameters can be obtained with the Beam Profile Monitor (BPM) from National Electrostatic Corporation (NEC) [1], recently installed in the LBP injector on the JET tokamak. In plasma experiments, the use of NEC BPMs is known in heavy ion beam probe work on the TEXT tokamak [2] and the LHD stellarator [3]. However, to our knowledge, there are not any BPMs in LBPs on any plasma device, except on the LHD stellarator [4] and the JT-60 tokamak [5] – in each of which there is an assembly of two wires permanently crosses the beam channel for position control.

The paper is organized as follows: the LBP injector on the JET tokamak is briefly considered in Section II; a short description of the NEC BPM is given in Section III; Section IV presents the results of BPM implementation on JET; Section V gives a summary.

## 2. THE LBP INJECTOR ON JET

Figure 1 shows the schematic of the LBP injector on JET. Beginning at the top, the diagram shows the Li+ ion source, the extraction and acceleration optics, the electrostatic steering plates, the neutralizer cell, the electro-magnet assembly and the Faraday cup. The BPM is installed between the magnet and the Faraday cup.

The $Li^+$ ions are produced by a thermionic emitter. Preparation of the emitter consists of coating a HeatWave Labs [6] emitter assembly (15 mm in diameter) with a thin layer of lithium β-eucryptite powder, followed by heating in vacuum until it completely melts. This procedure is repeated 30–35 times resulting in a ~0.3mm thick uniform glassy coating, with a slightly milky appearance. The life-time capacity (extracted charge) of such emitters is ~5–10 mA*hour, estimated for the time of 50% beam current decay.

The extraction and accelerating optics are of similar design and geometry to those described in the early work of McCormick [7]. The maximum energy of the diagnostic beam is 70keV. A two pairs of electrostatic steering plates controls the beam position in the radial and toroidal directions. The Li0 atoms created in the Na vapor neutralization cell [8] can be separated from the rest of none-neutralized Li+ ions by use of the electro- magnet, deflecting the charged particles in the radial direction.

The mechanically-movable Faraday Cup (FC) was the only diagnostic tool for beam characterization before installation of the BPM. It comprises a grounded cup with input window of diameter of $D_{FC} = 30$mm and a collector. A guard ring of the same diameter is arranged just after the FC input aperture, to suppress the secondary electrons when biased at negative potential. With the magnet switched -off, and the neutralizer cell activated (heated) both $Li^+$ and $Li^0$ are passed into the FC.

With a suppressing potential applied, only the charged component produces a signal. By measuring the FC currents with the neutralizer cell cold and hot, respectively Ic and Ih, the neutral component, In, and the neutralization efficiency, kn, may be calculated:

$$I_n = I_c - I_h \tag{1}$$

$$k_n = 1 - I_h / I_c \tag{2}$$

With the magnet switched -on and for known secondary electron emission yield, the intensity of the $Li^0$ beam can be measured at zero suppressing potential on the FC. By scanning of the beam across the FC, the beam profile can be roughly estimated.

## 3. THE NEC BPM

In the NEC BPM1, a single grounded wire, formed into a $45^o$ segment of a helix, is rotated by a motor about the axis of the helix. With reference to Fig.2, and in the frame of a rectangular Cartesian coordinate system, the axis of rotation is orthogonal to the beam direction (which is along the vertical Z axis) and at $45^o$ to each of the other two axes in the horizontal plane. The X axis passes through the JET machine centre in that plane and the Y axis points in the toroidal direction.

During each full revolution, the wire sweeps twice across the beam to give an X-profile in one half-revolution and an Y-profile during the next half-revolution. The secondary electrons created on the wire are collected by a cylindrical electrode arranged around the wire, to give information on the beam intensity at the wire position. The measured beam profiles can be represented by integral expressions of the form: $I(x) = \varepsilon\int j(x,y)dy$ and $I(y) = \varepsilon\int j(x,y)dx$, respectively, where the factor e accounts for the secondary emission coefficient of the wire and the efficiency of the electron collection system, and $j(x,y)$ is the two-dimensional current density.

The signal is displayed for both directions simultaneously on an oscilloscope. The magnetic pickup signals provide for position (fiducial) marking of the X and Y axes and also for oscilloscope triggering. When the scanner is not in use, the wire rotation is stopped and the wire is held out of the beam path by permanent magnets.

The NEC model BPM82 has been chosen for lithium beam control on JET. It has maximum scanning diameter of 5cm, effective distance between fiducial marks of 7.4cm and wire diameter of 1 mm. It should be noted that due to JET vacuum requirements the original Krytox-LVP lubricant has been replaced by fluorine-free Nyetorr 5100. Also, due to the demagnetization risk posed by JET stray magnetic fields, the original Alnico 8 permanent magnets have been replaced by harder NdFeB 28/30 magnets.

The sensitivity of the supplied current amplifier is adjustable from $10^3$ to $10^7$ V/A, and can be altered in steps of one decade. The range of the amplifier output signal at any sensitivity range is 0–10V.

## 4. RESULTS FROM OPERATION OF THE BPM

Figure 3 presents an example of two sets of observed $Li^+$ beam profiles with non activated (cold) neutralization cell. There were two slightly-different deflection voltages on the radial electrostatic plates and two different extraction voltages: $\Delta U_{rad} = 140$V, $U_{ext} = 4.9$kV, middle trace; and $\Delta U_{rad} = -110$V, $U_{ext} = 5.2$kV, bottom trace (total beam energy is 50keV in both cases). Top trace shows the fiducial marks (numbered 1 and 3) and the trigger pulse (numbered 2) generated from magnetic pickup signals.

In the middle and bottom traces of Fig.3, each of which show three successive pairs of toroidal and radial profiles, in any pair of profiles the amplitude of the left-hand (toroidal) profile is approximately two times lower than that of the right-hand (radial) profile, indicating the elliptical 2D shape of the beam. Comparing middle and bottom traces in Fig.3, it can be seen that there is a shift of the radial (right-hand) profile relative to the fiducial marks, in going from one trace to the other, brought about by the different deflection voltage settings. Looking at the shapes of the right-hand (radial) profile in the two traces a slight difference is discernible. This change of shape indicates that the location of the beam focus is different, caused by the different extraction voltages $U_{ext}$.

The data of Fig.3, with known effective distance between the fiducial marks (7.4cm, or 0.19cm/ms derived from the oscilloscope traces), permit the $Li^+$ beam dimensions to be estimated. We obtain ~ 1-1.2cm at FWHM, which is smaller than the FC aperture. Thus, the beam current intensity can be estimated directly from BPM measurements, after calibration using FC current measurements. Calibration yields an effective coefficient of ~0.18mA/V for the maximum of the radial (right-hand) profile.

The results obtained demonstrate an almost real-time (70ms) capability of the BPM for $Li^+$ beam position monitoring, visualization of the beam profile, and estimates the beam dimensions and intensity. High sensitivity control of the beam deflection and focus is also demonstrated.

Figure 4 shows the radial (right-hand) profile with activated (262$^o$C) neutralization cell and the magnet switched –on (curve A). The appearance of the small peak is due to the deflection of the Li+ component of the beam by the magnet. As the neutralizer temperature is lowered to 235oC (curve B), so the amplitude of the Li0 beam profile diminishes, with little change to its shape. In contrast, the Li+ beam profile amplitude changes only slightly, as the temperature decreases, but the shape of the profile broadens significantly. Curve C shows the overlapped profiles of the Li0 and Li+ beam components at low (235$^o$C) neutralizer temperature with the magnet switched –off.

The decrease in the $Li^0$ beam profile amplitude is due to a decrease in the neutralization efficiency, whilst the broadening of the $Li^+$ profile can be explained by space charge effect as the intensity of the $Li^+$ beam increases.

These observed qualitative properties can be used directly for optimization and estimation of the neutralization efficiency. In particularly, the optimization can be considered as completed, when the maximum profile amplitude is achieved without anomalous wings as presented on curve C in Figure 4.

Then, taking the secondary electron emission yield for $Li^0$ and $Li^+$ to be equal within 20% in this energy range [9], the neutralization efficiency can be estimated by:

$$k_n \approx I_{maxLi0} / (I_{maxLi0} + I_{maxLi+}) \tag{3}$$

where $I_{maxLi0}$ and $I_{maxLi+}$ are, respectively, the amplitudes of the $Li^0$ and $Li^+$ beams profiles. Figure 5 shows thus obtained the dependence of the neutralization efficiency with temperature of the neutralizer.

## SUMMARY

In summary, a NEC Beam Profile Monitor has been installed on the JET Lithium Beam Probe. It greatly facilitates operation of the diagnostic, allowing practically real-time monitoring, control and optimization of the main beam parameters. These include beam intensity, beam intensity profile and dimensions, beam position and neutralization efficiency.

## ACKNOWLEDGEMENTS

In memory of our dear colleague, Anatoly Korotkov, who died unexpectedly on June 22nd 2009 aged 56. This work was supported by EURATOM and carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

## REFERENCES

[1]. http://www.pelletron.com/bpm.htm

[2]. J. Schwelberger, P.M. Schoch, R.L. Hickok, T.P. Crowley, K.A. Connor, J.F. Lewis, IEEE International Conference on Plasma Science, May 22 – 24, Buffalo, NY, USA (1989).

[3]. T. Ido et al, Review Scientific Instruments, **77**, 10F523 (2006).

[4]. T. Morisaki, A. Komori, O. Motojima, and LHD Experimental Group, Review Scientific Instruments,, 74, 1865 (2003).

[5]. A. Kojima et al, Review Scientific Instruments, **79**, 093502 (2008).

[6]. http://www.cathode.com/

[7]. K. McCormick, S. Fielder, G. Kocsis, J. Schweinzer, S. Zoletnik, Fusion Engineering and Design, **34-35**, 125 (1997).

[8]. K. McCormick, Report IPP III/2 (1983).

[9]. K. Bethge, P. Lexa, Brit. Journal Applied Physics, **17**, pp. 181-186 (1966).

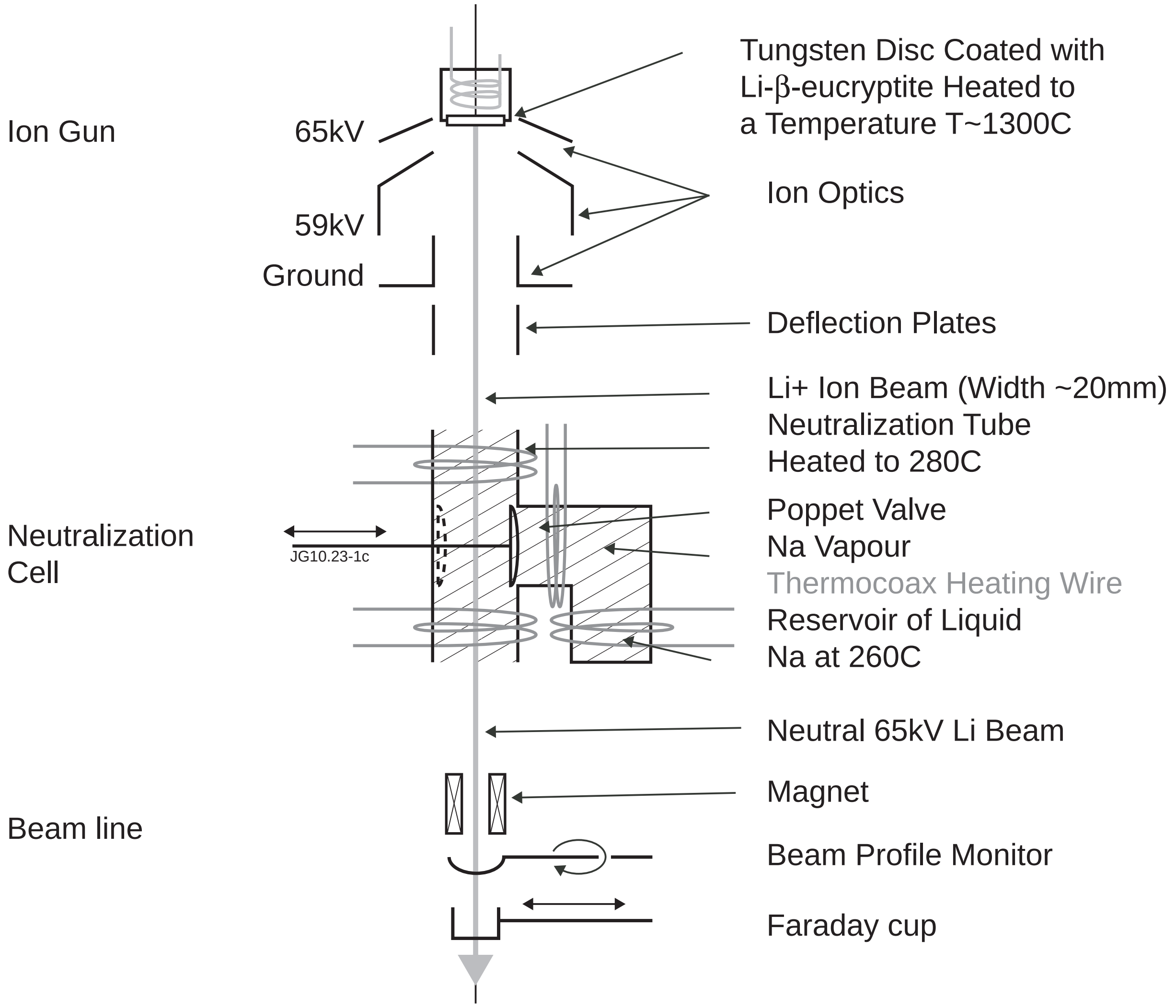

*Figure 1: Schematic of the Lithium Beam Probe injector on JET.*

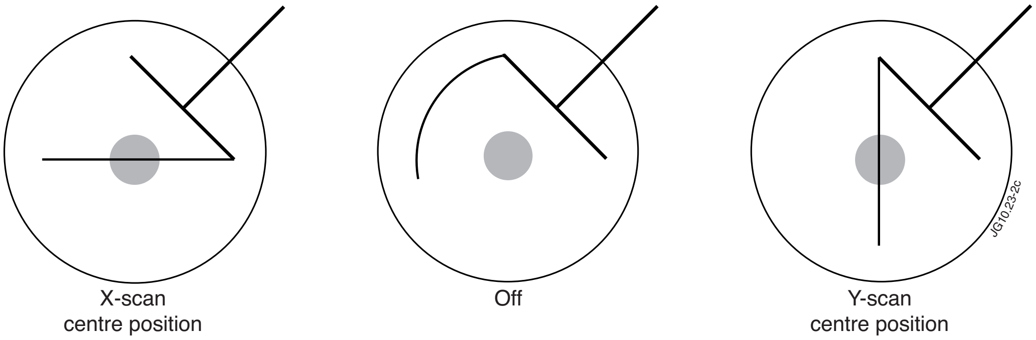

*Figure 2: Schematic of NEC BPM operation.*

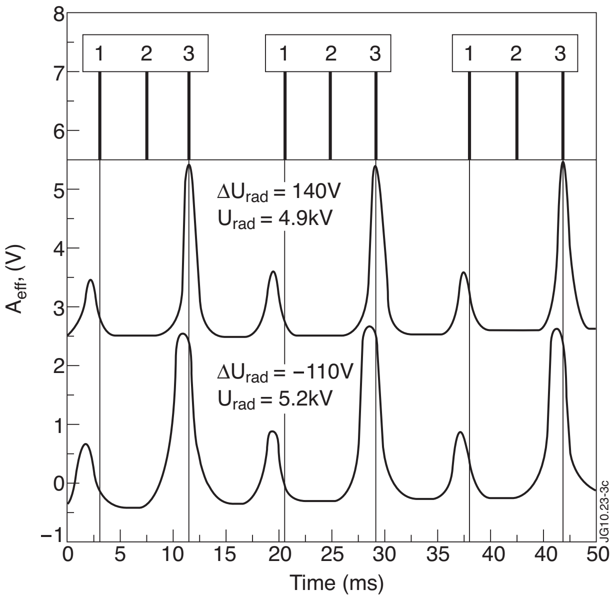

*Figure 3: Li$^+$ beam profiles for two deflection and two extraction voltages: $\Delta U = 140V$, $U_{ext} = 4.9kV$ (middle trace); $\Delta U = -110V$, $U_{ext} = 5.2kV$ (bottom trace). Top trace shows the fiducial marks (1,3) and the trigger pulse (2). Beam energy 50keV.*

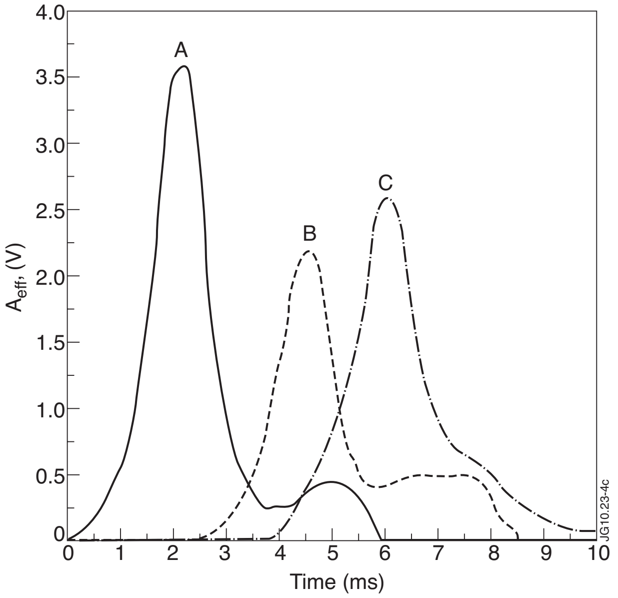

*Figure 4: Radial profiles with activated neutralization cell and magnet switched-on (curve A for 262$^o$C, curve B for 235oC) and switched –off (curve C for 235$^o$C).*

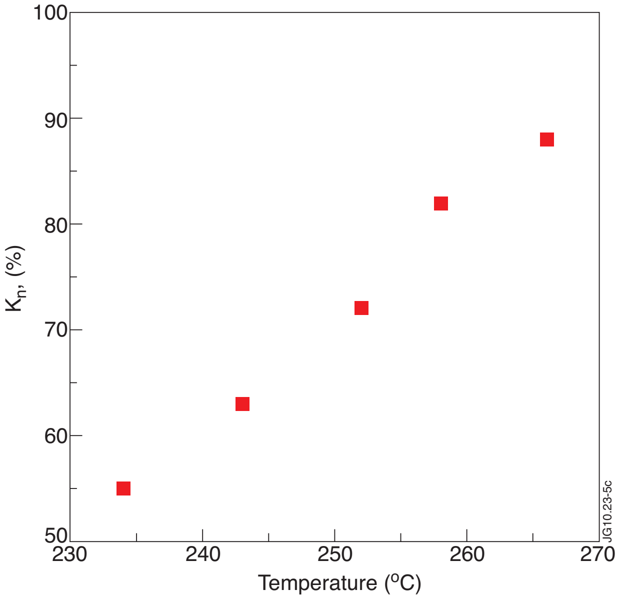

*Figure 5: Dependence of neutralization efficiency on neutralizer temperature.*