ESTIMATION OF TRANSVERSAL EMITTANCE USING AN ARTIFICIAL NEURAL NETWORK

E. Stiliaris and E. Meintanis
Institute of Accelerating Systems & Applications (IASA),
P.O.Box 17214, GR–10024 Athens, GREECE

Abstract

An expert system, utilizing an Artificial Neural Network (ANN), is under development. The ultimate goal of the project is the "one-shot" transversal emittance estimation of the e-beam in the 100-keV line of the IASA [1] Race-track Microtron. Input data consists of two video grabs from view screens, as well as the value of the current in a solenoid located between them. Simulations of the line, using the PARMELA code, have been providing training and test data to optimize a neural network. Current progress in the project, including the response of the system to real-world data and the automation of data feeding, will be discussed in the paper.

1 INTRODUCTION

The Diagnostic Line (T-line) at IASA is designed in such a way that allows the determination of the transverse emittance using at least two different procedures [1]. One technique is to use all three wire scanners without varying the excitation of any optical element. Another possibility is to vary the excitation of a lens and measure the modified beam size in the wire scanner situated downstream this lens. In this paper, another method based on the digitized image of the beam profile on two successive view screens is described. To avoid any nonlinearities in the resulting beam intensity, an artificial neural network is used.

2 THE METHOD

The system of two successive view screens and a lens-wire scanner (VS3-L6-VS4-WS1) at the 100-keV line (Figure 1) is used to determine the electron beam transverse emittance. The classical and most accurate method with the lens-wire scanner combination will serve also as a check for the network results. Both methods are described in the following.

2.1 Classical Method with Wire Scanners

The L6-WS1 system is used to determine the transverse emittance with the classical method. In this case, the lens is excited and the modified beam size is measured with the wire scanner situated downstream the lens (Fig. 2).

The beam transfer matrix for the system lens + drift

[1] Web-Address http://www.iasa.uoa.gr

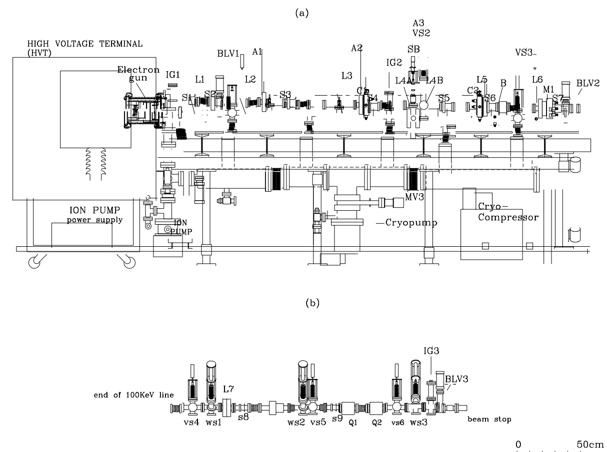

Figure 1: The 100-keV and the Diagnostic Line for measuring the Transverse Emittance

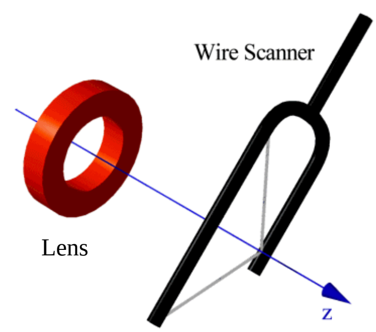

Figure 2: Emittance measurement with a wire scanner and lens excitation

space (from lens to the wire scanner) is written as

$$M_{sys} = M_D \cdot M_L = \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$$

where M_D refers to the drift space of length d and M_L represents the effect of the lens L. Taking as an example the x-plane then, for each value of the lens excitation, and assuming uncoupled x- and y-planes, the measured beam size x_2 and divergence θ_2 at the wire scanner location are expressed via the size x_1 and divergence θ_1 at the lens location by the equation:

$$\begin{pmatrix} x_2 \\ \theta_2 \end{pmatrix} = M_{sys} \cdot \begin{pmatrix} x_1 \\ \theta_1 \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \cdot \begin{pmatrix} x_1 \\ \theta_1 \end{pmatrix}$$

where the transfer matrix M has the form:

$$\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} = \begin{pmatrix} S_{11} + dS_{21} & S_{12} + dS_{22} \\ S_{21} & S_{22} \end{pmatrix}$$

The first of these equations gives a linear dependence for θ_1 as a function of x_1 for different values of measured beam profiles x_2 and lens lens excitation:

$$\theta_1 = -\frac{S_{11} + dS21}{S_{12} + dS_{22}} x_1 + \frac{1}{S_{12} + dS_{22}} x_2$$

A set of measurements therefore of x_2 as a function of the lens current encloses the beam transverse phase space, resulting in the form of a polygon.

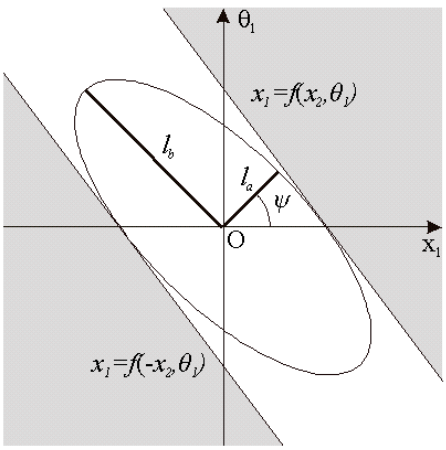

Figure 3: The enclosed area by the function $\theta_1 = \theta_1(x_1)$

The closed area can be further approximated by an ellipse which defines the transverse emittance of the beam. This method has been extensively used with the L6-WS1 lens-wire scanner combination (Fig. 1) to determine the emittance of the 100 keV beam at IASA [1] [2].

2.2 *The View Screen Method*

The alternative method used here utilizes the two successive view screens VS3 and VS4 of the 100 keV beam line (Fig. 1). Both are fluorescent view screens viewed by TV Vidicon cameras from ultra high vacuum view ports. The captured image can be digitized and the result is used as input to an artificial neural network. The ultimate goal of this technique is the "one shot" transverse emittance estimation of the electron beam in the 100 keV line during beam tuning or optimization procedure. The method could also be used in other beam line locations by combining any pair of view screens. Intensity nonlinearities in the captured images is supposed to be correctly handled by the network.

In the present situation the neural network input consists of the projected intensity across the x- and y-axis plus the lens excitation. Making an optimal compromise between position resolution and number of input nodes, the image bining was fixed to a square of 41x41 bins, resulting to 41+41 input nodes for each view screen (1 bin = 0.40 mm).

Therefore, the network architecture used in this case has a total number of $172 = 82 + 82 + 8$ input nodes corresponding to both view screens and the lens excitation respectively. The output nodes are always two, one for the horizontal ϵ_x and one for the vertical ϵ_y emittance.

2.3 *Neural Network Training*

The JETNET package has been used to make the network training [3]. It consists of fortran (F77) subroutines with a large number of learning algorithms, learning parameters and various other tools for performance and error control of the network. Here, a multilayer architecture with a maximum of four (two hidden) layers and the back-propagation updating (standard gradient descent) are used.

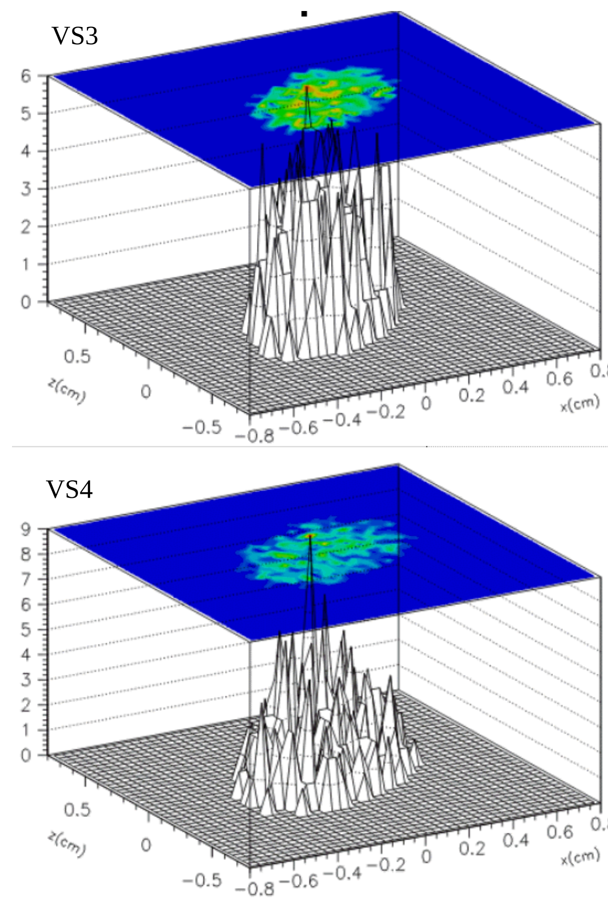

Figure 4: Projection of a training set on VS3 and VS4

Two different sets of training data were created with the PARMELA simulation program [4]. The first, with 6440 samples, has been exclusively used for the network training, while the second one, with 1000 samples, formed the basis for the network control and comparison between different network architectures [5]. Free parameters in the simulated samples are the input transverse emittances (ϵ_x, ϵ_y) and the lens current. A typical network input of a beam image formed on the view screens VS3 and VS4 is shown in Figure 4.

3 RESULTS

With a fixed network architecture consisting of two hidden layers with 80 and 30 nodes respectively, the normalized deviation

$$\frac{\epsilon_i^{net} - \epsilon_i}{\epsilon_i}$$

for both x- and y-emittance is shown in Figure 5. The ϵ_i^{net} value is the network output after training, while the ϵ_i represents the emittance true value. For an input emittance range 1–7 π mm mrad the deviation is better than 12% in both directions. The strong dependence on the absolute emittance value can be easily traced back to the finite position resolution of the bining.

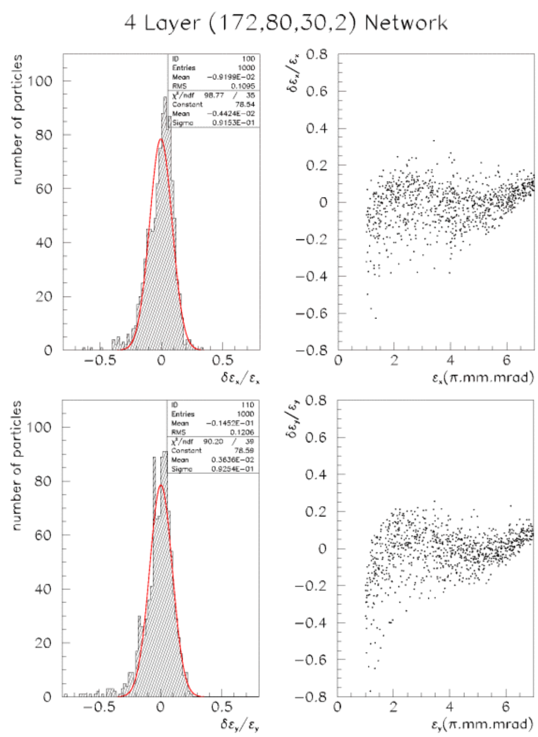

Figure 5: Network prediction results for a fixed architecture with two hidden layers

In Figure 6 the same deviation is shown as a function of the input lens current and of the absolute emittance in the other direction. As expected, there is no dependence on the lens excitation as well as no x-y emittance correlation.

Table 1: Prediction results for different architectures

LAYERS	NODES	σ_x	σ_y
4	172-80-30-2	0.1095	0.1206
3	172-60-2	0.1149	0.1244
2	172-2	0.1235	0.1367

In order to estimate also the optimal network architecture for this method, the training and test procedure has been repeated for one and for zero hidden layers. The results are summarized in Table 1.

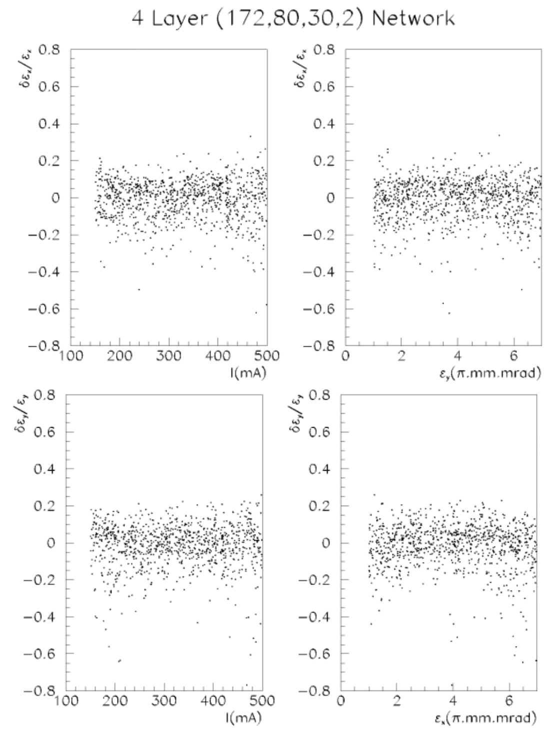

Figure 6: Dependence on lens excitation and x-y Emittance correlation

Current work of this project is now focused on the system response to real data. The combination L6-WS1 is used, as described above, to gain the "real" emittance value. An automatized procedure for the beam operator has already been designed and is under development.

4 CONCLUSIONS

The above described method of the transverse emittance estimation based on digitized images from two successive view screens gives very promising results. Although this method can not be compared in accuracy with classical methods based on beam profile measurements with wire scanners, it can be proved useful in cases where a very quick estimation is required.

REFERENCES

[1] S. Cohen et al., "The IASA RaceTrack Microtron Facility: A Progress Report", Proceedings of the Sixth European Particle Accelerator Conference EPAC'98, Stockholm, IoP, (1998) 752–754

[2] E. Stiliaris et al., "The IASA RaceTrack Microtron Facility", Nucl. Phys. A663&664 (2000) 1095c–1098c

[3] C. Peterson et al., "JETNET 3.0 – A Versatile Artificial Neural Network Package", Comp. Phys. Comm. 81(1994)185–220

[4] L.M. Young, "PARMELA, A Particle Dynamics Code for Electron Linacs", AOT-1, Los Alamos (1995)

[5] E. Meintanis, Diploma Thesis, University of Athens, 1999