NON-INTERCEPTIVE EMITTANCE MEASUREMENT OF A HIGH INTENSITY BEAM AT LOW ENERGY

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Abstract

A CW Electron Cyclotron Resonance source has been constructed at CEA-Saclay and is now under test. The aim is to reach a 100-mA proton current at 95 keV with an rms normalized emittance smaller than 0.2 π.mm.mrad and a very high reliability. In order to match this beam into the Radio Frequency Quadrupole linac (RFQ), its characteristics have to be monitored on-line. An emittance measurement unit (EMU) located close to the RFQ entrance is a very powerful diagnostic tool. We developed a non-interceptive EMU based on the video analysis of the residual gas illumination. Methods and results are presented and discussed.

1 INTRODUCTION

This work is a part of a wide range of activities presently being undertaken at the CEA in the field of high power proton or deuteron linear accelerators. We are studying the CW IPHI demonstration project [1]. This accelerator will consist of a high intensity light ion source (SILHI) [2], an RFQ [3] and a DTL up to 10 or 11 MeV. The main application of this kind of accelerators is the production of high flux neutrons by spallation reactions, for use in the IFMIF and nuclear waste treatment projects.

The SILHI requirements are: 100 mA proton or 140 mA deuteron in more than 90% of the total extracted beam, at 95 keV and with a rms normalized emittance of 0.2 π.mm.mrad. The ECR ion source operates at 2.45 GHz with an approximately 875 G axial magnetic field. The first proton beam was produced in July 1996.

In order to match the beam into the RFQ accurately, a precise knowledge of its characteristics measured close to the cavity entrance is required. Presently, beam position and size along the low energy test line are obtained from the CCD video cameras. The emittance is measured by means of a classical "hole-slit" type Emittance Measurement Unit (EMU). This kind of EMU is esteemed for its precision but presents several disadvantages (slow mechanism, interceptive system, r-r' emittance…). Moreover, the power density allowed by the sampler, (limited to 1 kW/cm^2), prohibits us from tuning the beam around the cross-over. So it was felt necessary to develop a fast and non interceptive EMU. We decided to study a CCD video camera based system and calibrate this EMU with the classical one.

Here, we present the method and the first results obtained.

2 METHOD

For the beam monitoring, four CCD video cameras - (MICAM VHR 2000 Model) - are in operation on the Low Energy Beam Transport (LEBT) line. Two cameras are located between the extraction system and the first solenoid and another set of two 1.5 meter behind this solenoid. In both the locations, H and V planes can be observed. The MICAM camera is equipped with a 752×582 pixel matrix, its sensitivity is 0.25 lux for a 1.2 F/D ratio. The beam area observed is about 120×90 mm. Remote controls, data acquisition and analysis are performed by using LABVIEW™.

The CCD cameras give directly a signal proportional to the light emitted by the residual gas integrated over the observed plane. It means that we can acquire only transverse (x-x') emittance. The light is considered proportional to the current density and to the residual gas pressure. The logical way to obtain the beam emittance is to employ the well-known 3 gradients method. We want to obtain the emittance value ε and the Twiss parameters of the beam (α, β, γ). Due to the relation $\alpha^2 = \beta\gamma$-1, we have in fact only 3 unknown parameters. The beam radius x is related to β, and the beam angle x' is related to γ. The principle consists in measuring the beam profile for at least three different solenoid currents. We then adjust the unknown parameters and transport the beam from upstream of the solenoid to the measurement position. The difference between the measured values and the calculated ones is the number we minimize. The beam transport has to be done with space charge. From the experience of previous measurements we take a beam neutralization of 97% [4]. Space charge and solenoid focusing (transfer from one plane to the other) imply that we cannot use a matrix formalism. The beam transport is calculated with the well known envelope equation :

$$\begin{cases} \widetilde{x}'' + k^2(z) \cdot \widetilde{x} - \dfrac{K}{2 \cdot (\widetilde{x} + \widetilde{y})} - \dfrac{\widetilde{\varepsilon}_x^2}{\widetilde{x}^3} = 0 \\ \widetilde{y}'' + k^2(z) \cdot \widetilde{y} - \dfrac{K}{2 \cdot (\widetilde{x} + \widetilde{y})} - \dfrac{\widetilde{\varepsilon}_y^2}{\widetilde{y}^3} = 0 \end{cases}$$

where $\widetilde{x}$ and $\widetilde{y}$ are the rms transverse dimensions,

$K = \dfrac{qI}{2\pi\varepsilon_0 m(\gamma\beta c)^3}$ is the defocusing factor due to space charge forces, $k^2(z) = \dfrac{q^2 B^2}{4\gamma^2 m^2 \beta^2 c^2}$ is the confinement term due to the magnetic field and

$$\widetilde{\varepsilon} = \sqrt{\langle r^2 \rangle \langle r'^2 \rangle - \langle r \cdot r' \rangle^2}$$ is the rms emittances to be calculated

At present time, we use only the camera that looks at the horizontal plane behind the solenoid. With the assumption of a cylindrical beam, the space charge forces can still be calculated. We do not expect a big difference in that case.

It is more reliable to optimize the values with about 10 measurements. Moreover, we improve the S/N ratio by averaging about 20 video columns.

The measurement code has been developed using Labview 4.0. It automatically acquires the beam and line parameters (energy, current, solenoid currents...), proposes some solenoid current values and acquires the data. It then launches the optimization code developed in C++, and displays the result.

3 RESULTS

3.1 Qualitative approach.

By changing the solenoid current we can obtain a convergent beam, a divergent beam or a cross over in front of the video diagnostics. We call the "cross-over curve" as the curve of the beam size as a function of the focusing:

A complete analysis as a function of the position of the measured points on this "cross-over curve" has been done. We considered the localization of the acquisition points on this curve as shown in Figure 1 :
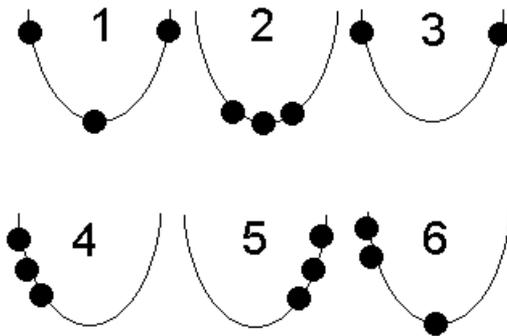

Figure 1 : Different locations of acquisition points on the "cross-over curve".

Cases 4 trough 6 generate the worst solutions: the minimization algorithm converges rarely and the results are never reproducible. Case 3 produces uncertain results. Case 1 with points equally spaced, represents the best compromise for fitting a curve that describes the dots. It produces the most reliable results and is also the "closest" to the reference EMU ones.

Preliminary exploration of the system shows that it is better to limit the beam size at the acquisition point to 2 to 3 times the cross over size. This is probably due to some optics limitation in the acquisition system.

This emittance measurement is fast. It takes about 1 minute to acquire and obtain the twiss parameters. Under the conditions defined earlier, it is a reproducible measurement, which is one of our main criteria.

3.2 Quantitative comparisons.

In order to validate this EMU, a complete comparison has to be made with a reference system. We have developed several years ago a precise "hole-slit" measurement unit. The smallest step size of the sampler is 0.6 μm, but we normally never work below 0.2 mm. Under such conditions, the acquisition takes about 10 min to be completed. A typical example is given in Figure 2.
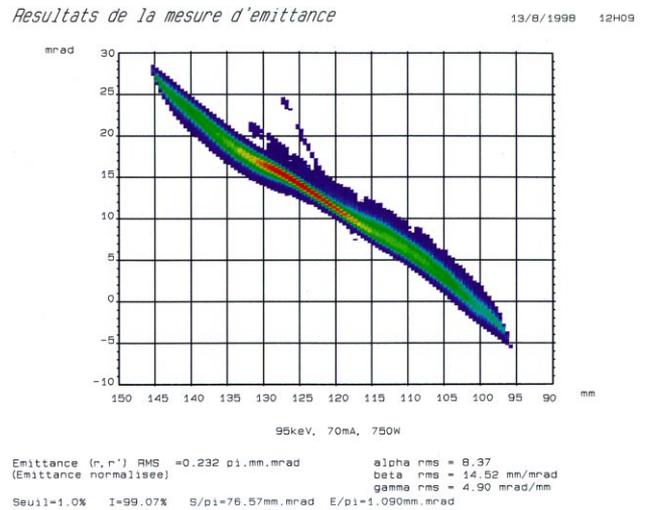

Figure 2 : Typical measurement with the reference EMU.

Typical values obtained with this reference unit are in the range of 0.23 π.mm.mrad (rms, r-r'). It depends mostly on the extracted current, pressure and the potential on the intermediate electrode. With the assumption of a cylindrical beam and a cylindrical velocity distribution inside the beam, the r-r' value equals to $\sqrt{2}$ times the x-x' emittance value. This gives us an rms x-x' emittance of 0.16 π.mm.mrad. Under the same conditions, we measured the emittance with the video EMU. The result is around 0.3 π.mm.mrad, with a standard deviation of 0.0028.

We are able to produce an emittance increase of about 20% by changing the source parameters. In that case, both EMU measurements show an increase of 20%.
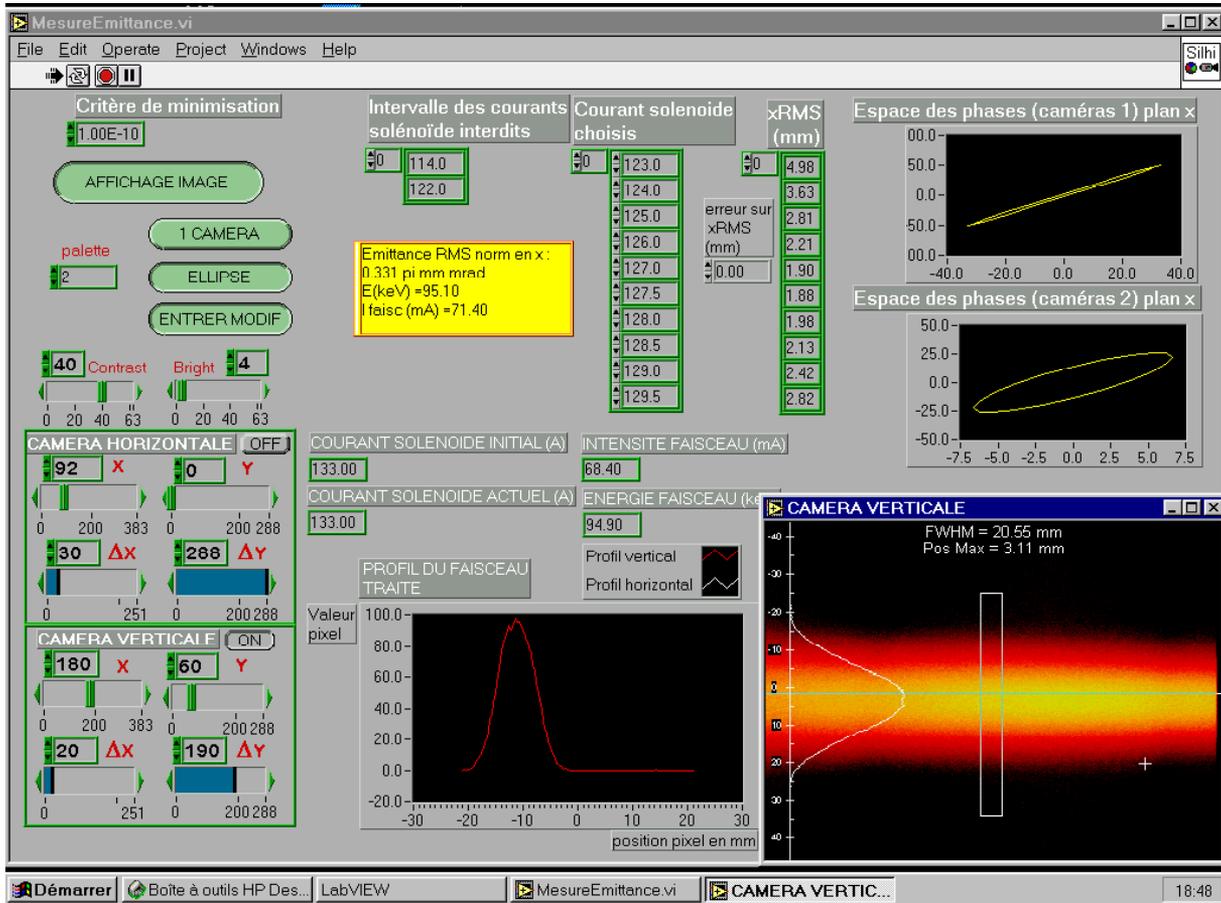
Figure 3: Front image of the video EMU.

3.3 Interpretation.

To explain this discrepancy between the two measurements, we have to carefully consider the nature of the information given by the video EMU. The light emitted originates from the background gas de-excitation. The profile measured on the video camera suffers from an enlargement due to the diffusion of the excited particles before they emit. In that case the profile increase should have a fixed error, independent of the beam size but will depend on the background pressure. Based on this assumption, we have subtracted 0.4 mm from all the measured rms beam size. It then produces a nice reproducible value of about 0.18 π.mm.mrad for the video rms emittance measurement.

Other acquisition errors are certainly present. For example, we can list the possible errors due to the optics and possible non-linearity of the CCD with light intensity.

4 CONCLUSION

So far, the EMU provided reproducible measurements with the use of some hypotheses. The measurements are fast and easy to perform. Extensive set of measurements will be needed to validate the method. A complete analysis of the collected light has also to be performed, in order to confirm the systematic observed rms error. Studies are underway for different source/LEBT tunings conditions (pressure, current…).

5 ACKNOWLEDGMENTS

6 REFERENCES

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