HIGH SENSITIVE BEAM EMITTANCE ANALYZER

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Abstract

A new computer-controlled beam emittance analyzer was developed at Neue Technologien Gelnhausen (NTG). The emittance meter is a ready-to-use system consisting of a 45^{o} slit and wire-grid profile system for measuring transversal beam emittances and beam profiles. The main new feature is the highly sensitive current measurement electronics (SME), which consists of 32 precision, low-noise, integrating amplifiers with FET op-amp, switchable integrating capacitors, and low leakage FET. They integrate the low-level input currents in parallel during a measurement period specified by the user, and the resulting voltages are read out from the integrating capacitors. Because of the very low noise and low input leakage current, measurements of currents in the order of pA are viable. The input signal current may be positive or negative. The channel capability is expandable to 128 wires in each of the two planes. An emittance beam analyzer has been installed at the ISOLDE off-line separator at CERN. In this article the design, the electronics and the newly developed software is explained, and the first results are presented.

1 INTRODUCTION

Measurements of phase space distributions are of great importance. The ease with which a particle beam can be transported, the minimum spot size that can be achieved at a given target location, the accuracy with which beam energy can be measured, the microstructure in time and the precision with which scattering angles can be determined in a physics experiment all depend on the distribution of the particles in the phase space. Furthermore, the so-called emittances that are defined in the phase space influence all aspects of accelerator design and operation. Therefore measurements of phase space distributions becomes essential for the accelerator designer, the experimentalist, and the operator [1].

2 BEAM EMITTANCE ANALYZER

2.1 Mechanical components

Mechanical components of the emittance measurement device include 2 vacuum chambers, 1 connection tube between the chambers, 1 slit blade with 2 slits (for x- and y–plane), 1 profile grid and 2 high precision UHV-feedthroughs. The first vacuum chamber houses the slit blade, which is mounted to the linear feedthrough. The profile grid is mounted to the second linear feedthrough and is located in the second vacuum chamber. Slit and profile grid are aligned in an angle of 45° to the vertical (resp. horizontal) axis of the vacuum chambers. For that reason, the emittance of both planes (x and y) can be measured, one at a time, by a single linear motion of slit and grid and only 2 UHV-feedthroughs are required.

The vacuum housing of slit and grid consists of 2 vacuum chambers linked by a vacuum tube with a diameter of 100 mm. The basic resolution of the measurement can easily be changed by variation of the tube length. Each vacuum chamber consists of ports for vacuum gauges and pumping.

The profile grid consists of a frame, holding 2 x 30 tungsten wires (30 wires in each plane). The thickness of the wires is 0.2 mm and the gap between the wires is 2 mm. This spacing allows measurement of beams with a diameter up to 60 mm. The grid covers a cross section of 80 x 80 mm. To increase the resolution, the grid can be moved into intermediate positions.

The slit plate is made from tantalum, carrying 2 slits (1 in horizontal and 1 in vertical direction). The slit width is 0.2 mm and the dimension of the slit plate is 200 x 200 mm.

The slit plate and the profile grid are mounted on UHV high precision linear feedthroughs with precise ball screws that are driven by 3 phase stepping motors. Slit and grid can be moved in steps of 25 µm.

2.2 Electronics

The current measurement electronics (SME) consist of 32 precision low-noise integrating amplifiers with FET op amp, switchable integrating capacitors, and low leakage FET switches. They integrate at the same time low-level input currents for a user-determined period, and store the resulting voltage on the integrating capacitor. Because of the very low noise and input leakage current the electronics can measure currents in order of pA. The input signal current can be positive or negative. An input relay multiplexer selects the wire-plane for measurement. The trigger delay and integrating time is user programmable (1ms - 10 s) and integrating capacitors between 10 pF and 100 nF in five steps can be selected. A high resolution (13bit+S) ADC digitizes the integrator outputs sequentially. Automatic correction eliminates the integrator offsets depending on the integrating time and capacitor. The offset values measured in beam pauses are stored into a two dimensional array. After each current measurement the corresponding stored offset will be subtracted. The residual effective resolution after offset correction is better then 11bit+S.

A microcontroller with firmware controls the timing, data acquisition and data transfer. RS485 serial interface connects the measurement electronics to the host computer. The baud rate is also programmable (1.2-153.6 kBd). Modular 3U shielding enclosures contain the integrating electronics in subgroups of 2x8 channels. The channel capability is expandable up to 128 wires in each plane.
This development is the basis for high sensitive and stable current measurements like for the profile grids and beam emittance analyzer as used for beam diagnostics at COSY-Juelich [2].
The MTA-ITA-LAI (KFKI) Budapest has acquired the licence for this development and the first 2x32 channel system was built for the beam emittance analyzer produced by the NTG Gelnhausen.

2.3 Software

Proemi is a software package for controlling the measurements and evaluating the beam profile and the phase-space recordings. It is written in C/C++ for PC based computers. It uses a standard DOS system and a small but fast DOS based graphical user interface which provides an easy operation and allows for use of small PC-systems without harddisc. Nevertheless, software versions for MS-Windows and Linux systems are under construction. The user has two programs. One which contains all necessary routines to setup and control the measurement device and to perform high resolution profile and emittance measurements with online data evaluation. This program has to be installed on the device control computer. The second program may be installed on any desired PC and offers a wide range of profile and emittance data evaluation and display functions. All actual available methods to measure and evaluate the ion beams profile and emittance data are described in software description Proemi.app, 2001, NTG.

3 MEASUREMENTS AT ISOLDE/CERN

At the CERN/ISOLDE (Isotope Separator On Line) facility [3,4], the quest for ion sources with high chemical selectivity, efficiency and long lifetime still remains, but in recent days also a strong demand for excellent beam optical properties has arisen. With the increased use of the High Resolution Separator (HRS), and the request for highly mass resolved radioactive beams, the transverse emittance of the extracted beam becomes an important issue as the resolution is inversely proportional to the horizontal emittance. Furthermore, the ion injection into charge breeding and trapping devices require high brightness beams for a high efficiency.

In order to attain a better beam quality, the here presented commercial emittance meter from NTG was installed at the ISOLDE off-line separator where targets are tested with respect to material purity and the ion source efficiencies are determined. Now also the emittance and brightness are measured for different stable elements. An ambitious programme has been launched aiming for a complete survey of the emittance dependence on the various ion-source parameters.
At the ISOLDE off-line mass separator, the ions are extracted from the ion source by an axially moveable extraction electrode (puller), which is followed by an einzel lens and a double focussing 55° dipole magnet. The emittance meter was positioned behind the magnetic focal plane, permitting measurements of monoisobaric beams.

One of the ion-source types investigated was a standard plasma ion source (MK7, FEBIAD type [5,6]). The measurements have, among other things [7], showed that the axial position of the extraction electrode is of major importance for the emittance. The emittance minimum is found for an extraction distance of 80 mm, with a brightness optimum between 60 and 80 mm. The emittance increases with a factor of 3 for H_2^+ and almost doubles for Ar^+ when the puller is displaced ±30 mm. The orientation of the phase-space ellipse was recorded as a function of the distance. A small, but still significant, emittance increase with the anode voltage was found (scanned from 80 to 220 V while the anode current remained constant at 30-40 mA throughout the test). The geometrical 95% emittance, $\varepsilon_{geo}^{95\%}$, went up with 3-4 π·mm·mrad. After optimisation, the emittance for the plasma ion sources was found to be 8-10 π·mm·mrad, for typical operation conditions and an extraction voltage of 30 kV.

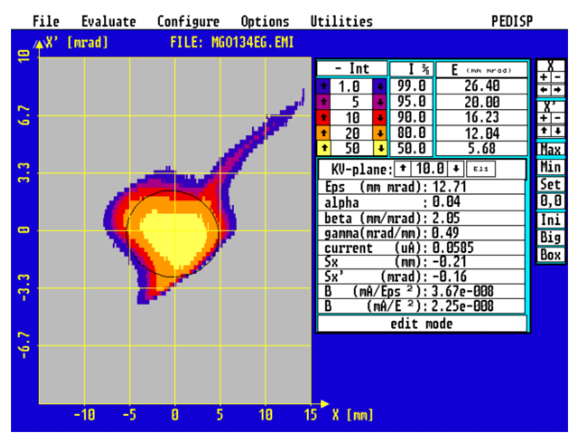

Figure 1: Contour plot of the phase space recording for a 65 nA CO^+ beam. The $\varepsilon_{geo}^{95\%}$ is 20.00 π·mm·mrad, while the ε_{4rms} is calculated to 12.71 π·mm·mrad.

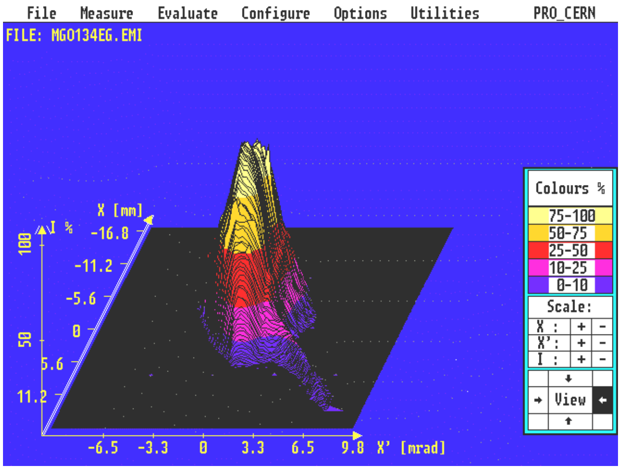

Figure 2: Three-dimensional intensity representation of the emittance for the 65 nA CO^+ beam.

To detect possible aberrations, detailed phase-space recordings were taken for the different settings. For example, Fig. 1 illustrates the phase-space for an aberrated 65 nA CO^+ beam. A slit step-size of 100 µm was used, and with 7 intermediate grid steps an angular resolution of 0.25 mrad was obtained. The integration time was set to 500 ms. The same emittance recording is displayed three-dimensionally as an 'intensity-mountain' in Fig. 2. For certain separated beams, the intensity is very low (in the low nA region) and then a longer integration time is necessary to distinguish the signal, see Fig. 3 and 4.

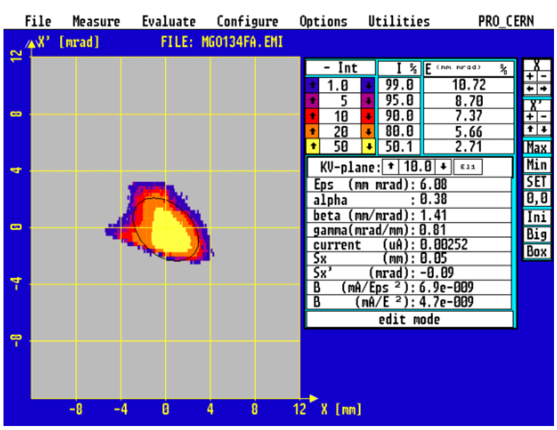

Figure 3: Emittance measurement for a low current beam, 2.8 nA of Ar^{2+}. The integration time was increased to 1000 ms.

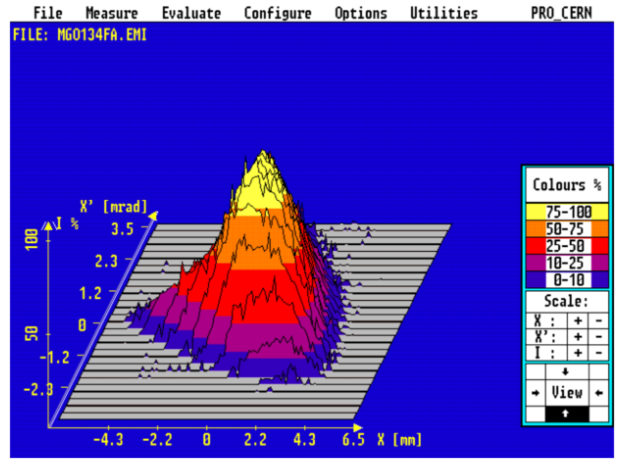

Figure 4: Three-dimensional intensity representation of the emittance for the 2.8 nA Ar^{2+} beam.

4 CONCLUSIONS

The beam emittance analyzer is used in routine operation. One of the main advantages is the very low noise and input leakage current yielding a current sensitivity in the region of pA. Another advantage is the possibility to measure the emittance in both planes sequentially by a single linear motion of slit and grid using only two UHV-feedthroughs.

The detailed emittance investigation at ISOLDE will continue, at the off-line separator and with complementing measurements at the ISOLDE beam lines, with the aim to present a full comparison between the different ion source types and their operation parameters (e.g. gas pressure, line material, extraction hole diameter etc). Furthermore, a standardized procedure for the emittance documentation of each produced target/ion source unit is to be invoked. From the obtained Twiss parameters the mass separator settings can possibly be pre-calculated, and from that the mass resolution and beam transmission can be predicted.

5 REFERENCES

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