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A device for automated phase space measurement of ion beams

J. Lukas, A. Priller *, P. Steier

VERA Laboratory, Faculty of Physics, University of Vienna, Währinger Str. 17, 1090 Vienna, Austria

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Abstract

Equipment for automated phase–space measurements was developed at the VERA Lab. The measurement of the beam's intensity distribution, as well as its relative position with respect to the reference orbit is performed at two locations along the beam line. The device basically consists of moveable slits and a beam profile monitor, which are both coordinated and controlled by an embedded controller. The operating system of the controller is based on Linux with real-time extension. It controls the movement of the slits and records the data synchronized to the movement of the beam profile monitor. The data is sent via TCP/IP to the data acquisition system of VERA where visualization takes place. The duration of one phase space measurement is less than 10 s, which allows for using the device during routine beam tuning.

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Keywords: AMS; Beam diagnostics; Phase space measurement

1. Introduction

In order to guide ions optimally through a beam line, it is helpful to know about the distributions of the particle's positions relative to the default orbit together with their directions of movement. The combined information on these distributions is called the phase space density of the ion beam. Different devices can be used for ion beam diagnostics, e.g. beam profile monitors, moveable slits, and Faraday cups give information on the beam's position. The direction distribution can be measured indirectly by combining two of these devices. The setup realized at VERA is based on the combination of moveable slits [1] and a beam profile monitor (BPM) [2], which are separated by a field-free drift space of 1 m (Fig. 1) [3,4]. These components allow measuring the phase space by manually moving the slits and capturing the BPM data with a storage oscilloscope. However, this procedure is so time consuming and tedious, that it was only done in a rare case in the past [5,6] with great success. By building an automated device, we want to render this method applicable for routine beam tuning.

2. Principle

The transformation of the lateral phase space coordinates (horizontally or vertically) for a field-free drift space is given by

$$\begin{aligned} x &= x_0 + z x_0', \\ x' &= x_0' \end{aligned} \tag{1}$$

where z is the axial drift length and x' the ratio of transversal and axial momentum in the xz-plane. At $z_0 = 0$, we select a certain transversal position x_0 by using a slit with 0.1 mm aperture. After a known field-free drift length z, we measure the lateral beam profile. The spatial distribution of the beam's intensity at this position reflects the lateral momentum distribution. Repeating the measurement for different positions x_0 selected by the slit allows calculating the phase space density distribution. From this

* Corresponding author. Tel.: +43 1 42 77 51 703; fax: +43 1 42 77 95 17.
E-mail address: alfred.priller@univie.ac.at (A. Priller).

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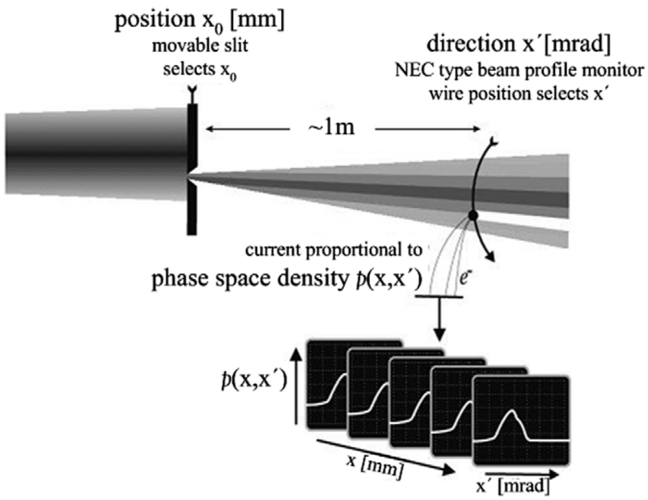

Fig. 1. Schematics of the layout for a phase space measurement by hand. A rotating wire of the beam profile monitor reads the position (direction) distribution for the selected slit position x_0 (vertical distance to the reference orbit). A storage oscilloscope is used to acquire the data. The corresponding phase space distribution is calculated and visualized offline.

information, one can extrapolate the beam properties for any position z along the beam line by applying transformation (1). By integrating numerically over the direction coordinate x', one obtains the beam profile at position z_0. Instead of seeing the profile only at the monitor position, one can calculate a picture of the complete beam along the field-free beam line between ion optical or scattering components (Fig. 2).

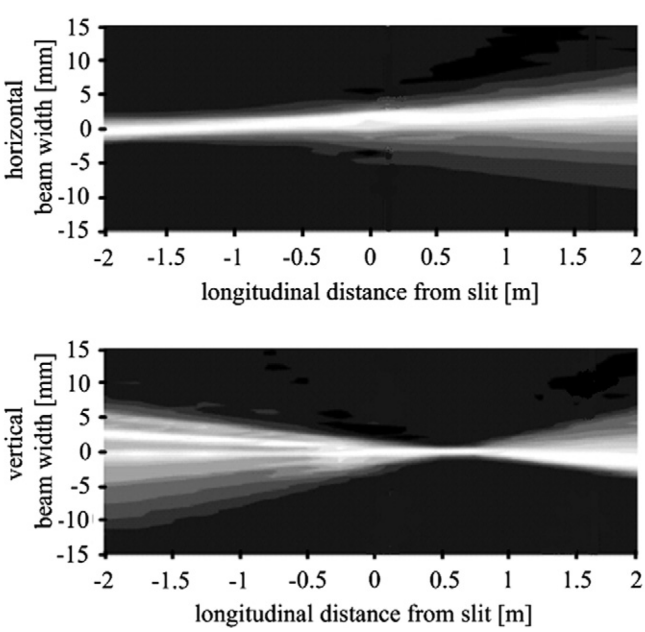

Fig. 2. Intensity distribution of an ion beam from its measured phase space data. Notice that the beam width axis is scaled in mm and the distance along the beam line is scaled in meters. The upper (lower) picture shows the distribution in the horizontal (vertical) plane. Notice also that this figure is adapted from [4] and is not correlated with the figures in Section 4.

3. Realization of the automated device

A fully automated phase space measurement device requires a control system for the coordinated movement of the two baffles forming the slit. To measure the directional distribution of the cut-out piece of beam, a beam profile monitor in combination with a triggering system to get the position of the scanner wire is used. The acquisition of the intensity distributions is done by a data acquisition system together with analog to digital conversion. An embedded controller records the data from the analog digital converter and sends the data for the slit position, as well as the intensity distribution to the accelerator control computer across a TCP/IP (Fig. 3).

3.1. Slit controlling system

The measurement of phase space makes high demands on this unit. The movement of the two baffles forming the slit must be synchronized to keep the opening of the aperture constant. To meet this requirement, we use stepper motors. In the designed configuration, one step should move the baffles 2.5 μm. Digital indicators indicate the positions of the baffles with a resolution of 1.0 μm within the range used for scanning the beam (±4 mm with respect to the default orbit). However, the precision of the positioning is affected by mechanical tolerances of the drive, e.g. insufficient tension of the timing belts. Operation shows that the opening of the aperture is constant within 25 μm over all the scanning range.

3.2. Triggering system

The triggering system correlates the movement of the scanner wire with the BPM data acquisition. The beam

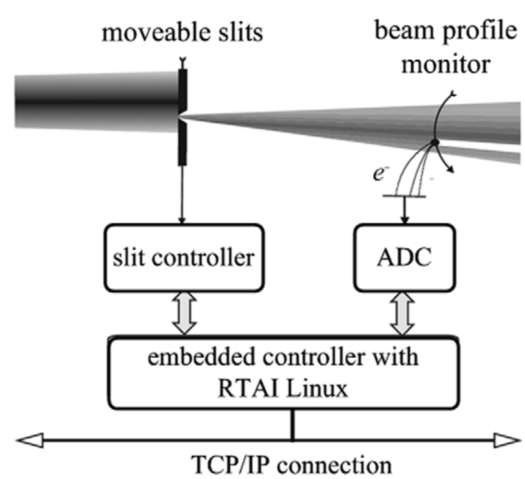

Fig. 3. Configuration of the automated phase space measurement device. The slits are served by the slit control system. A 16-bit ADC is used to acquire the intensity distribution. An embedded controller with a Linux operating system sends the data via TCP/IP to the accelerator control system.

profile monitor delivers per revolution a start signal (fiducial mark) and two time markers for the x and y center positions [2]. The fiducial mark is used by the triggering system to start one individual measurement cycle (frame).

3.3. The measurement cycle

Data acquisition and data transfer to the control computer is done asynchronous and in parallel. For one direction (horizontally, x, or vertically, y) the data acquisition sequence of one so-called BPM-frame consists in principle of three phases:

1. *Initialization*: The trigger starts the frame, the momentary values of the digimatic indicators are logged and a timer delay allows the scanner wire to reach the measurement area. During this delay the data from the previous cycle are sent to the main computer.
2. *Data acquisition*: While the scanner wire crosses the measurement area, the BPM-signal is sampled periodically using a 16-bit ADC.
3. *Idling*: Wait for next trigger.

3.4. Software solution

The central point is a DIL/NetPC with an AMD 410SC micro controller, which is connected with the hardware via a PC104 digital-IO card and a PC104AI16 card. Simultaneously, it serves as port (via TCP/IP) to the accelerator control computer (Fig. 4).

An embedded controller performs the entire measurement procedure. The operating system of the embedded controller is based on Linux with a real-time extension.

4. Demonstration of functionality

For first tests, the phase space measurement device was mounted at the heavy ion detection beam line of VERA [7]. We used a NEC standard type beam profile monitor, as well as a NEC double slit assembly with manual drives which was motorized by the electronics workshop of VERA. The distance between the slits and the beam profile monitor was 1 m. For the test measurements, we tuned a ^{238}U beam. Beam profiles of the beam's vertical and horizontal intensity distributions with fully opened slits are shown in Fig. 5.

For measuring the phase space density in one direction (x or y), one beam profile with a resolution of 1040 points covering a range from −10 to 10 mm was recorded for each position of the slit, which moved from −4 to +4 mm with 123 equidistant steps. Fig. 6 displays calculated horizontal

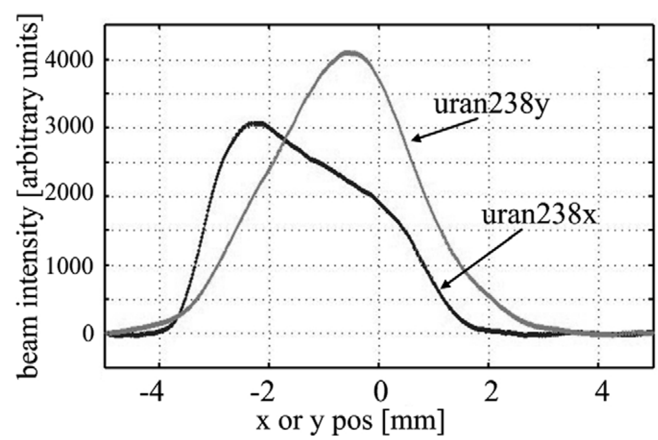

Fig. 5. Beam profiles for the horizontal (x) and vertical (y) direction of a ^{238}U beam, respectively (slits fully opened).

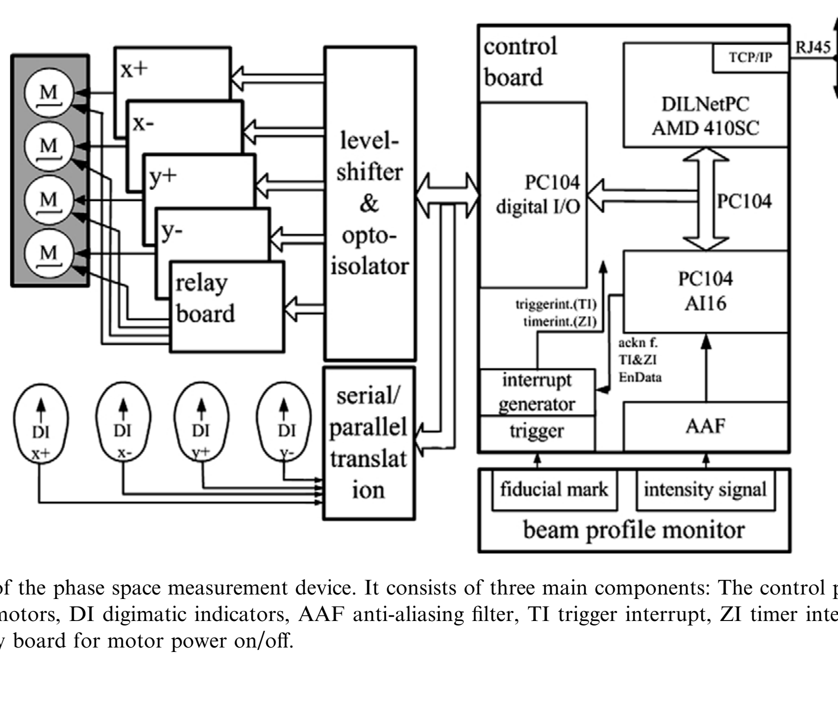

Fig. 4. Hardware approach of the phase space measurement device. It consists of three main components: The control port, the slit controller and the BPM controller. M stepper motors, DI digimatic indicators, AAF anti-aliasing filter, TI trigger interrupt, ZI timer interrupt, AI16 analog input with analog digital converter, relay board for motor power on/off.

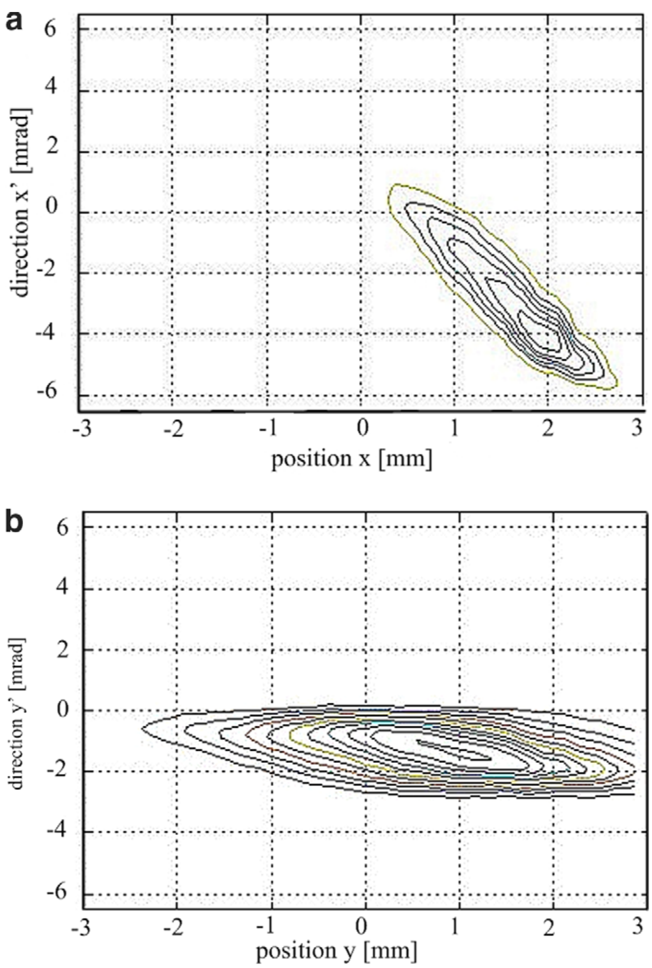

Fig. 6. Phase space distribution in x (a) and y (b) direction at the position of the slits. These distributions were calculated from data recorded by the automatic phase space measurement device. The beam profiles measured for the same tuning using fully opened slits are shown in Fig. 5.

and vertical phase space distributions at the slit position. The phase space ellipses exhibit immediately that the beam waist is after the slit for both, x and y. They also show that the beam is above the center of the beam line and to the right ($x \sim 2$ mm and $y \sim 1$ mm).

At present, the accelerator control computer does calculation and visualization. This computer offers the user a menu to configure and start the phase space measurement, which will then continuously measure and update the phase space image during tuning. We now plan to mount phase space measurement devices at all other important locations along VERA's beam line, as well.

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