Advanced Beam Diagnostics for a Compact Cyclotron

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Abstract

The diagnostic systems developed for the CV-28 cyclotron in the KFA Jülich are reported. Beam profiles are obtained by rotating wire scanners driven by stepping motors. The units have a spatial resolution of 1 mm and measure the beam in the intensity range from about 100 nA up to 50 μA. The energy measurement system uses noninterceptive pick-ups and applies a new method for the determination of the mean energy. The energy can be obtained with high accuracy on an extremely short length base. A personal computer controls both systems and evaluates and displayes the measured data.

1. INTRODUCTION

The CV-28 compact cyclotron of the KFA has been in operation in the Institut für Festkörperforschung since 1976. It is used for a wide range of applications, the average operation time is 2400 hours in a year. The cyclotron is really operated as a multi-particle and variable-energy machine - it is usual to have several different beams a day, mostly on different targets, too.

Diagnostic elements can give a great help to the operators by providing the information required for optimizing the machine setup and beam transportation. On the other hand, they must not spoil the efficiency of the operation, they must be rugged and reliable in construction, and intelligent and flexible in use. The excellent cost/performance ratio of personal computers made it possible to build highly automated and still low-cost diagnostic systems for the cyclotron in the KFA, which measure beam parameters essential for the operation.

2. SYSTEM COMPONENTS

Both systems have been built around an IBM compatible AT computer dedicated to beam diagnostical tasks and located in the cyclotron control desk. Plug-in data acquisition cards from National Instruments interface the control and measurement electronics to the computer.

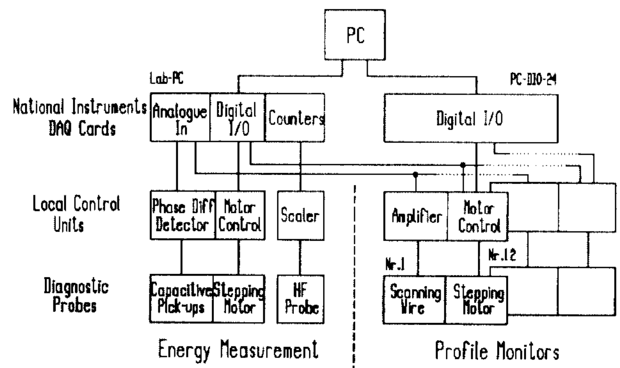

Figure 1. System hierarchy

The block diagram in Fig.1 shows the interconnections of the elements of the systems with the PC. The Lab-PC multifunction card accepts the analogue signals and converts them with 12-bit resolution into digital values. The digital I/O ports on the card are shared between the two systems - they drive the common control lines for the profile scanners and provide all the required control signals for the energy measurement. The counters are used for timing and frequency measurement tasks. The PC-DIO-24 digital interface card provides the dedicated control signals for the scanners, allowing the connection of maximum 12 units into the loop.

3. PROFILE MONITOR SYSTEM

The system gives information about the position and shape of the extracted beam at 9 different locations of the transport system. The monitoring devices are

Hortig-type rotating scanners, designed and manufactured by the ATOMKI [1]. They are driven by stepping motors, the diameter of the scanned region is over 60 mm. The scanning wire performs the consecutive turns in opposite directions. It is directly connected to the electrical vacuum feedthrough with a flexible cable, thus avoiding the use of a sliding contact. By this way not only the reliability of the device was increased but also a possible noise source could be excluded.

The software of the system provides a convenient user-friendly environment for the operators. By the implementation the Virtual Instrumentation (VI) technique was applied. After selection from a menu, the front panel of a virtual instrument appears on the screen, which contains besides the picture fields for the scanners the symbols and status of the control keys, too.

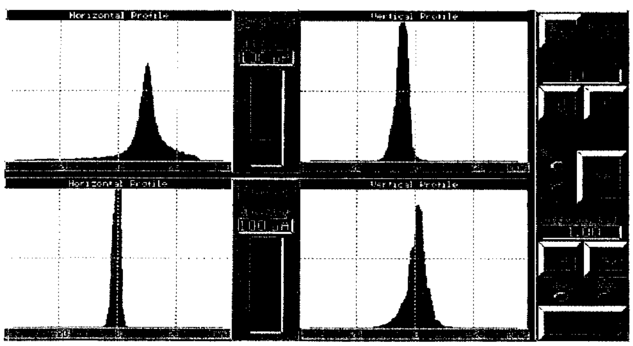

Figure 2. Front panel of the VI for the scanner system

Fig.2 shows a typical display picture as seen by the operator, using two devices simultaneously. The device number of the selected units are displayed in the middle of the picture fields. Between the horizontal and vertical profiles the total intensity values are shown as a bar graph. The operator can initiate any action by pushing a single key. The panel on the right side shows the control keys with the preset mode of operation and displaying. All the routines, controlling the movement of the wire and displaying the measured intensity value are written in machine language. They run fast enough on even a 12 MHz AT286 machine to provide a total scanning time of about 1.7 s.

The system has been in operation since October 1992. There are two devices in the main beam line before the switching magnet and every beam line has an own unit installed near the target location. It works very reliable, there has not been any hardware or software problem yet. The information provided by the system proved to be especially useful for fine tuning the amplitude of the beam wobbling on the targets.

4. ENERGY MEASUREMENT

Since the method of this novel energy measurement has been described elsewhere [2], only a brief summary will be given here. The velocity of the extracted beam is determined by measuring the spatial separation between consecutive bunches in the transport system. The system applies two uniform capacitive pick-ups, one of them can be moved longitudinally along the beam axis. Its central position is about 2.5 m away from the fixed probe, which corresponds to the expected bunch-to-bunch distance in the extracted beams of the CV-28 cyclotron. The travelling distance of the moving pick-up covers a possible energy deviation up to ±12% from the nominal value.

A special wideband signal processing electronics has been developed to compare the relative phases of the HF-pulses induced by neighbouring beam bunches into the two probes. The detector circuit produces a unipolar DC signal which is proportional to the phase error. By moving the probe the phase error can be modified. The value of the detector output signal reaches a minimum when the phase error cancels, i.e. the distance between the probes and the spatial separation of the bunches are equal. The time interval between consecutive bunches is given by the frequency of the accelerating voltage, which can be measured precisely.

The measurement is completely automated. The PC drives the probe between the final positions and measures the value of the error signal and the frequency of the RF voltage at every position. After completion of a total cycle, the position of the minimum of the error signal is determined by fitting a second-order polynomial to the measured data. The beam energy is then calculated from the determined velocity and the known rest energy value of the particles. The useful intensity range of the measurement extends from 1 to 50 μA, the magnitude of the error depends slightly on the beam current. At 1 μA mean intensity an accuracy of $3 \cdot 10^{-3}$ has been achieved, above 5 μA it has improved to about $1 \cdot 10^{-3}$.

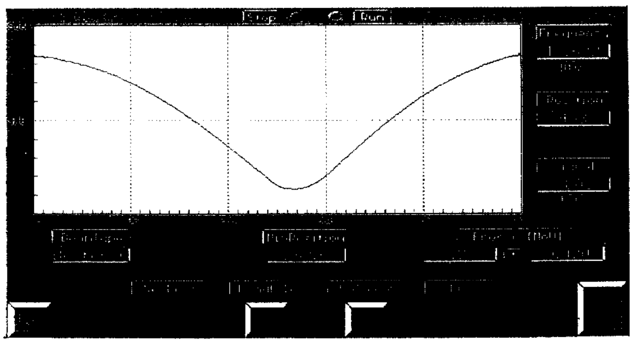

Figure 3. Display picture of the energy measurement system

The front panel of the VI designed for the system is shown in Fig.3. The large analogue display field is used to show the measured error signal as a function of the probe position. The digital display windows on the right show continuously the instantaneous values of different signals during the motion. At the end of every measurement cycle the calculated position of the minimum and the determined energy value appear in the windows below. The time of the measurement is about 50 s.

Table 1 shows the mean energy of some particle beams measured by the system. The proton data are a good evidence that the energy of the extracted beam of a cyclotron can depend significantly on the machine setup even in the case of constant RF frequencies.

Table 1
Measured beam energies

Beam	E_{nom} [MeV]	Freq. [MHz]	Bunch dist. [mm]	E_{meas} [MeV]
p	20	23.249	2527.0	18.553
p	20	23.247	2550.4	18.905
d	8	10.632	2475.8	7.272
α	28	14.076	2554.0	27.096

The energy values shown in Table 2 were taken every half an hour during a long irradiation with an alpha beam of E_{nom}=28 MeV. They are a good measure of both the system and the cyclotron stability. The observed greatest deviation from the average is only about $1 \cdot 10^{-3}$.

Table 2
Results of a serial measurement during a long irradiation

Meas.	Position	Energy [MeV]
1	404.0	27.157 ± 0.004
2	401.9	27.129 ± 0.017
3	401.1	27.120 ± 0.064
4	400.3	27.110 ± 0.014
5	403.8	27.155 ± 0.005
6	399.5	27.099 ± 0.019
7	403.4	27.150 ± 0.005
8	400.9	27.117 ± 0.009
9	403.7	27.153 ± 0.004
10	400.5	27.113 ± 0.009
Average:		27.130

The system has been in operation for about a year and allows the quick verification of the actual beam energy before the experiments.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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