FAST LONGITUDINAL PHASE SPACE DIAGNOSTICS FOR THE INJECTOR LINAC OF MAMI*

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Summary

A device for fast analysis of the longitudinal phase space of an electon injector linac employs crossed deflection of the beam by a magnetic dipole for energy and by the transverse field of a rf-cavity (TM_{110}-mode) for phase analysis, respectively. The design values of 0.5° in phase and 1 keV in energy for the resolution of the analyzing system are deduced from computations made with parmela [3,4,5]. The system is auto optimizing and can display the longitudinal phase space on a video screen without any calculations. Future operators will thus be able to find a good parameter set of the injector just by starting the diagnostics system and watching the variation of longitudinal phase space in function of the parameters of the injector linac. The apparatus and first measurements are presented.

Introduction

In the final setup of the Mainz Microtron (MAMI B [1]) a linac will be used as injector instead of the former Van de Graaff, the latter being hampered by its lack of reliability and stability in energy [2], because of bad vacuum and its inability to work with a cathode for polarized electrons. The large number of parameters of the injector linac necessitates a fast diagnostics system for measuring its output distributions in energy and phase and for displaying the longitudinal phase space directly. The principle of the system built for this purpose is shown in Fig. 1. By arranging a magnetic dipole (energy analyzer) and an rf-cavity (phase analyzer) for crossed deflection a picture of the longitudinal phase space is obtained e.g. on a ZnS-screen placed at the end of the beam line.

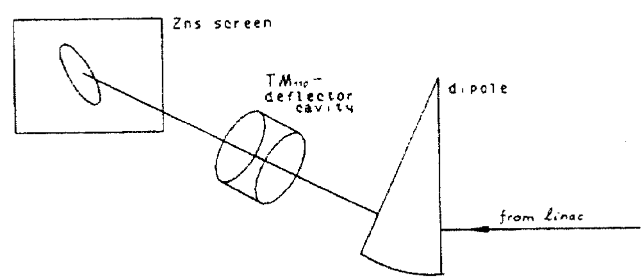

Fig. 1: Principal function of diagnostics system.

Analysis of Phase and Energy

Imaging Principle

To also obtain quantitative information on the electron distribution in phase space, however, in our setup the beam is scanned over two pairs of slits placed orthogonally at positions of horizontal and vertical waists, collecting the charge in a faraday cup (Fig. 2). Vertical and horizontal scannings are achieved respectively by deflection with steering coils and by phase shifting the rf-input of the cavity, information on energy spread and bunch length being derived from coil current and phase-modulation amplitude of the rf. The resolution is limited for energy by the ratio of energy dispersion of the deflecting dipole to vertical beam envelope and for bunch length by the amplitude of rf-deflection to horizontal beam envelope

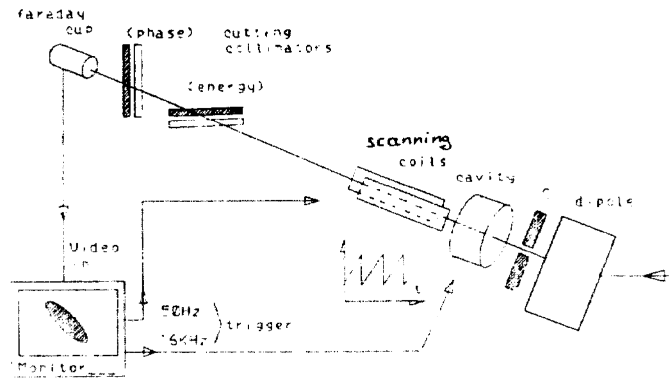

Fig. 2: The imaging system of the phase space analyzer.

(cf. Fig. 3 and 5). When scanning the beam with the frequencies used in TV cathode ray tubes (50 Hz vertically, 16 kHz horizontally), the signal of the faraday cup can be used as video input signal, enabling thus the longitudinal phase space to be displayed on a TV set, the brightness informing on charge density. The absolute energy of the bunch is determined by the current/field-characteristics of the deflecting dipole.

For the sake of simplicity and easy operability of the system no attempt has been made to provide isochronous deflection by a magnet system. Instead, the collimator C next to the deflecting dipole cuts away electrons with too high deviation from the beam axis, that is too high phase advance.

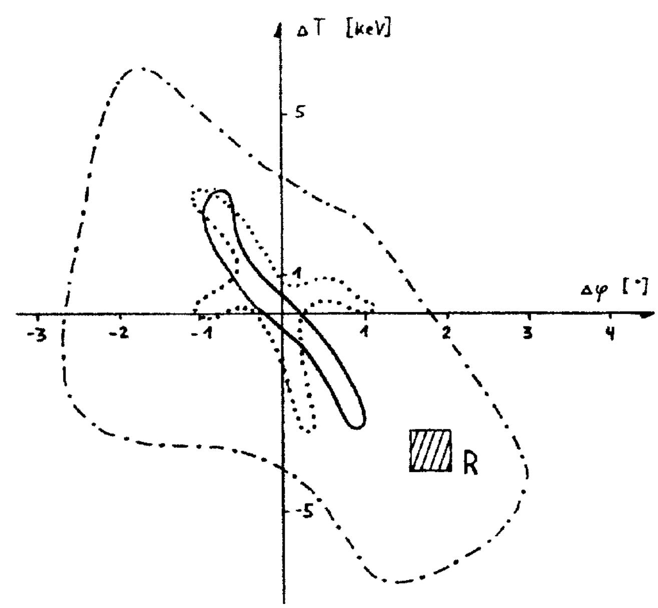

Fig. 3: Longitudinal output of linac as calculated [4,5] with PARMELA, compared with design value R of resolution of the diagnostic system (dashed and full curve - linac output without and with space charge effects (100 μA), dashed-dotted curve - phase space envelope for realistic mistunings of linac [3]).

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Dipole

In order to avoid hysteresis effects, the deflecting dipole is built of Hyperm (a soft-magnetic Ni-Fe-alloy), available only in sheets of thickness 0.5 to 1.5 mm (cf. Fig. 4a). The poleface of Rogowski-shape was optimized arranging the sheets according to computations with POISSON and SCHEIBCHEN. Inactive clamps (not included in Fig. 4) limit the extension of the fringe field. To decrease the remanence, the filling factor of the pole face is only 1:2 (Fig. 4b). A remanence of 150 mG was measured, which is a factor of two higher than expected. The reason may be a slight deformation of the annealed Hyperm in assembling the dipole.

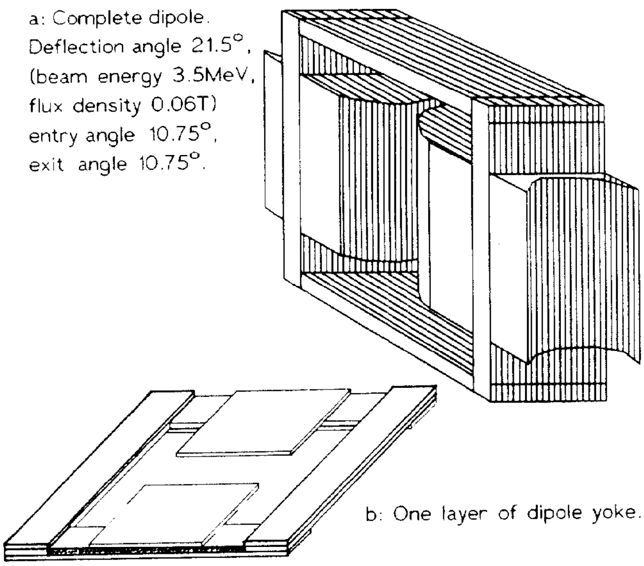

Fig. 4: Magnetic dipole made of Hyperm sheets (coils and clamps omitted)

Scanning Coils

In principle, the energy scanning might be achieved by wobbling the field of the dipole. However, it would then be difficult to avoid field distortions due to eddy currents in both the Hyperm sheets and the vacuum chamber. Therefore, the energy-proportional deflection is done with separate ironless deflecting coils immediately behind the rf-cavity. In order to avoid distortion of the sawtooth-shaped time function of the deflecting field by eddy currents, the beam pipe at the coils is made of 0.2 mm bronze reinforced at the outside by a 5mm epoxy resin coating.

Deflecting Cavity

The deflecting cavity for the diagnostics of bunch length is a TM_{110}-mode circular resonator (2450 MHz). Though its deflection efficiency is 25% less than that of a rectangular TE_{101}-resonator, it was chosen for its superior beam optical qualities [6]. For obtaining the design value of 0.5° in phase-resolution, it needs the rather high power of 1.5 kW, in spite of putting it as far away as possible from the faraday cup immediately behind the deflecting dipole. Putting it farther upstream in front of the dipole was not possible, because it introduces an additional energy spread (Panofsky,[8]), which would have been mixed into the energy analysis done by the dipole. In addition, the cavity is fed from the same rf-source as the 14 MeV-RTM and by a standard waveguide attenuator phase shifter its amplitude can only be lowered by a factor of 40, so that it would permanently disturb the main beam.

The cavity was brazed from OFHC copper and stainless steel, thus integrating an efficient all-around cooling system. Its resonant frequency (i.e. phase) is held constant by a tuning plunger. Power input is via a standard waveguide (WR 340) and vacuum window a used for the MAMI rf-sections. The main data of the resonator ar [7]: Diameter 148.5 mm, length 55.4 mm, mode stabilization b inductive posts (diameter 6 mm, wall distance 12 mm, TM_{110}-mode splitting 130 MHz), quality factor 22500 and deflection: 0.3 mrad $* \sqrt{P/\text{Watt}}$. In the arrangement of Fig.1 the zero of th deflecting field corresponds to the middle of the bunch, in ou arrangement every part of the bunch can be chosen to b undeflected by shifting the phase.

Beam Line Design

The design of the beam optics is shown in Fig. 5. In orde to realize the high resolution required, very narrow waists must b obtained at the locations of the two collimating slits. This i achieved by means of two quadrupoles placed in front of th deflecting magnet. The first quadrupole Q1 simultanously increase the beam envelope vertically and horizontally by its short foca length. The second quadrupole Q2, producing a vertical waist a the location of the energy-collimator, allowed to build the dipole a a rectangular magnet, which simplified its construction. It i therefore only active in the horizontal plane, producing the horizonta waist at the phase-collimator.

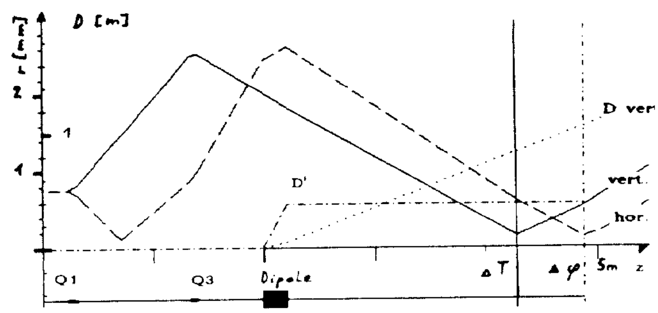

Fig. 5: Transverse envelopes and dispersion D of electron beam

First measurements, state of construction

The components of the system for automatic self-optimizatio e.g. for tracking the linac output-energy by the current of th deflecting dipole, are still under construction. The deflector cavit has been operated up to 2kW without any vacuum- or sparking problems. Some hand steered measurements were performed an the system successfully measured the energy stability and the spec trum of the linac [3].

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