THE GUN/CHOPPER SYSTEM FOR THE MAINZ MICROTRON*

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Summary

The design and setup of the gun/chopper system for the 3.5 MeV injector-linac [1] of the 850 MeV CW electron accelerator MAMI [2] is presented.
The gun delivers a 100 keV DC electron beam with a maximum current of 1.5 mA. Chopping is done with a frequency of 2.45 GHz by a system working with a novel rf-cavity type, which yields a circular deflection with only one rf-input. A compensation scheme allows bunch-lengths down to ±10° without increasing the transverse emittance delivered by the gun.

Setup

The arrangement of the components on the 100 keV beamline is shown in figure 1. The design of the prebuncher is presented elsewhere on this conference [1], a detailed description of the wire scanners is given in [3]. It is planned to replace the first wire scanner with an inflection magnet for a polarized electron beam [4]. All elements on the beamline are magnetically shielded by a sheet of 1.5 mm Hyperm.

100 keV electron gun

The gun-setup [5] is shown in Fig. 2. A special feature is, that it consists of a compact 12.5 keV emittance-forming unit (in similar form already used in the Van de Graaf injector [6]) and a 87.5 keV booster unit. The connection flange is easily accessible, e.g. for mounting another emittance-defining aperture or a cathode for polarized electrons. The final anode is inserted as a reentrant nosecone equipped with a solenoid (B=0.03 T max.) to focus the beam out of the 87.5 keV-insulator. The cathode is of the barium-dispensor type (Siemens MK20), at nominal heating of 1080° and a vacuum better 10^{-6} Pa a lifetime $>10^{4}$ h is prospected. The maximum operating voltage of the gun is 120 keV, however, from demands of linac beam dynamics [1] and a high safety against break down 100 kV were taken. The high voltage stability of the power supply is better 10^{-5}. At the maximum beam-current of 1.5 mA the transverse emittance is 0.94 $\pi\cdot$mm$\cdot$mrad; at lower currents the emittance goes down by changes in the optics of the 12.5 keV-unit with its emittance filter at the end (roughly according to $0.2+0.6\ \pi\cdot\mathrm{mm}\cdot\mathrm{mrad}\cdot\sqrt{I/\mathrm{mA}}$).

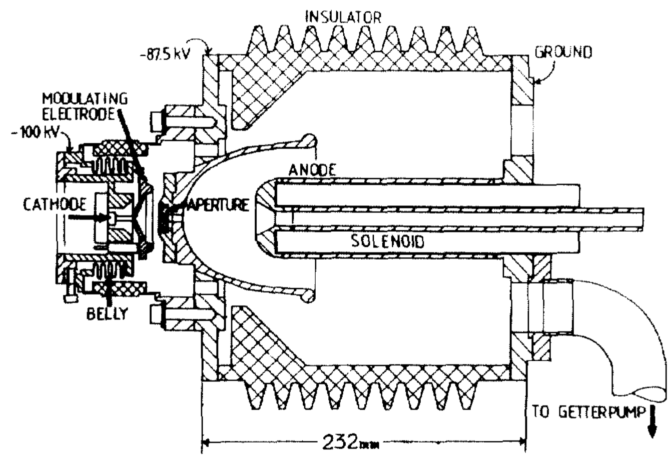

Fig. 2 The 100 keV gun

Chopper system

The 3.5 MeV injector linac demands a chopper system, which yields a bunchlength of ±20° or less [1]. To obtain this value without increasing the transverse emittance delivered by the 100 keV electron-gun, a system consisting of two circular deflecting rf-cavities, a slit-collimator with adjustable slit-width and a solenoid-pair (fig. 3) was built up [7].
The bunchlength can be tuned both by variation of the rf-amplitude and the slit-width.

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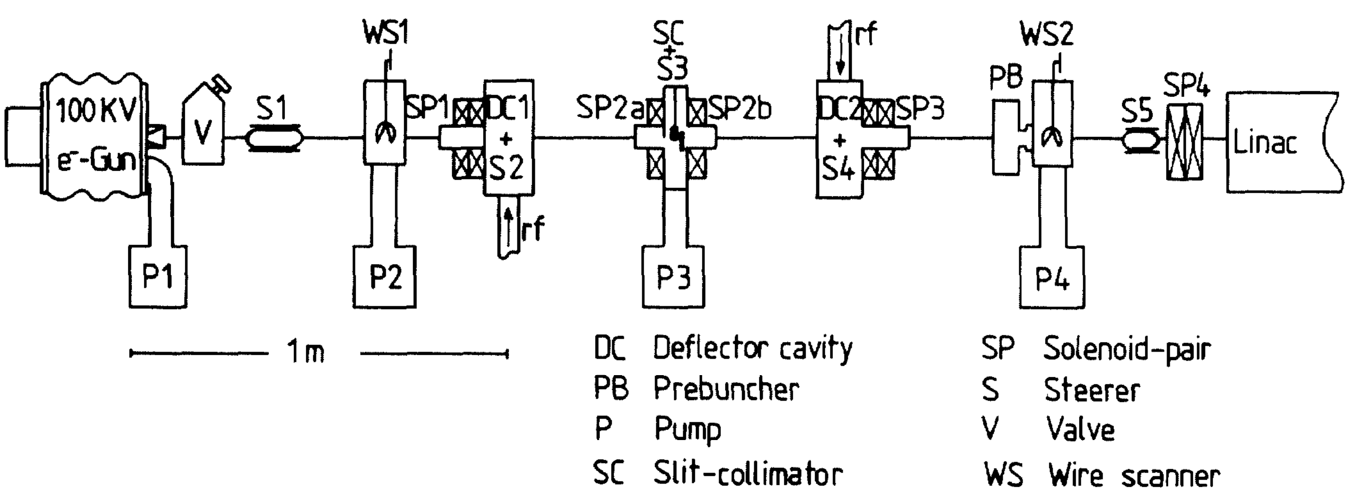

Fig. 1 The 100 keV beamline

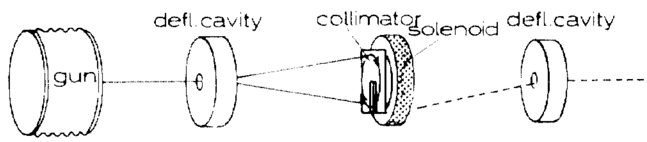

Fig. 3 Scheme of the chopper system

The focal length of the solenoid pair 2 (fig. 1) is half the distance between the cavities and the slit. Hence the part of the beam, which passes through the slit is focused to the axis at the second cavity. If the second cavity has the same amplitude and phase (in the coordinate system of the bunch) as the first one, it cancels the transverse momentum imparted to the beam there [8].

The horizontal and vertical emittance of the chopped beam can be evaluated by measurement of the horizontal and vertical beam size at wire scanner 2 for different focal lengths of the solenoid-pair 3 [3].

Deflector cavities

The circular deflection by the chopper cavities is realized by a spatially screw-shaped transverse magnetic field along the beam axis (Fig. 4). The direction of the resulting magnetic force on an electron then depends on its entry phase into the resonator.

For an idealized consideration this field can be described by:

$$\left.\begin{aligned} B_x &= A\cdot\sin\omega t\cdot\sin\frac{2\pi}{\lambda}\cdot z \\ B_y &= A\cdot\sin\omega t\cdot\cos\frac{2\pi}{\lambda}\cdot z \end{aligned}\right\} \text{ for } z \in \left[-\frac{\lambda}{4}, \frac{\lambda}{4}\right]$$

$$B_x = B_y = 0 \qquad \text{for } z \notin \left[-\frac{\lambda}{4}, \frac{\lambda}{4}\right]$$

(λ-distance covered by the electrons during one rf-period, A-amplitude of the rf-field)

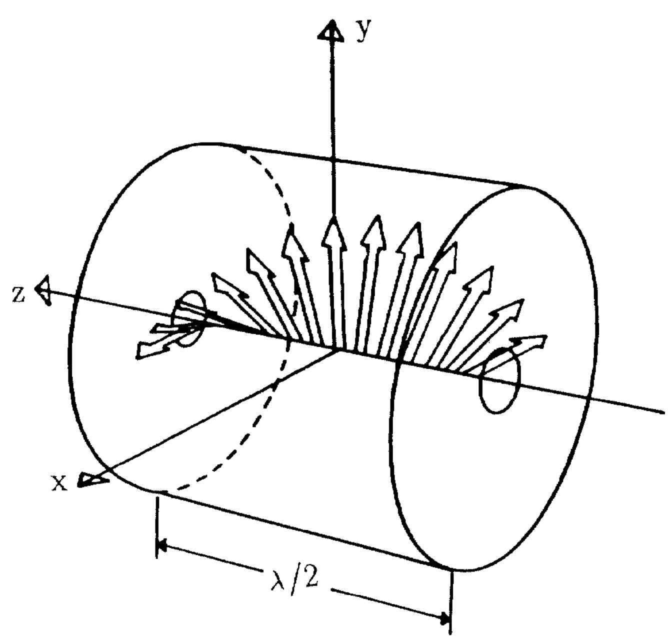

Fig. 4 Idealized scheme of the deflecting field

Integration of the resulting equation of force yields the required circular deflection:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \frac{\pi\cdot e\cdot A}{2\cdot m\cdot\omega}\cdot 10^3\cdot\begin{bmatrix} \sin\varphi \\ \cos\varphi \end{bmatrix}$$

where x',y' is the resulting deflection in mrad (e/m-charge mass ratio of the particles, φ-phase of the particles relative to the r.f.-field).

Several different geometries to achieve the required field distortion in both rectangular and cylindrical cavities have been investigated by bead pull measurements [7,8]. The cavity finally chosen, optimized for closely circular deflection, is shown in fig. 5.

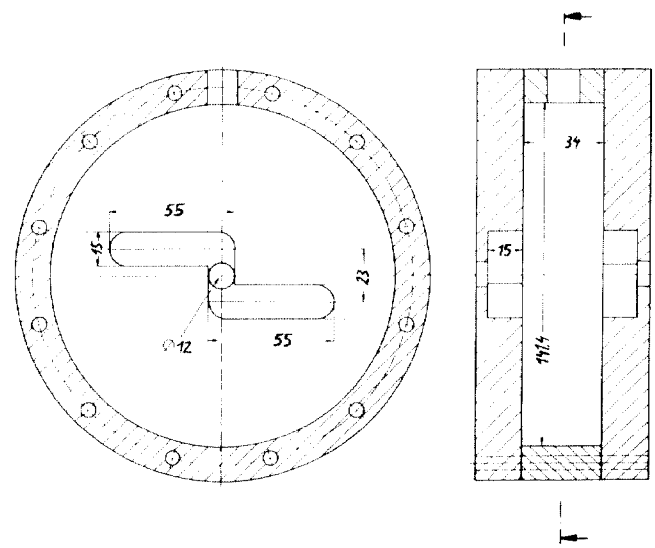

Fig. 5 The chopper cavities.

By evaluating the bead pull measurements, it was found, that the deflection angle α for 100 kV electrons is $\alpha/\text{mrad} = 1.24\cdot\sqrt{P/\text{Watt}}$ for cavities made of AlMg3 (P = rf-input power). The determination of α with the electron beam results in a 7% higher value, presumably caused by the uncertainty in the measurement of cavity-Q and the calibration of the bead. These results got a not very precise but vivid verification after decomposing the chopper: The beam had drawn visible traces in some brownish colour on the tungsten jaw of the slit collimator (Fig. 6).

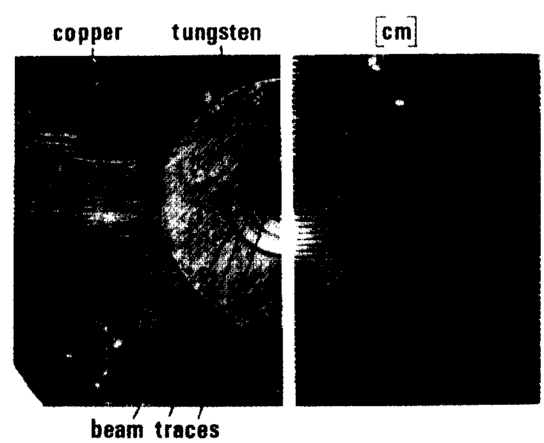

Fig. 6
Part of the decomposed chopper slit-collimator. The three thick beam-traces correspond to the mostly used rf-amplitudes.

Imperfection of the compensation scheme

An electron passing the first cavity with phase φ and a small transverse deviation (x,y) gets a change in longitudinal momentum

$$\Delta p_z \simeq \frac{\pi}{2}\cdot e\cdot A\cdot \gamma\cdot (y\cdot \sin\varphi - x\cdot \cos\varphi)\cdot 10^{-3}$$

where x and y are given in mm ($\gamma = m/m_0$). This follows from [10,11]

$$\vec{p}_t = -\beta\cdot c\cdot \nabla_t(\Delta p_z) \qquad (\beta = \frac{v}{c})$$

This change in longitudinal momentum causes a shift $\Delta\varphi$ of the electron entry phase into the second cavity, depending on the transverse particle position:

$$\Delta\varphi = \frac{\pi}{2}\cdot\frac{e\cdot m\cdot A\cdot L\cdot \omega}{p_z^2}\cdot (y\cdot \sin\varphi - x\cdot \cos\varphi)\cdot 10^{-3}$$

(L-distance between the cavities in m). In consequence of this phase shift the bunch is lengthened due to the finite transverse beam diameter in the cavities and the compensation of the transverse momentum is imperfect. The broadening of the longitudinal momentum itself is compensated however in the second cavity, apart from higher order effects.
On account of this effects it is recommendable to realize a certain bunch-length with a rf-amplitude as low as possible and a small collimator slit width. This adjustment has the additional advantage, that it is insensitive to small deviations from the correct rf-phase in the second cavity (see below). The described effect is essential for all deflector-cavity types and not a special attribute of the cavity used here.

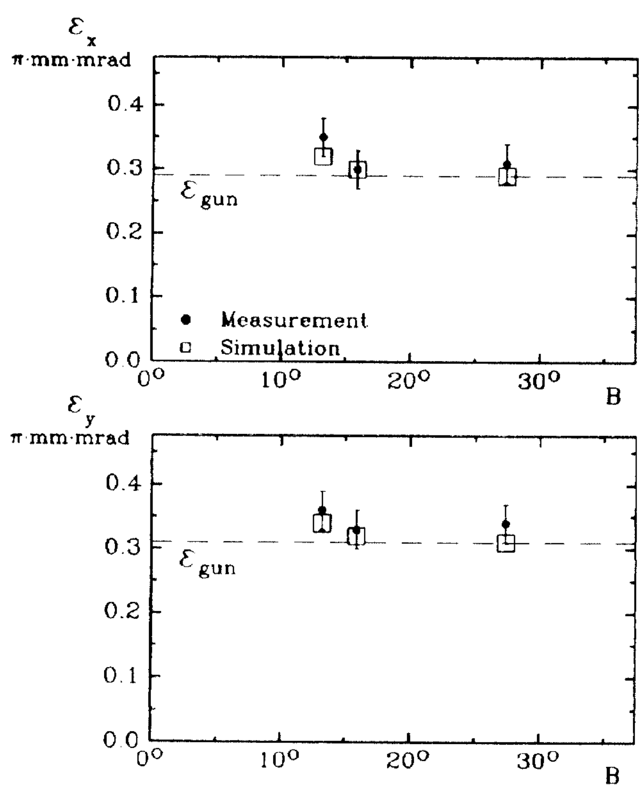

Fig. 7
The horizontal and vertical r.m.s. beam emittance vs. total bunchlength (gun current=80μA).

Transverse emittance of the chopped beam

The effect of the chopper on the transverse emittance was investigated: a) for different rf-amplitudes and correct phase adjustment of the second cavity and b) for different rf-phases of cavity 2 relative to cavity 1. The results of the measurements were compared to calculations with a multiparticle simulation code, which computes the r.m.s.-emittance of the chopped beam.
a) It turned out that it is possible to obtain a bunch-length lower than ±10° without a significant increase in transverse emittance (Fig. 7).
For shorter bunches respectively higher rf-amplitudes the imperfection of compensation described above becomes predominate. The good agreement between the measurements and the results of the simulation shows, that there are no unknown effects, which are relevant to the beam quality of the chopped beam.
b) The investigation of the phase dependence showed that the sensitivity to misadjustments grows with the width of the collimator-slit. If the width of the slit is equal to the diameter of the unchopped beam at the collimator, a phase error of 10° causes an emittance growth of about 13%, with a slit width three times larger the emittance growth is 43% ! In normal operation the phase can be optimized and kept constant safely within ±2°.

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