Design of an Active Beam Splitter for MAMI *

H. Euteneuer, H. Herminghaus, M.O. Ihm, K.-H. Kaiser
Institut für Kernphysik, J.-Gutenberg Universität, D-55099 Mainz, Germany
V.I. Shvedunov, A.V. Tiunov
Institute of Nuclear Physics, Moscow State University, 119899 Moscow, Russia

Abstract

The design of a beam splitter for the Mainz Microtron, working by active bunch-to-bunch rf-energy-modulation within an already realized energy-loss beam transfer system is described.

1 INTRODUCTION

The Mainz Microtron (MAMI, [1]) delivers a low emittance cw-electron-beam between 180 and 855 MeV, in steps of 15 MeV, with a current of up to 100 μA. It has to serve five experimental areas [2]. However, in spite of the partly very low electromagnetic cross sections, the full current cannot be used for many of the experiments, be it because of thermal limitations at the target, be it by counting rate limits of the detectors (e.g. $i \leq 100$ nA at the tagged photon facility). Moreover, for modern sophisticated coincidence detector setups, the testing and adjustment time which generally needs only low beam currents is often comparable to the final data-taking time. Therefore at MAMI [3], just as at other cw-electron-accelerators ([4],[5]), a beam splitter would considerably enlarge the usability.

This splitter should be able to deliver a cw-beam of undiminished high quality to several experiments simultaneously. Because most of the experiments at a low emittance accelerator like MAMI rely on a very monochromatic and halo-free beam [1], any simple passive "peeling" devices [4], generating a parasitic beam by inserting an absorbing edge or a wire into the mainstream, will be rejected. One has to apply a clean active bunch-by-bunch rf-separation; the freedom for the energies and currents of the different beams clearly depends on the structure of the existing accelerator and the amount of money and manpower one wants to investigate for the splitter.

2 BASIC DESIGN

There are two principal methods to split a bunched beam: using direct rf-deflection by a TM_{110}-structure followed just by a drift space, or applying acceleration/deceleration to succesive bunches by a TM_{010}-section and using the dispersion of a subsequent beam transport system for separation. In both cases the differential deflection will be small and a septum magnet has to be placed at the end of the system for final beam splitting.

The use of TM_{110}-deflectors is well documented [6] and has also been taken into account for MAMI [7]. There are two main disadvantages: First, the shunt impedance for this mode is only 20 to 25% of that of a TM_{010}-structure at the same frequency, which means very high power consumption or a very long drift space, and second, the rf-structure is rather difficult to fabricate, e.g. the cavities are quite unwieldy with their by a factor of 1.6 bigger diameter, and mode spacers for clear separation of the orthogonal modes have to be inserted. Therefore, if an appropriate design of the magnetic beam transfer system is possible, the use of an energy modulating rf-section is highly preferable.

The principle of the beam splitter planned for MAMI is shown in fig. 1: the transfer system is built achromatic, but it consists of two compensating opposite chromatic halves and in transverse phase space it produces approximatly a parallel to parallel transformation. The energy modulating rf-structure then has the same function as the inelastic scattering target in an energy loss spectrometer.

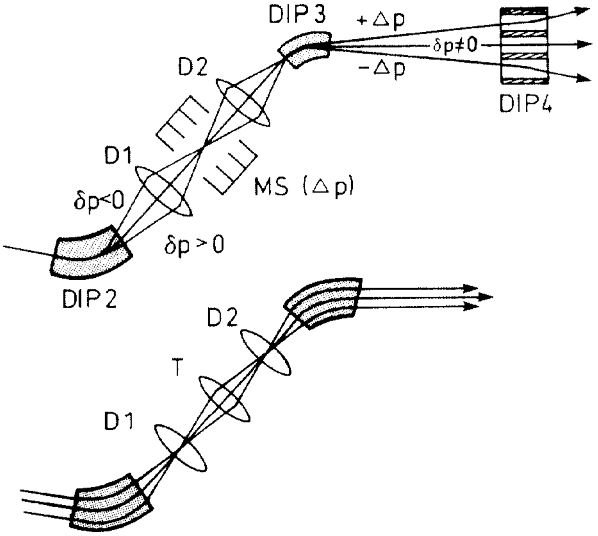

Figure 1: Energy-loss principle of the MAMI beam splitter

3 REALISATION OF SUBSYSTEMS

This type of beam transfer system is already realized at MAMI [8]. To make it working as a beam splitter, only the rf-section has to be inserted and the beam optically quite neutral ±3° switching magnet at its end has to be replaced by a septum magnet plus two beam steerers. The main dipoles of this system are more or less modified magnets

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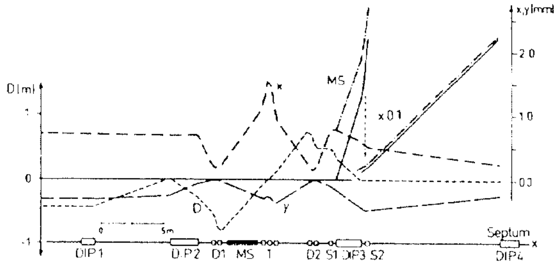

Figure 2: Horizontal and vertical beam envelopes and dispersion of the transfer system. MS-energy modulation section on.

we got via CEA from the dismantled 2 GeV double storage ring "DCI" at Orsay. The trajectories for two 855 MeV beams, separated by 1.3 MeV in the rf-section are shown in fig. 2. The two quadrupole doublets D1 and D2 are used for complete compensation of the total dispersion. They have nearly no influence on the transverse optics which is set mainly with the triplett T at a place of large beam diameter. The two singuletts S1 and S2 support the edge focussing of DIP3, and S2 is horizontally defocussing to maximize the beam separation at DIP4 (septum). T together with S1 and S2 makes a double focus there. The system was optimized for a large distance DIP2 to DIP3 (up to 3.0 m mechanical space for the rf-section) and DIP3 to DIP4 (11.7 m, which means a beam separation of 22 mm/0.15% $\Delta p/p$); at the same time one gets low focusing powers for the quadrupoles of the rather complicated optics.

For the rf-system one has to decide the number of splitted beams and then choose the operating frequency. In principle, there are a lot of possibilities $\nu = m/n \cdot \nu_o$ with m/n a rational number and $\nu_o = 2449.532$ MHz the MAMI-frequency. However, for $m/n > 1$ only integer +0.5-numbers are useful, because otherwise the bunches being accelerated on the slope of the short rf-wave, the very narrow energy spectrum of MAMI (30 keV FWHM at 855 MeV [1], 1.2° bunch length) would be distinctly deteriorated. For the subharmonic choice $m/n < 1$, one should not go too far below 1 GHz, because otherwise for a fast coincidence electronics the cw-character of the beam would be lost. A very important point is of course the availability of a power klystron at the chosen frequency.

For MAMI, an operation at $\nu_o/3$ delivering 3 or 2 beams with a principal intensity ratio of 1:1:1 or 2:1/1:2 respectively, or at $\nu_o/2$, delivering two beams of equal principal intensity has been considered (fig. 3). The two possibilities are compared in table 1, where for the 1.3 MeV-modulating section an on axis coupled structure was assumed ($r = 76$ MΩ/m at 2450 MHz). It should be noted, that a 2.4 m long TM_{110}-deflecting structure behind DIP3, making for 3 beams a separation of ±22 mm on the 11.7 m distance to DIP4, would consume a power of 131 kW at 816 MHz.

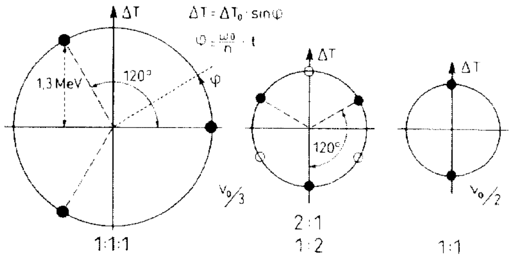

Figure 3: Phase diagrams for splitting at $\nu_0/3$ and $\nu_0/2$.

Clearly the $\nu_o/2$-solution has distinct advantages: only 15% of the power consumption at $\nu_o/3$, i.e. simpler rf-components (cooling, rf-vacuum windows etc.), no worsening of the MAMI-spectrum, a smaller diameter rf-section, which could be fabricated at the internal brazing facility built up for the MAMI-sections ([9], diameter of the furnaces) and a mechanically simpler subharmonic chopper. The price of this setup would be about 600 kDM, only 30 to 40 % of the 816 MHz solution. Because a beam splitter at MAMI can deliver beams of one energy only, the simultaneous operation of more than two experiments seems to be quite unlikely.

A fixed current ratio of 1:1 of the two beams would, of course, be very unflexible. On the contrary, demands for ratios of up to 1:1000 are to be expected (e.g. 10 – 100 nA to the tagged photon facility, several ten μA to an (e, e' p)-experiment). Therefore, also the chopper setup (fig. 4, [10]) in front of the MAMI-injectorlinac has to be replaced by a subharmonic one, without changing its total length. The two circular-deflecting single-input cavities will just be exchanged by a factor of two bigger ones and their power consumption (higher by a factor of $2^2/\sqrt{2}$ because they have to deflect twice the angle for the same chopping ratio and because of their higher Q-value) of 1 kW for 20°-chopping can easily be served by the spare power of the 7 kW-klystron. At the chopping collimator (beam diameter there 0.7 mm on a circle of up to 25 mm diam-

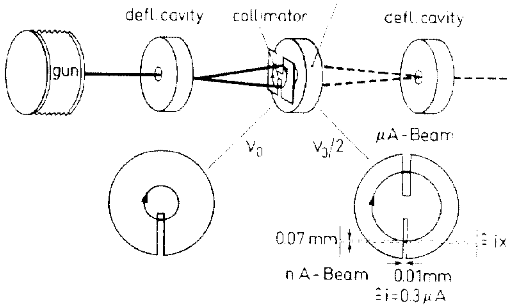

Figure 4: Scheme of $\nu_0/2$ subharmonic chopper setup.

Table 1: Comparision of $\nu_0/3$ and $\nu_0/2$ subharmonic splitter

Op. frequency	816.51 MHz	1224.77 MHz
Modulating Section	13 cells, $L = 2.39$ m, $\varnothing \approx 33$ cm	21 cells, $L = 2.57$ m, $\varnothing \approx 22$ cm
RF-Power (at 855 MeV)	21.5/7.2 kW (3/2 beams)	3.1 kW
Klystron	Television Kl. (Thomson, Philips, EEV ...) 25 - 45 kW, $\eta = 45\%$	RPA TORIY, Kl. Veter-1; 7 kW, $\eta = 43\%$, permanent magnet
No. of Beams	3 or 2 (Intensity 1:1:1 or 2:1/1:2 with standard chopper)	2 (Intensity 1:1 with standard chopper)
Deterioration of MAMI-Spectrum	5 keV FWHM	0.01 keV

eter) two slots at 180°, independently changeable around a width of 1 mm have to be introduced, as well as a third retractable very narrow one for fine continuous regulation of currents in the nA-range. The design has been done and showed that a slot adjustable in the 0.005 to 0.01 mm range can be realized by a 1:10 lever actuated by a flat wedge, which would mean currents of some 100 nA. A second orthogonal fixed width slot of 0.07 mm then cuts away 90% of this beam. Naturally this whole design could be easily modified for a $\nu_0/3$ three beam splitter.

For 1.3 MeV energy modulation, the beam separation at the septum is 22 mm. The beam radius there is typically 0.25 mm horizontally and vertically. Therefore, the construction of a window frame double septum was quite straightforward ([3],[11]) with POISSON and MAFIA. The main dimensions of the 1.4 m long magnet are given in fig. 5. It deflects the 855 MeV beam by ±3° with a bending radius of 28 m at 1.02 Tesla. The power consumption is 2 x 5.2 V x 380 A, cooled away by 1 l/min water, the windings being outside the three 16 x 2 mm vacuum pipes. The field gradient $\Delta B/B$ across the beam is $< 5 \cdot 10^{-4}$ at the entrance and exit. The right/left field asymmetry is $< 10^{-4}$ when shifting the coils by ±1 mm and $5 \cdot 10^{-4}$ when allowing a gap of 1 mm in one of the side yokes. The fringe field was calculated with MAFIA, it is naturally quite uncritical with the small entrance and exit angles.

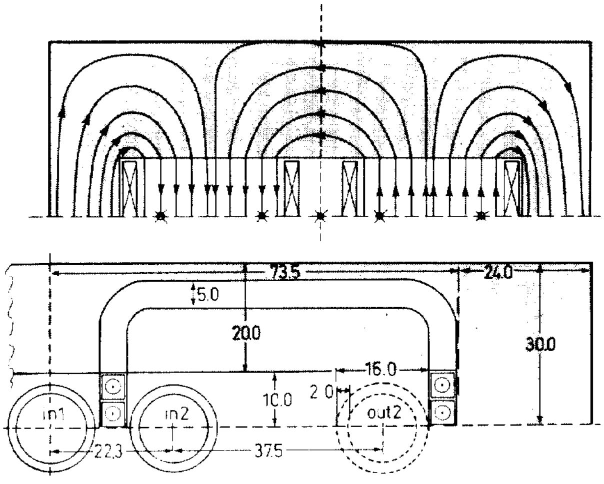

Figure 5: The double septum magnet (for two and three beams).

The scheme of the beam switchyard to the experimental areas A1-A4 [2] for two and three beams is shown in fig. 6, it needs two additional steerers and ±0.2% field changes of DIP3.

It should be noted that the beam splitter would also be useful for the longitudinally polarized beam installed at MAMI [12], at least at 440.65 and 881.30 MeV, because the deflection from the transfer system to three of the experimental areas is ±90° [1].

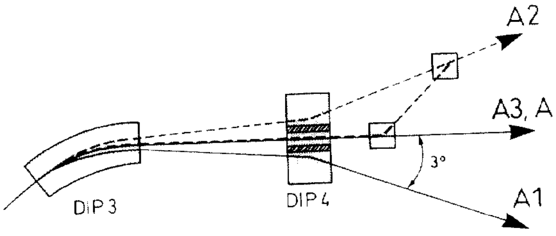

Figure 6: Scheme of beam switchyard.

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