DOWNSCALING THE ENERGY OF THE MAMI-B CASCADE TOWARDS 100 MeV*

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Abstract

New experiments could benefit from energies of 100 MeV, significantly lower than 180 MeV which is the lowest energy routinely available with the microtron cascade of the Mainz Microtron (MAMI-B). This article describes the difficulties which arise due to the drastically reduced injection energy of the first microtron (RTM-1) and presents the results of the beam tests which have been performed. We suggest a new beam extraction system from RTM-2 which will avoid these problems.

PROBLEM DEFINITION

Recently, searches for new gauge bosons with masses from 10-1000 MeV have been started at MAMI-C. MAMI-C is a three stage race track microtron (RTM) cascade [1] which was extended by a fourth stage, a harmonic double sided microtron [2]. Due to the demands of hadron physics experiments the cascade is designed for energies between 180 MeV and 1.6 GeV.

In order to become sensitive to the lower mass range given above the beam energy must be reduced to approx. 100 MeV. In this paper we describe possibilites to achieve this under the restriction that a major redesign or rearrangement of the RTMs is not desirable in the near future.

Different Energies with MAMI

Energy variation is foreseen only for stage 3 and 4. It is achieved without changing machine parameters, by mounting a small deflecting magnet onto different recirculation orbits. The recirculation dipole then transfers the deflected beam to the linac side of the microtron where it still has the same angular kick with respect to the reference orbit. Beams from any turn can therefore be transferred into one single extraction beamline [1].

At the time of the assembly of the cascade a lower beam energy than the injection energy into the third stage was not deemed necessary. Therefore a simpler fixed extraction system is installed on the final turn of RTM-2. In contrast to stages 3/4 the extracted orbit does not pass the linac axis anymore (see Fig. 1). The lowest available energy for experiments is for this reason the 180 MeV output energy of RTM-2. The RTM-2 beam can be delivered directly to the experiments without having to pass stages 3/4.

Two Possibilities for Lowest Energies

In order to satisfy the desire for considerably lower beam energies down to 100 MeV two possibilities exist:

- The microtron coherence condition [3] requires that the energy gain per turn and the magnetic field of a fully relativistic particle fulfill

$$\frac{\Delta E}{B} = n \cdot \frac{ec}{2\pi} \cdot \lambda \qquad (1)$$

with ΔE the energy gain per turn, B the magnetic dipole field, λ the RF wavelength and e, c electron charge and velocity of light respectively. The parameter n is an integer positive number. For CW operating RTMs like MAMI $n = 1$ is the common choice in order to minimize the energy gain required from the linac. It is therefore possible to modify the energy gain of a RTM-stage by scaling the dipole field; in our case a downscaling by almost 50% would be necessary. At MAMI, scaling of a few percent has already been realized in several occasions, for instance for spin tuning [5] or for increasing the energy of MAMI-C above its design value [6]. The additional effort in order to find a machine setting for the new field value was less than two days of beamtime in any case. Due to the good reproducibility of the parameters this effort is required only once and therefore completely acceptable for the users. The downscaling method does not require additional investments and seems, at first glance, to be the method of choice. Its problems arise from the fact that the injection energy into the RTM has also to be scaled, since otherwise the orbits do not fit into the fixed geometry – i.e. the vacuum chamber spacers and beam tubes of the recirculations. Due to this the scaling scheme for RTM-2 requires also scaling of RTM-1. For heavy downscaling the injected beam into RTM-1 becomes more and more non-relativistic. We discuss the limitations which result from this fact below.

- In the early phase of the MAMI project (MAMI-A) RTM-2 was indeed equipped with a similar extraction scheme as nowadays available for stages 3/4. The necessary hardware can be reinstalled with comparatively small effort. However, compared to the present situation, the beam will then be extracted towards the opposite side of the RTM-2 (Fig. 1). Addressing this problem by a rearrangement of the cascade was excluded due to the extended shutdown time this would require. As a manageable alternative, a new separate beamline for the beams with energies different from the RTM-2 standard output energy can be integrated into the existing arrangement. This extra beamline would rejoin the existing 180 MeV beamline towards

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the experiments. It has the advantage that the beam dynamics is not altered, but it requires additional investment and time for its installation. We also discuss this second option below.

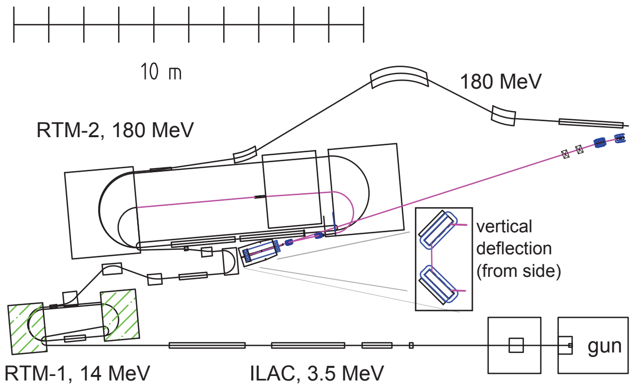

Figure 1: Existing RTM-2 extraction (black beamlines) with possible new variable energy extraction beamline (magenta). The two 90° bends (View from the side shown in a separate box) will bring the beam over the RTM-2 dipole magnet.

OPTION 1: DOWNSCALING

The envisaged reduction of output energy from 180 MeV towards 100 MeV requires a similar relative reduction of magnetic field and injection energy of the participating RTM stages. The critical component is the injection into RTM-1.

The MAMI injector (ILAC) [4] can easily provide stable conditions also for these non-nominal energies by varying the accelerating phase of its third accelerating structure. This option has already been applied for fundamental physics experiments at energies between 1 and 3.5 MeV [8]. Since the longitudinal phase space also does not change significantly at injection, the necessary modification of input energy is feasible as far as it concerns the ILAC.

A lower injection energy (2 MeV) was already used at MAMI A, when the injected beam was provided by an electrostatic accelerator. At that time, however, the same magnetic field for RTM-1 as today was used and the nominal output energy of RTM-1 was achieved by two additional recirculations.

Longitudinal Dynamics

In our downscaling experiment an important difference with respect to the electrostatic injector set-up lies in the fact that the energy gain now is smaller (see Eq. 1). The electrons remain non-relativistic for a larger number of turns and undergo phase shifts because they still are subject to velocity changes. Simulating particles with a code that takes into account the realistic field distribution in the dipoles (and therefore realistic time of flight data for the particles) we could nevertheless predict that stable longitudinal motion can still be achieved under such conditions. Figure 2 shows the longitudinal acceptance at injection energies of 1.56 MeV, 2 MeV and 3.5 MeV.

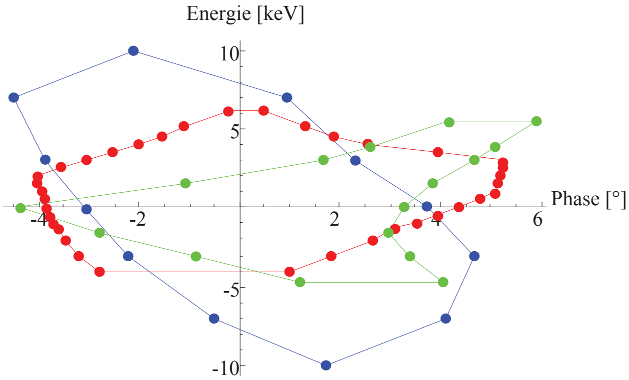

Figure 2: Acceptance ellipses of RTM-1 for different injection energies (blue: 3.5 MeV, red: 2 MeV, green: 1.56 MeV).

For 1.56 MeV kinetic input energy the beam reaches 7.5 MeV kinetic output energy, which after a corresponding scaling of RTM-2 would satsify the requirements. However, the distorted shape of the acceptance indicates that operation at such low energies will become difficult. For a first feasibility study we therefore resorted to a somewhat higher energy of 2 MeV [7] which corresponds to a reduction of electron velocity from $\beta = 0.992$ at nominal energy to $\beta = 0.979$. Though successful acceleration of the beam was demonstrated the main disadvantage of the downscaling showed up in the transverse horizontal motion.

Transversal Dynamics

The vacuum system of RTM-1 consists mainly of the dipole chamber and connecting beamtubes. These beamtubes are mounted on a fixed pattern: as a consequence of the microtron conditions the separation of two recirculating orbits is $n\lambda/\pi = 3.90$ cm which holds for $\beta = 1$ particles. The numerical value corresponds to $n = 1$ and the MAMI RF wavelength. The beam orbit diameters can be made identical on the higher turns, since the particles can fulfill the condition from Eq. 1 for both injection energies. If this is realized, however, the lower orbits are shifted with respect to each other since the orbit radius also scales with the velocity. This leads to a shift of the orbit for the lower energy beam of the order of 1 cm, which provokes beam losses on the injection line, since the beam tube radius is of the same order. In our experiment we observed a loss of approx. 50% in the first few turns during acceleration in RTM-1 which is inacceptable for high intensity operation. We conclude that the orbit shift is prohibitive towards a strong reduction of the input energy for the given set-up. Of course these problems may be solved by designing a new vacuum system and such new equipment could probably be even made compatible with high and low energy injection. However, as explained already above, this option is excluded due to the continuous usage of the RTM for the ongoing experiments. Taking further into account the reduction of the longitudinal acceptance (Fig. 2), we consider this method therefore only suitable for small downscaling, we estimate the practical limit to be of the order of 160 MeV.

OPTION 2: SPECIFIC BEAMLINE

Whereas providing an extracted beam for RTM-2 is comparatively simple (see Fig. 1) the challenge is in the fact that the beam is extracted at a rather unsuitable place, lying in a corner between the RTM-1 and RTM-2. In order to avoid further congestion a compact beam deflection into the vertical plane is necessary. This can be achieved by an achromatic and telecentric 180° deflection system consisting of two 90° segment magnets, which will bring the beam into a height where it is possible to pass over the RTM-2 magnets.

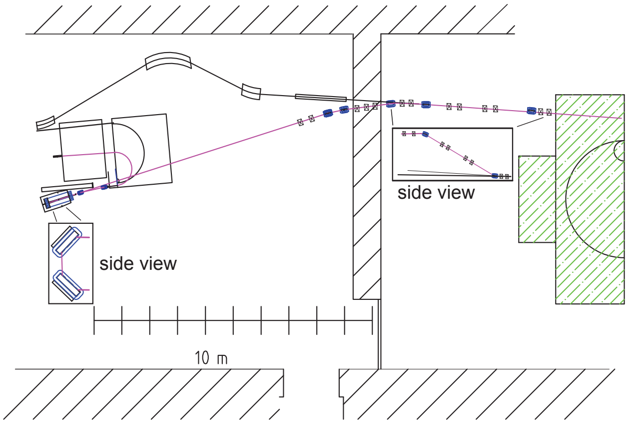

Figure 3: Extra beamline (magenta) from RTM-2 to experiments: Top view and side view (in separate boxes).

In the desired energy range from 80 MeV to 160 MeV the edge focusing properties of the magnets can be controlled by a reverse field region in front of the pole. This is an alternative solution to the field gradient method which is successfully used for the 90° dipoles for the recirculation system of MAMI-C. A similar magnet system was already used for 14 MeV beam transport at MAMI-A [9]. Further beam transport towards a reunification with the existing 180 MeV beamline does not suffer severely from space restrictions and seems feasible.

CONCLUSION

We find that the extra beamline is the best solution to provide a high intensity beam of approx. 100 MeV for experiments at MAMI without changing the existing arrangement and/or hardware of the microtrons. The installation requires certain investments for the magnets and a shutdown period of several months, which is not negligible due to the fact that MAMI-C is operating between 6000-7000 hours per year for the existing experiments. The realization of the project depends on the priority that is given towards the low energy experiments in comparison to those which take place at standard energies.

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