STATUS REPORT ON THE HARMONIC DOUBLE SIDED MICROTRON OF MAMI C [#]

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Abstract

The Mainz Mikrotron MAMI is a cascade of three Racetrack Microtrons, delivering since 1991 a high quality 855MeV, 100µA cw electron beam for nuclear and radiation physics experiments [1]. An energy upgrade of this machine to 1.5GeV by adding a Harmonic Double Sided Microtron (HDSM, [2]) as a fourth stage is well under way. Here we give a review of the experiences gained during fabrication and testing the main components of the HDSM and report the status of its construction. Initial operation of the machine is expected for the second half of 2006.

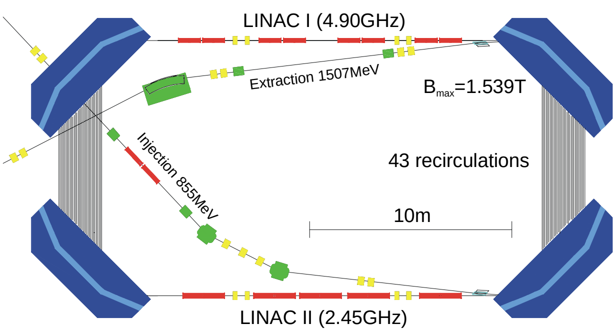

Fig. 1: General layout of the HDSM.

INTRODUCTION

The HDSM (Fig.1) mainly consists of two symmetric pairs of 90°-dipoles, each forming an achromatic 180° bending system. To compensate for the strong vertical defocusing due to the 45°-pole face inclination at beam entrance and exit, these dipoles incorporate an appropriate field gradient normal to the pole edge. This allows a rather simple scheme for transversal focussing, with only two quadrupole doublets on each of the two dispersion free anti-parallel linac axes. One of the linacs operates at 4.90 GHz (twice the MAMI standard frequency) for an synchronous acceleration energy gain per turn below 20MeV and thus a moderately powered rf-system The other linac operates at 2.45GHz for higher longitudinal stability [2].

RF-SYSTEMS

2.45GHz Linac: The necessary max. accelerating gradient of 9.3 MV/pass is realised by five on axis coupled biperiodic rf-sections [3], similar to the ones used at MAMI B. A total of 128kW dissipated rf-power plus 28kW for beam load at 100µA is needed. Each section is fed by an individual 50kW-klystron TH2174, manufactured by THALES as a modernized but totally compatible version of the old MAMI B tube TH2075. The klystrons are individually steered via their input power, ca. 35% below saturation, by rf-amplitude (measured as the average of two section probes) and -phase (measured at the sections input waveguide) stabilisation systems, completely designed and built at IKPH. This allows, with an HV-ripple of 0.4%pp, for an amplitude stability of better then $10^{-5}/10^{-4}/10^{-3}$ and a phase ripple < 0.2°/0.4°/0.7° at 100Hz/1kHz/10kHz respectively. The relative phasing of the sections is easily set by low power coaxial ceramic phase shifters. The steering of the two symmetrical section tuning plungers is done by a PC-controlled step motor driving system, which achieves a long-term phase stability of the accelerating field of <±0.04°. The high power waveguide components (WR340, air), as the Y-circulator (AFT), bi-directional couplers and water loads (SPINNER) and flexaguides (AIRTRON) were put into operation without problems. The sections vacuum windows, the water cooled straight waveguides and E- and H-bends were all built in house at IKPH. All five 2.45GHz klystrons are fed by a single 30kV/27A primary thyristor steered power supply designed and manufactured by BRUKER; a second equal unit serves for the 4.90GHz linac. The complete linac was set into operation in 08/2005. Reconditioning of each section did not take longer than one day. The whole 2.45Gz rf-setup worked very well from the beginning and is together with the complex interlock system fully integrated into the MAMI control system. The precise relative phase adjustment of the 5 sections has to be done as a last step.

4.90GHz Linac: This linac consists of eight accelerating sections [3], each two of them fed by one klystron TH2166. For the gradient of 9.0MV/pass 117kW of dissipated rf-power plus 38kW for 100µA beam load are necessary. An additional section pair and a klystron is needed in the injection path for longitudinal phase space matching between RTM3 and the HDSM.

At 4.90GHz for nearly all high cw-power rf-components prototypes had to be developed, built and tested before a series production could be started. Ten series accelerating sections were delivered by ACCEL between 08/2005 and 02/2006. Development and manufacturing of 5+1spare 4.90GHz/60kW klystrons were offered by the two companies THALES and CPI. Neither of them expected any problems in fulfilling this task; the contract was given to THALES in 09/2000. But obviously

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the problem had been underestimated and it took a long series of prototypes and 27 instead of 12 months expected, until the first tube was at IKPH for urgent high power component prototype tests. Moreover, this tube showed severe multipacting problems, so that further design modifications were necessary, and the last tube was delivered in 05/2005 with a total delay of 26 months. IKPH entered a framework sales agreement with THALES, which guarantees the availability of this klystron TH2166 for at least the next six years; however with a reduced specification of 50kW at 45% efficiency. This guarantees a just safe enough regulation reserve ca. 20% below saturation for 1.5GeV operation of the HDSM. After successful prototype tests all high power waveguide components (WR187, air) e.g. the 4-port differential phase shift circulator (AFT), the air cooled flexaguides (CMT) and the sections vacuum windows (THALES and CPI) are delivered. Because two sections are fed by one klystron via a 3dB divider, a high power phase adjustor must be placed in one of the waveguide branches behind it. It was realised at IKPH by a Ø=5mm Al_2O_3-ceramic rod with variable intrusion depth into a WR187 H-bend and allows to compensate a waveguide length difference of 16mm by its 70° phase range. The steering and stabilisation systems for the five 4.90GHz modules are built in the same way as the 2.45GHz units. The amplitude signal is taken as the average of 2×2 probes from the section pair and the phase from the waveguide input to one section. Actually three of four linac modules and the matching module are ready installed. The first module is in operation for tests of the low power rf-steering system. The missing fourth linac module is under installation after the last big HDSM-components passed its position into the accelerator hall. The 4.90GHz linac is expected to be operational within 08/2006.

90° BENDING MAGNETS

The magnetic and mechanical design of these dipoles was completely done at IKPH [4]. In 2000 the manufacturing contract was awarded to the company SFAR STEEL. Each of the 250to dipoles consists of only a symmetric upper and lower pole piece, clearly the favourable geometry to avoid any field discontinuities. They were casted from high permeable iron. The machining process for a high precision surface of the partly concave pole pieces was elaborated in close collaboration with IKPH. To get the appropriate field gradient for compensation of the vertical defocusing, the gap width opens up from 85mm to 139mm, corresponding to a decrease of the magnetic field from 1.53T to 0.95T. The first magnet was delivered and installed and the field quality checked in 02/2002. It took only till 12/2002 to get all magnets in place and aligned.

To stay within reasonable limits with the necessary corrector magnet strengths and to avoid noticeable deterioration of the longitudinal beam dynamics the relative deviation of the magnetic field from the design field gradient must be in the order of 10^{-4}. This level is only accessible by applying the surface coil correction technique, developed at IKPH for the homogenisation of the RTM magnets [5]. Due to the complicated pole profile it was expected that not only symmetric, but also asymmetric field errors must be corrected. A procedure had been developed to extract both by a simultaneous measurement of the magnetic field in and ±25mm out of the midplane and to construct surface correction coils which compensate them simultaneously [6].

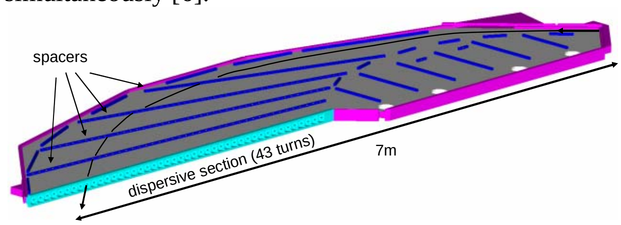

Fig. 2: Layout of 90°-dipole vacuum chamber.

In 09/2003 all magnet field measurements were finished. These were not only done at the nominal field of 1.53T but also at 1.64T and 1.71T, to explore the capabilities of the magnets for a later energy upgrade. It turned out that in the central areas of the magnets the field deviations are already in the order of 10^{-4}. Due to this high manufacturing quality the asymmetric field components are well below 1mT, and therefore only much simpler identical upper and lower correction coils for the symmetric field errors had to be constructed. They were produced by water jet cutting of 3mm thick Al-plates, and in 06/2005 the four pairs of coils were ready for installation. The desired field accuracy of 10^{-4} was easily achieved. Only at the outer edges, at the linac axes and the highest energy return paths, a rather strong field decay exists, reaching far into the fringe field region and thus not be correctible by surface coils. This behaviour was already predicted by TOSCA-simulations and is due to the triangular cut necessary to fit the magnets into the corners of the accelerator hall. At 1.53T this lack of field results in an unacceptable 2.2mrad deflection error at low energy. Therefore at the entrance and exit of each magnet an individually designed vertical iron shim is attached to its front face, which, together with corrector magnets on the return paths and linac axes, corrects the angle and position errors [6]. Each magnet is fed by an individual power supply (478V, 260A, short/long term stability 3ppm/10ppm) manufactured by DANFYSIK. By use of NMR-probes the field is regulated to better than 10^{-5}. Since 02/2006 all four magnets are ready for operation.

OTHER SUBSYSTEMS

Vacuum-Systems: Due to the low gas conductance of the linac sections (beam hole 14/10mm at 2.45/4.90GHz), each linac is equipped with a ∅=100mm parallel bypass tube incorporating 5 resp. 8 “double ended” 150l/s diode ion getter pumps (IGP), and from the ends of each rf-section a short pumping line enters this bypass. Additionally each vacuum window of the sections is equipped with a 35l/s IGP, which provides an rf-power interlock to protect the sensitive ceramic in case of arcs or multipacting phenomena. For start up each line is equipped with 2 resp. 3 turbo molecular pumps (TP) with $10m^3/h$ capacity. This system will guarantee an average vacuum pressure of 10^{-7}mbar, which is sufficient for the high power operation of the rf-sections.

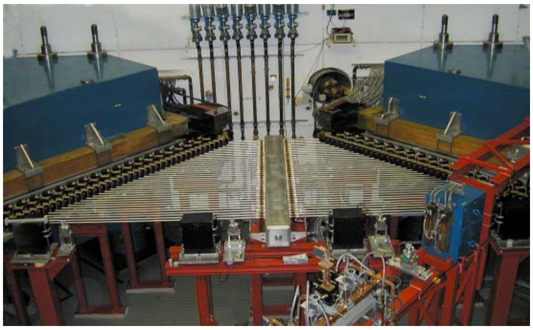

Fig. 3: Return path vacuum system of dipole 3 and 4.

The four big 7m×2m vacuum chambers (Fig.2) for the 90°-dipoles were fabricated in house from 20mm thick Al-plates. Long flat rods are inserted to support the top and bottom plates against atmospheric pressure. These spacer rods have holes at the appropriate positions for the recirculated beams (calculated by tracking calculations with PTRACE using measured magnetic fields), allowing for a minimum free aperture of ±7mm in all directions. Thanks to the small transversal emittance delivered by RTM3 and an only moderate increase of the normalised emittance due to synchrotron radiation ($\varepsilon_{x/y}$ < 8/1 nm rad at 1.5GeV), with average beta functions of less then 20m, simulations with SYTRACE predict a loss free beam transmission with free apertures as low as ±4mm. To take into account the unavoidable some mm distortions of the chambers during the welding process, on each chamber a net of geodetic points was defined and measured with a numerically controlled theodolite system AXYZ (Leica) before and after welding. Based on these measurements the spacer bars were placed through flange holes on the backside of each chamber at their correct position with respect to the beam paths. Each chamber will be equipped with three 300l/s IGPs and one 520l/s TP. For the fresh system worst case estimations predict an sr-induced (at 100μA) / surface gas desorption coefficient of 10^{-4} / $1.5\cdot10^{-3}$ mbar l/s, resulting in a sufficiently low base pressure of 10^{-6}mbar. The 43 vacuum tubes (Al, $\varnothing_i$=13mm) between each magnet pair are interrupted in the middle by a common high conductance pumping chamber, with two 300l/s IGPs and an 520l/s TP. Fig.3 shows the ready installed return paths system of dipole 3 and 4. A total of 192 iron core H-type corrector dipoles for centring the beam in each recirculation on the resp. following linac path (max. ±2mrad at the max. energy of 1.5GeV) are mounted on these return path tubes. Presently the system between dipole 1 and 2 is under installation.

Injection and Extraction: All horizontal bending systems in the injection beam line are designed to act as simple drift spaces of similar length in both horizontal and vertical direction. This will allow for an easy matching of the transverse beam ellipses to the HDSM acceptance. The 4.90GHz rf-module for longitudinal matching is installed in a 4m long section, where the beam is shifted down by 400mm from the MAMI B beam plane to the HDSM midplane. The inflection into the first HDSM orbit is done by two slender C-magnets at the end of the 2.45GHz linac and the beginning of the first return path. The minimum aperture in this system is ∅=15mm; it is ready for operation. The extraction system is somewhat more complicated. This is on one hand due to the fact, that beam extraction should be possible in steps of 15MeV from each of the 43 return paths, and secondly a lack of space dominated the installation of beam optics components. This did not allow a solution with simple achromatic deflection systems; it was only possible to design an altogether achromatic beam transport to the beamline tunnel. At present only the parts of the extraction system necessary to guide the beam on a small low power beam dump in the HDSM hall are under installation, to start as soon as possible with first beam tests.

Beam Diagnostics: In the injection and extraction system as most simple tool for beam steering and beam size control, especially during first operation, a total of 19 viewing screens (ZnS) are installed. On the axis of each linac 2 additional screens with central openings of ∅=5mm are mounted, which allow for some control even of the recirculated HDSM beam. For automatic beam optimisation and stabilisation 12 high-Q rf-cavities are foreseen (most TM_{110} for position, some additional TM_{010} for intensity and phase control). By a new multiplexer and digitalisation system arbitrary combinations of these monitor signals can be either displayed as life signals in the MAMI control room or digitized for computer beam steering. The diagnostic pulse monitor system, with three low-Q rf-cavity monitors on each linac axis to deliver position, intensity and phase information is described in [7]. The new digitalisation system is already in operation for the MAMI B RTM cascade. Furthermore a lot of sr-cameras will be installed at the 90°-magnets and the beam line dipoles.

SUMMARY

After final assembly of the return path system at dipole 1 and 2 and the 4.90GHz linac the first operation of the HDSM is expected in October 2006. Following a period of low beam power commissioning in diagnostic pulse mode (10ns high intensity pulse trains with max. 10kHz rep. rate), the delivery of cw beams for nuclear physics experiments is planned before end of 2006.

REFERENCES

[1] A. Jankowiak, EPJ A direct, i2006-09-016-3
[2] A. Jankowiak et al., EPAC2002, Paris, p. 1085
[3] H. Euteneuer et al., TUPCH118, these proceedings
[4] A. Thomas et al., EPAC2002, Paris, p. 2379
[5] H. Herminghaus et al., EPAC88, Rome, p.1151
[6] F. Hagenbuck et al., EPAC2004, Lucerne, p. 1669
[7] M. Dehn et al., TUPCH033, these proceedings