The MPI-K Accelerators

M. Grieser, R. von Hahn, R. Repnow

The accelerators at the MPI have been operated reliably and successfully without major problems during the past two years, serving various experiments at the storage ring (TSR) and – to a smaller extent – single pass experiments in the old experimental area.

1 The MP-Tandem

During the year 2006 (2005) the MP-Tandem Accelerator delivered 15 (19) different particle beams for experiments during 2621 (3008) hours. Fig. 1 shows the terminal voltages used during the two years. Table 1 lists the various ion species supplied by the MP for fixed target and storage ring experiments.

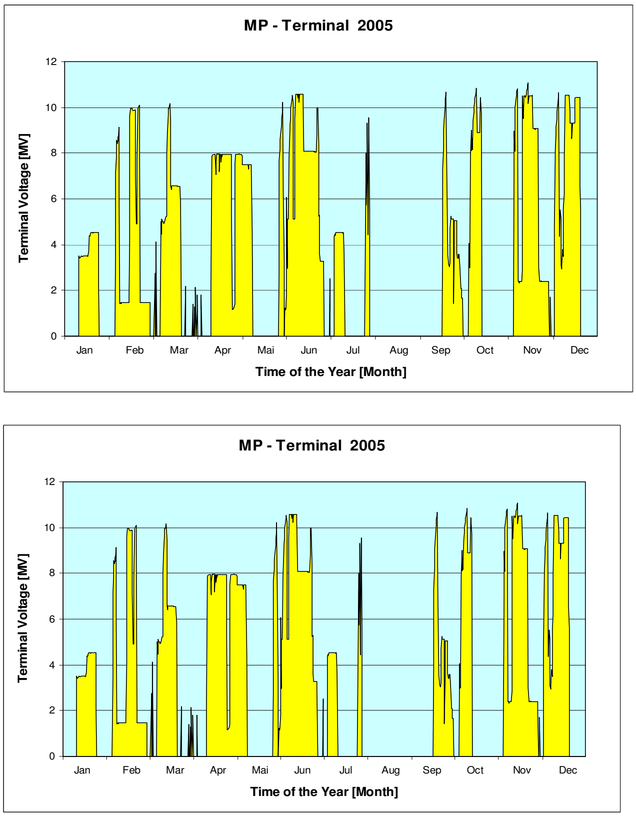

Fig 1: Terminal Voltage of the MP-Tandem used during the last two years.

For about 65 % of the beam time the MP was used for TSR injection, with a noticeably increasing fraction of molecular ions from the tandem. As the tandem principle demands for at least one charge exchange process during acceleration the achievable molecular beams are not very prolific and mostly more intense pilot beams with the same rigidity have to be provided in order to facilitate the adjustment of the beam transport system and to optimize the storage ring settings.

As introduced already in previous years the beamtimes were scheduled with 30% time periods for maintenance and service. Though basically sufficient time was available to fulfil the experimental requirements, several periods with parallel operation of the MP-tandem serving single pass experiments and the HSI serving the TSR storage ring were organized.

The operation of the tandem accelerator was very reliable, and no considerable downtime due to machine failures had been encountered.The MP-tank only was opened for inspection and routine services two times in both years and small modifications or repairs were made to the systems. To avoid further problems with the terminal faraday cup in case of spurious electronic signals a mechanical switch now is used to keep the device in the idle position if not in use. The type of vacuum gauge in the terminal was changed to an all-metal sealed version as a non-pressure-safe feedthrough was detected during a disassembly for cleaning. A high voltage steerer supply was changed which had failed during the terminal checkout procedure.

Ions	2005			2006		
	<10MV	>10MV	Sum	<10MV	>10MV	Sum
^{1}H	121		121	173	30	203
$^{2}H_2$				24		24
^{3}He	85		85			
^{4}He	604		604			
^{7}Li	472		472	222		222
^{12}C	240		240	252		252
^{13}C	54		54			
^{12}CH	113		113	50		50
$^{12}CH_2$	304		304			
^{12}CD				24		24
^{16}O	57		57	48		48
$^{16}OH_2$	24		24			
^{19}F		136	136			
^{24}Mg		142	142			
^{12}CNH	11		11			
^{27}Al	18		18			
^{28}Si	200		200	120		120
^{12}CF				540		540
^{31}P				274		274
^{36}S	8		8			
^{47}Ti					30	30
^{48}Ti				162		162
^{56}Fe	166	151	317		181	181
^{59}Co	48	24	72			
^{63}Cu					150	150
^{65}Cu				46		46
^{197}Au	31		31	103	192	295
Sum:	2556	453	3009	1876	745	2621

Table 1: Ion species delivered from the MP-Tandem (in hours)

The generating voltmeter failed during an experimental period, however, with a backup unit in a slightly off center position operation could be continued after only a short interruption. A rough bearing and a worn sliding contact were fixed during the next scheduled tank opening.

After two service periods the pressurizing of the accelerator tank had to be stopped because of SF6 leaks at the large man hole and at a small electric feedthrough of the GVM after service, respectively. In both cases the tank was evacuated again to fix the leaks.

2 The RF-Linac-Postaccelerator

While in 2005 the linac system essentially was used as a beam transport system to the storage ring TSR it actively was used for 565 hours during 2006 to boost the energy of four different particle beams from the MP-tandem as shown in table 2 and for additional 812 hours to provide RF-power for the accelerating resonators of the High Current Injector. In both applications neither the full number of rf generators nor the maximum rf power was needed thus resulting in relatively smooth operations.

However, the cryopump vacuum system, which has to run continuously for all TSR-beamtimes needed some extra attention, as several large He-compressors feeding complete chains of pump-heads broke down almost simultaneously during operation. However, as most of the units already accumulated more than 240000 operating hours with rather low service we can attest them exceptional reliability. Most of the failures could be fixed using available spare parts from units decommissioned already years ago in other laboratories.

2006					
Ions	E_{MP} [MeV]	Q_{MP}	E_{NB} [MeV]	Q_{NB}	Time [h]
^{47}Ti	120	10	245	18	30,0
^{48}Ti	122	10	240	18	162,0
^{56}Fe	60	5	280	16	181,0
^{197}Au	83	7	297	25	192,0
Sum					565,0

Table 2: Postaccelerated beams in 2006

The nsec-beam bunching and pulsing system at the MP also did not always work as required. High resistive shorts to ground or broken connections in the slit current circuits prevented the buncher phase regulation system from adequate operation.

3 The High Current Injector

During the last two years the High Current Injector (HCI) delivered in about 3653 hours of beam operation 9 different molecular and atomic ions for experiments to the Test Storage Ring (Table 3), as pilot beams or for direct transfer to the coulomb explosion imaging device. For most experiments the final RFQ energy of 0.5 MeV/u was sufficient, in 812 hours the required higher beam energies was delivered by using the 7-gap-resonator-section of the HCI. For beams with very weak intensities from the ion source more prolific pilot beams were used for preparation and tuning of the required beams.

Beam	Energy [MeV]	Accelerator
D_2^+	1,92	RFQ
D_2^-	1,92	RFQ
H_2^-	0,96	RFQ
D^-	0,96	RFQ
H_3^+	5,13	RFQ & 7-gaps
HD^+	1,44 and 5,13	RFQ & 7-gaps
$^4He^-$	1,92	RFQ
$^3He^4He^+$	7,82	RFQ & 7-gaps
$^4He_2^+$	11,0	RFQ & 7-gaps

Table 3: Atomic and molecular ions delivered by the High Current Injector for different purposes

Beam	Energy [MeV]	I [µA]	Lifetime [s]
H_3^+	5.13	4	7
HD^+	1.44	10	20
$^7Li^+$	2.97	5	59
$^7Li^+$	13.36	8	67
$^{16}O^{6+}$	35.7	30	328
$^{19}F^{6+}$	74	50	118
CH^+	7.2		6
$^{24}Mg^{11+}$	80.24	50	243
$^{28}Si^{2+}$	13.36	30	17
$^{28}Si^{3+}$	30.1	45	13
CH_2^+	6.68		3
$^{28}Si^{3+}$	30.07	45	13
$^{31}P^+$	3.02	15	6
CF^+	3.02		6
$^{48}Ti^{18+}$	240	100	79
$^{56}Fe^{7+}$	72.75	123	146
$^{56}Fe^{8+}$	95	21	15
$^{56}Fe^{9+}$	93.17	32.45	15
$^{56}Fe^{10+}$	115	100	16
$^{56}Fe^{16+}$	280	131	89
$^{59}Co^{10+}$	97.7	88	36
$^{59}Co^{12+}$	136	52	54
$^{63}Cu^{17+}$	70	19	38
$^{97}Au^{25+}$	297		3

Table 4: Measured beam lifetimes and beam currents at the TSR during 2005-2006

4 The Heavy Ion Storage Ring TSR

In the reporting period, the TSR was used for atomic-, molecular- and accelerator physics experiments for more than 7000 hours in approximately 50 beam times. The various ion species stored in 2005-2006 are listed in table 4. For some molecular and atomic ions the intensities of the stored beams were below 1 µA and could thus not be measured by the current transformer of the TSR. The beam lifetimes listed in table 4 refer to at the TSR average vacuum between $3x10^{-11}$ and $8x10^{-11}$ mbar.

For Coulomb Imaging Experiments with D_2^- molecules, the TSR was used as a delay line. The ion beam was injected into the TSR without using the bump magnets, after 1 to 10 turns, depending of the setting of the TSR quadrupoles, the molecules left the ring and were transferred to the experiment.

5 The 3 MV Pelletron

Interest in heavy molecular ion beams has increased considerably for experiments at the storage ring TSR. The High Current Injector , however, is limited to A/q<9 while the MP-tandem is hampered by the necessity of negative ion injection and consecutive charge exchange (stripping), which seriously limits the availability and/or the yield for these ion species.

The 3 MV Pelletron which mainly was used for noble gas ion beams after the PIXE experiments were discontinued, can be a versatile source for energetic molecular ions. Because of storage time reasons sufficiently high energies near the rigidity limit of the TSR are required.

In order to increase the available energies without sacrificing the heavy ion terminal for reinstalling the fourth active accelerating section it was decided to modify the optics of the accelerator to a compressed geometry tube increasing its electrical length by additional short sections. Separate grading resistor chains for column and tube will be installed to cope with the additional accelerating gaps of the tube.

The rf-source in the terminal – most suitable for light ions – will be replaced by a cold cathode Penning ion source more suitable for heavy molecules. As this type of source had been installed in the early PIXE phase the reinstallation only is a minor effort.

6 Ion Source Developments

Due to a reconstruction program of the infrastructure of the institute the old ion source test bench system had to be transferred to a new site. The chance was taken to rebuild the vacuum-, control- and cooling system to more recent standards. After completion the test bench was intensely used for various projects.

For a TSR-experiment with a D_2^- beam from a sputter source at the HSI a negative mass-4-pilot beams had to be provided. As the transfer of the charge-exchange duoplasmatron from the MP injector seemed to be impractical a relatively compact, dedicated Helium-source (NEC-Alphatross) was borrowed from the Weizmann-Institute. This source was adapted to the MPI-vacuum system and slightly modified in order to allow a transport of the fully Rb-loaded source between accelerators. After reproduction of the performance data at the test bench the source was mounted to the HSI-injector where it successfully delivered µA pilot beams of $^4He^-$ easily alternating on request with the D_2^- beams in low pA quantities.

Pos. Molecule	Source Material	Neg. Mass	Neg. Ion	Pos. Int.
OH_2^+	$LiO_2 + H_2O$	A41	$LiO.OH_2^-$	0.3 nA
HF^+	CHF_3 +ZrH	A39	F_2H^-	2.0 nA
CF^+	CF_4+Mo	A69	CF_3^-	4.0 nA
CNH^+	CH_3NH_2 + Ta	A27	CNH^-	2.0 nA
CNH_2^+	CH_3NH_2 + Ta	A28	CNH_2^-	3.0 nA

Table 5: Molecular beams from the Tandem

The Heinicke-Baumann PIG source was operated in the sputter mode with a special Cu-Li-cathode in order to check whether by optimizing the yield of Li^{2+} the production rate of metastable Li^{1+} could be increased. However, the maximum intensities of doubly charged Li were too low for practical applications.

Extended scheduled periods of continuous HSI-operation were used to test and optimize ion sources for the production of different molecular beams of interest with the MP 300 kV injector. As in many cases useable quantities of positive molecules can be gained as fragments from heavier negative molecules after stripping those tests preferentially are made at the MP injector with the tandem to be used for further detailed analysis of the ions from the source.

Most efforts have been invested in the attempt to produce a $(OH_2)^+$ beam with a tandem. While this molecule can be very easily produced directly from cold sources a negative molecule could not be detected in useful quantities whatever source type or source gas was used. Also negative cluster molecules from Methanol or water injection did not result in positive $(OH_2)^+$ ions. Finally, a $(LiO.OH_2)^-$ cluster could be generated using the sputter source from which the requested beam with intensities of about 300 pA was analyzed and successfully delivered for storage in the TSR.

Table 5 gives the results for a variety of positive molecules generated with the tandem. Best results in all cases were achieved using the sputter source for negative ions. In spite of all efforts the measured intensities all are in the range of a few nA only, showing the practical limitations of a tandem for this type of experiments.

7 Accelerator Electronics

The well proven 'EUNET' hardware control system for accelerator components has been extended in several directions. New modules were developed to cope with new demands of future experimental systems, comprising a multichannel, high resolution ADC–module (24bit , 4 channels), a versatile, programmable dual channel serial interface module for controlling complex, semi-intelligent devices and a universal, multi-purpose module easily to be adapted to new applications via a dedicated plug-in card.

In order to facilitate the setup of small systems for control via PC's or laptops a TCP/IP based EUNET crate controller was built, allowing a direct connection between a standard computer and an EUNET crate without additional servers. A set of newly developed digital knobs now additionally can be connected using standard USB-ports. Using the XML-based software system of the HSI-group an intelligent, interactive local control system easily can be set up without programming efforts.

Dedicated hardware for the cryogenic storage ring e.g. amplifiers for multichannel cryogenic measurements and magnetic field control have been developed and built in quantities.

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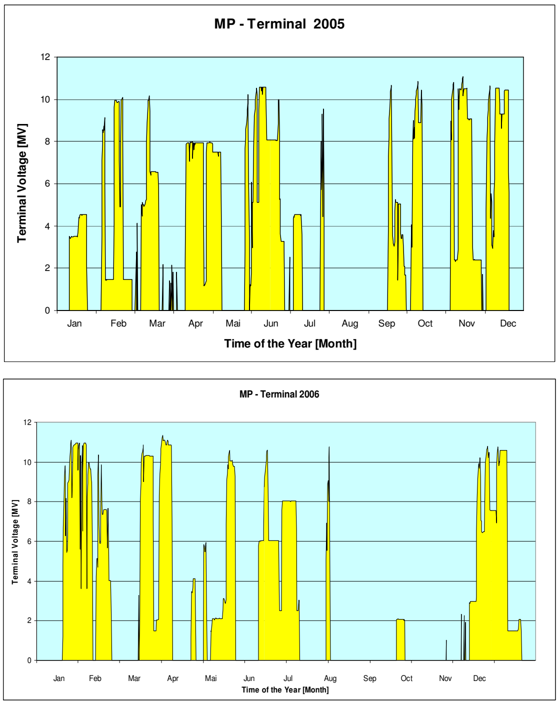

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