UPGRADING THE HEIDELBERG MP-TANDEM POSTACCELERATOR COMBINATION

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Summary

The Heidelberg Tandem Postaccelerator Combination is undergoing a stepwise upgrading program intended to further considerably extend its mass and energy range as well as to increase the available intensity of heavy ion beams.

In a first step in 1982 a resonator module of four newly developed β = 0.12 spiral-splitring resonators had been added to the high energy end of the linear accelerator. These resonators deliver rf-voltages of 0.5 MV (CW) and 1.0 MV (df = 0.25) each, increasing the effective acceleration voltage of the booster to 22.5 MV.

To improve the performance of the accelerator system for heaviest projectiles two extensions are under construction. A 3 MV negative ion injector based on a reconstructed single ended pelletron accelerator is nearing completion. It is designed to facilitate the injection of well isotope separated low emittance beams of the highest masses into the low acceptance acceleration tubes of the MP-Tandem, thus reducing beam loading and allowing for considerably higher intensities of beams like ^{197}Au, ^{208}Pb, and ^{238}U.

Later on a module of four β = 0.04-spiral-splitring resonators will be installed in front of the linac to match the velocity of heavy ions like ^{238}U to the presently operating machine.

I. Introduction

The Heidelberg MP-Tandem Postaccelerator Combination[1] is in full user available operation since the end of 1979. Its general physical layout is shown in Fig. 1, where the three major components can be clearly identified: the upgraded MP-Tandem[2] with a maximum acceleration voltage of 13 MV, the room temperature linear accelerator using independently phased resonators, and the almost completed 3 MV negative ion injector. The arrows in the drawing indicate the beam direction in the postacceleration mode of the system. As details of the Tandem Linac Combination have been reported elsewhere[3], Table 1 is intended to describe the facility by a list of typical heavy ion beams delivered for experiments in CW and in the pulsed mode; part A of Table 1 refers to the machine before the first upgrading step. The final energies in this list are values required for individual experiments, thus not necessarily indicating the maximum capability at the ion species listed. An increasing demand for particle beams of higher masses and energies led to the here reported upgrading program.

Table 1. Particle energies

Ion	E_{MP} (MeV)	q_i	→ q_f	E_{NB} (MeV)	E/A (MeV/amu)	Note
		A	(1980-1981)			
^{12}C	84	6	6	164	13.7	
^{16}O	96	7	7	194	12.1	
	96	7	7	153	9.6	CW
^{32}S	108	8	14	332	10.4	
	108	8	14	228	7.1	CW
^{58}Ni	96	7	21	452	7.8	
^{79}Br	96	7	22	476	6.0	
^{127}J	96	7	26	527	4.1	
^{197}Au	156	12	33	648	3.3	
		B	(1982)			
^{4}He	35	2	2	63	15.8	
^{12}C	81	6	6	174	14.5	
^{16}O	96	7	7	212	13.2	
^{19}F	96	7	9	175	9.2	CW
^{28}Si	108	8	13	225	8.0	CW
^{32}S	132	10	15	402	12.6	
^{127}J	177	14	31	795	6.3	
	224	20	31	840	6.6	
^{197}Au	156	12	32	720	3.7	

II. The 3 MV Heavy Ion Injector

The MP-Tandem as an injector for a heavy ion postaccelerator suffers from several deficiencies: The present 200 keV injector does not allow a clear separation of isotopes with masses higher than A = 20. As many heavier elements interesting for nuclear physics consist of several isotopes of almost equal abundance, unseparated isotopes or even molecular ion species are loading the acceleration tube, thus limiting the tolerable injection intensities as well as reducing the lifetime of stripper foils. In addition, the particle transmission through the acceleration tube is decreasing from about 50% for masses around A = 30 to less than 25% at masses above A = 100.

In order to avoid these shortcomings and to improve the efficiency of the tandem-postaccelerator combination a novel injection system for heavy ions has been built which will start operation in the near fu-

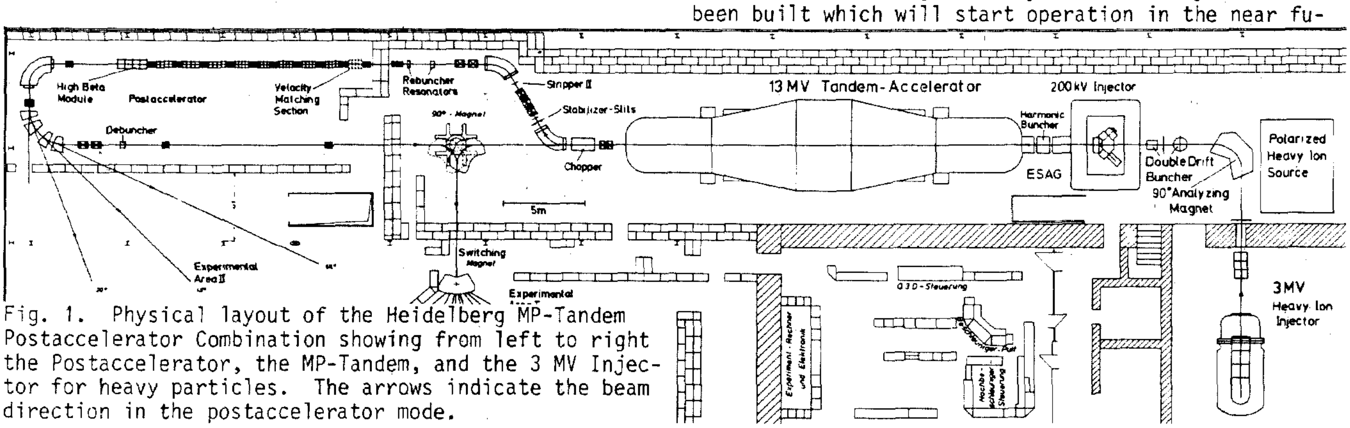

Fig. 1. Physical layout of the Heidelberg MP-Tandem Postaccelerator Combination showing from left to right the Postaccelerator, the MP-Tandem, and the 3 MV Injector for heavy particles. The arrows indicate the beam direction in the postaccelerator mode.

ture. It consists of three major components:
a) a high intensity heavy ion sputter source within the terminal of a 3 MV negative preaccelerator,
b) a high resolution mass separator,
c) a double drift bunching system.

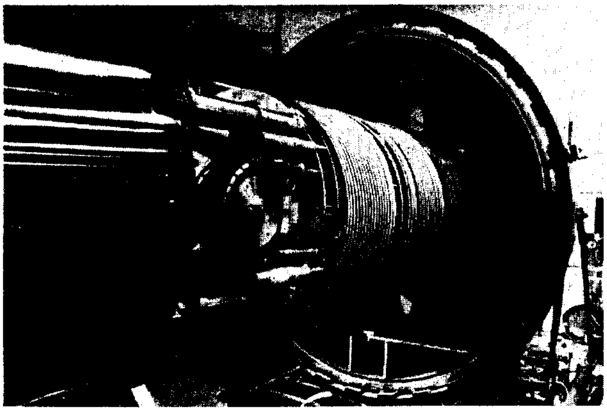

Fig. 2. The 3 MV Heavy Ion Injector under construction. The three active sections and the two pelletron charging chains can be clearly identified.

The 3 MV injector (Fig. 2) is constructed by rebuilding a former 4 MV proton pelletron accelerator using the pressure vessel, insulating column, charging system, and acceleration tube from this machine. Major modifications have been made by adding a quick disconnect flange for a fast access to the high voltage terminal, by increasing the charging current by the installation of a second pelletron chain, and by installing a resistive voltage divider replacing the string of corona discharge points used before.

One of the four acceleration sections has been shorted out in order to accommodate components of the heavy ion source - for the beginning a commercial sputter source (Hiconex 834) specially designed for high pressure environments. The lifetime of this source, which has been extensively tested, can be expected to be several weeks, before an opening of the tank should become necessary.

The terminal ion optics consists of two electrostatic lenses and a 40 kV preacceleration gap for the negative ion beam extracted at 20 keV. A 15° analyzing magnet will allow a rough separation of ion species at a variable aperture in front of the acceleration tube in order to avoid excessive tube loading by most abundant beams.

Readout of parameters and control of the equipment in the terminal are achieved by a system of local microprocessors housed in functional units of the terminal electronics and coupled via a serial light link bus.[4] For optimum spark protection the various doubly shielded electronic compartments are self-contained to the widest possible extent. Communication with the outside world is accomplished via two serial light links operating at 187 kbaud. The light links of up to 16 processors, which may be installed at different electrical potentials in the terminal are combined and fed via only two single fiber links across the 3 MV voltage difference to a common master processor on ground potential, which is mainly handling communication tasks. It is connected via a parallel bus to a dual ported CAMAC memory on the parallel CAMAC branch of the postaccelerator control system.[5]

A large double focussing 90° dipole magnet with a bending radius of 160 cm is used for the stabilisation of the injector terminal potential via a slit regulation system as well as for the high resolution mass analysis of the injected beams. This magnet can bend singly charged ions up to mass A = 120 at full energy and will separate single isotopes up to heaviest masses, e.g., ^{238}U, for which the acceleration voltage has to be decreased accordingly. Thus the injector will be able to provide separated isotope beams from natural source materials over the whole mass range.

As the energy of ion beams injected into the MP-Tandem is increased by the injector by roughly an order of magnitude, the transverse emittance is reduced by a factor of three. Furthermore, because of the higher beam energy, the excursions due to inclined field effects inside the acceleration tube are greatly reduced. For both reasons a near 100% transmission through the tandem should be achievable, certainly allowing much higher injection intensities.

Bunching singly charged heavy ions of 3 MeV at a minimum mass of A = 12 before injection into the MP-Tandem requires rf-voltages well one order of magnitude higher than obtainable by the presently operated "Harmonic Buncher." Therefore a newly developed double drift bunching system[4] will be installed as indicated in Fig. 1. It consists of a two-gap helix loaded resonator operating at 13.56 MHz (U_{rf} = 65 kV_p) and a single-gap folded coaxial resonator at 27.12 MHz (U_{rf} = 15 kV_p) approximately 2 m downstream. Longitudinal ray-tracing calculations predict a bunching efficiency of well over 50% intensity into a time window of less than 1 ns.

III. Upgrading the Postaccelerator

Figure 3 is a cutaway drawing of the resonator type used in upgrading the rf-linear accelerator. This structure, named the spiral-splitring, makes use of a $\lambda/2$-line resonator wound as two counterrotational spirals ① that extend into one common connecting segment ② concentric with the resonator tank. The large area of this connecting segment at the location of the current maximum helps to improve the electrical as well as the mechanical properties of the resonator. The single leg ③ supporting the line resonator extends radially from the connecting segment to the tank. Two active drift tubes at the spiral ends and two grounded ones in the end flanges form the three accelerating gaps of the structure, a distance of $l = \beta\lambda/2$ apart. Thus this type of resonator still has a wide-banded transit time factor suitable for the desired high flexibility to accelerate ions of very different velocities and charge to mass ratios. The width of the outer gaps as well as of the drift tube bore is 2.0 cm; the center gap width is 2.8 cm. As in the spiral resonators used so far, tuning is done by a capacitive tuning plate ④, coupling of the rf-power by a turnable inductive loop ⑤ in the vicinity of the connecting segment. One important requirement in designing this structure was, besides a high shunt impedance and stability, to ensure the use of proven resonator components and manufacturing techniques developed for the spiral resonator part of the machine.

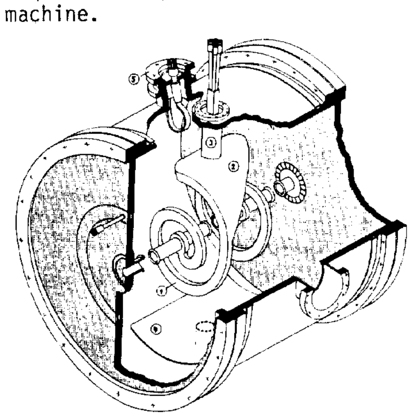

Fig. 3. Cutaway drawing of the spiral-splitring resonator. Tank inner diameter is 50 cm. Numbers refer to the text.

Characteristic parameters of these resonators determined in model measurements for two design velocities are listed in Table 2. The usable acceleration

Table 2. Electrical and mechanical parameters of the spiral-splitring resonators

Design velocity β	:	0.12	0.04
Operating frequency (MHz)	:	108.48	108.48
Quality factor Q	:	4500	4200
Shunt impedance Z (Mohm/m)	:	33.0	57.0
Maximum voltage U_0 (MV)			
(N = 20 kW CW)	:	0.52	0.46
(N = 80 kW df = 0.25)	:	1.04	0.92
Tank			
Inner diameter (m)	:	0.50	0.50
Inner length (m)	:	0.408	0.182
Drift tube bore (m)	:	0.02	0.02

voltage is about 40% higher than for a comparable single spiral resonator. At the beginning of 1982 four of the β = 0.12 resonators were stacked in one high beta module and installed at the high energy end of the linac (see Fig. 4). This module has increased the effective acceleration voltage of the postaccelerator in the pulsed mode to 22.5 MV.

Ion beams and energies used for experiments in the year 1982 after the installation of this module are listed in part B of Table 1. Now even ^{4}He beams of 63 MeV energy and good beam quality are an attractive addition; the final energy of ^{127}J ions could be increased to over 800 MeV (6.6 MeV/u). One power prototype of the β = 0.04 resonators has been tested at the heavy ion beam of the MP-Tandem, confirming the data in Table 2. A module of four such resonators will be installed as a low velocity matching section for heaviest particles in front of the existing linear accelerator.

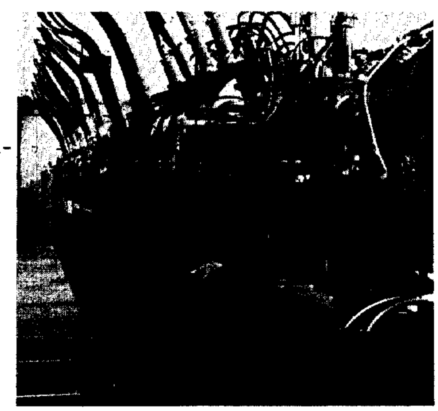

Fig. 4. View onto the Heidelberg Postaccelerator. The newly installed high beta module can be seen in the foreground.

The further improvement in performance due to the addition of this module can best be evaluated from Figs. 5 and 6, giving the specific final energy and the effective usable acceleration voltage, respectively, as a function of the ion mass. The calculations for these diagrams assume the full operation of the 3 MV injector and stripping in two foil strippers, one in the terminal of the MP-Tandem at 12 MV potential, the other in front of the postaccelerator. Charge states higher than the equilibrium charge states were selected, still yielding 10-25% of the maximum possible beam intensity. The labels NB 36, NB 40, and NB 40 S in Figs. 5 and 6 refer to different steps of the upgrading, NB 36 describing the performance of the postaccelerator in its present configuration with 32 spiral and 4 spiral-splitring resonators. The NB 40 curves hold after the installation of the low velocity matching section; NB 40 S describes the limit of a future extension option in which part of the present spiral resonators could be replaced by spiral-split ring resonators, keeping the overall physical dimensions of the postaccelerator and its beam transport fixed. As these modifications again could be done in separate upgrading steps not further detailed here, a shaded area is drawn in Fig. 5.

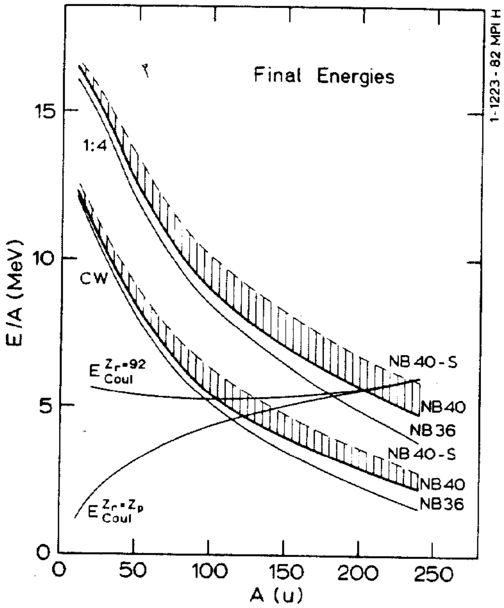

Fig. 5. Specific final energies of the MP-Tandem Postaccelerator Combination as a function of the projectile mass in CW and pulsed mode (1:4). The presently operated machine is labeled NB 36, the machine extended by a low velocity matching section NB 40. NB 40 S describes a further upgrading option.

Figure 6 shows a noticeable increase in effective acceleration voltage resulting from the introduction of the velocity matching section for heaviest particles. For ^{238}U the voltage in the pulsed mode increases from 19.8 MV (NB 36) to 25.6 MV (NB 40), 40% of this increase being due to the now better matched velocity profile for these ions. The NB 40 S curve shows an effective acceleration voltage of over 32 MV for ^{238}U, resulting in final energies of approximately 6 MeV/u.

Because of the modular construction of the Heidelberg postaccelerator as well as the flexibility of its computer-control system,[5] upgrading steps of the kind described here can be efficiently done with a minimum of downtime. The installation and running in of the

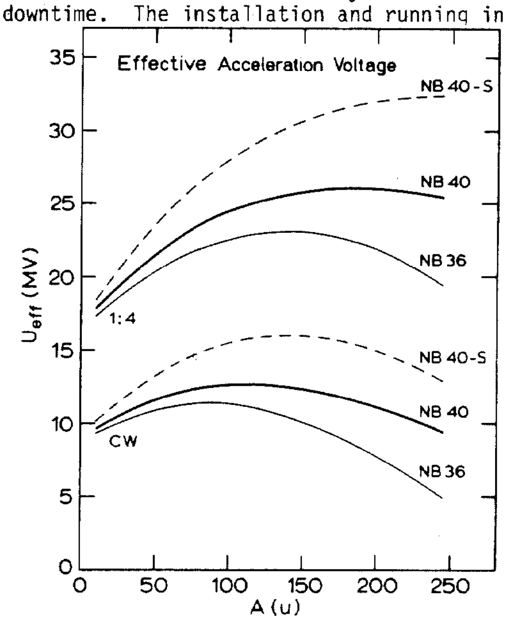

Fig. 6. Effective acceleration voltages of the postaccelerator in different upgrading steps as a function of the projectile mass. Labels are as in Fig. 5.

β = 0.12 module, for example, could thus be accomplished in a normal shutdown period of the MP-Tandem.

IV. Conclusion

The Heidelberg MP-Tandem Postaccelerator Combination, a flexible and versatile heavy ion facility, is undergoing an upgrading program further improving its performance on an extended mass and energy range. Two of the upgrading steps, the installation of a 3 MV Heavy Ion Injector for the tandem accelerator and a β = 0.12 spiral-split ring module are almost completed or already in operation. A low velocity matching section improving the operation at heaviest projectiles will become operational in 1984.

Acknowledgement

The authors want to thank Prof. P. Brix for his continuous support and encouragement, Prof. U. Schmidt-Rohr for valuable help in the realisation of the project. The skillful and enthusiastic work of many technicians of the Max-Planck-Institut is gratefully acknowledged. The work has been supported by the Bundesministerium für Forschung und Technologie.

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