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THE FIRST YEAR OF OPERATION AT THE HEIDELBERG HEAVY-ION POSTACCELERATOR

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Summary

The 3MV stage of the Heidelberg Heavy Ion Postaccelerator being the first one to use the independent phasing concept of short linear accelerator cavities in a booster application behind an MP-Tandem accelerator, went into operation in December 1977 and is in the state of full user-availability since May of 1978. The machine uses spiral resonators at room temperature. Ten such resonators with design velocity $\beta_o = 0.10$ at 108.48 MHz are operated either in CW at 20 kW or in pulsed mode (df = 0.25) at 80 kW. Due to the flexibility of the independent phasing of the 10 resonators presently in operation, acceleration voltages as high as 3.3 MV (CW) could be demonstrated for ions between ^{12}C and ^{58}Ni. 5.5 MV have been achieved in pulsed operation. An energy resolution of $\Delta E/E \lesssim 4 \cdot 10^{-4}$ allowing rebunched pulse widths of $\Delta t_{FWHM} < 70$ ps could be measured, showing the tandem like beam quality. The machine is exclusively computer controlled, prerequisite for the operation of the many parameters of a tandem-postaccelerator-combination. The overall availability of the postaccelerator together with the MP Tandem was above 80% of the scheduled user beam time. The operation of the 3 MV stage will be interrupted for a 4 months' shutdown late 1979 to allow for the extension of the machine to its full 10 MV (CW) acceleration voltage by the addition of 20 more spiral resonators.

I. The spiral resonators

Development, construction and prototype tests of the normal conducting spiral resonator of the Heidelberg type have been reported on the 1977 Particle Accelerator Conference and are described in[1]. Fig. 1 shows a cut drawing of the structure to summarize the main features of this type of resonator. The

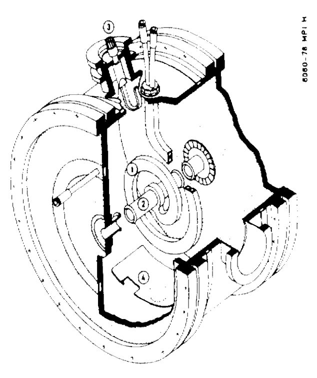

Fig. 1
Cut drawing of the Heidelberg spiral resonator. Tank inner diameter is 35 cm.

dominant element in the figure - labeled 1 -, is a $\lambda/4$ line resonator wound as a spiral. The leg of the spiral is screwed to the outer shell of the resonator, while the free end, the location of the voltage maximum, holds the drifttube 2 between the two grounded tubes forming the accelerating gaps. Gap width and drifttube bore are 2 cm each; gap to gap distance is $\ell = \frac{\beta_o \lambda}{2}$. Thus the structure has a very widebanded transittime factor[2] necessary for the desired high flexibility to accelerate ions of very different initial velocities and charge to mass ratios at the MP-Tandem injecting. The rf-power is coupled to the resonators by a turnable inductive loop 3 extending into the resonator near the leg of the spiral. The resonance frequency is maintained by a servo loop controlled capacitive tuning plate 4. Characteristic parameters of the resonators are listed in Table I.

Table I. Parameters of the spiral resonators used in the 3 MV stage of the Heidelberg Postaccelerator

Operating frequency (MHz)	108.48
Quality factor Q	3500
Design velocity β_o	0.10
Shuntimpedance Z (MΩ/m)	30
Input power N_{CW} (kW)	20
N_p (kW) (25% duty cycle)	80
Effective voltage ($\phi_s = -20^0$)	
U_{CW} (MV)	0.33
U_p (MV)	0.60

To demonstrate how an array of independently phased spiral resonators satisfies the essential design requirement of a high flexibility the usable accelerating voltage is plotted in Fig. 2 for the 10 resonators of the first construction stage. U_{eff} is

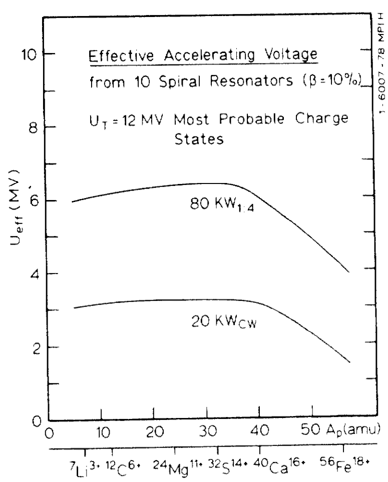

Fig. 2 Effective accelerating voltage as function of ion mass for the 3 MV stage of the Heidelberg Postaccelerator.

given as a function of the Ion mass for CW and pulsed operation. On the second abszissa the charge states used in the calculation are marked. They are the most probable ones found when stripping in a second foil stripper in front of the postaccelerator. The almost flat characteristic of the curves for both operating conditions shows that up to a maximum mass of A ~ 40 this first part of the postaccelerator has equal accelerating efficiency for all ions. Operating the machine this behavior can be obtained by simply electronically shifting the phasing of the independently powered resonators - no mechanical or constructive changes as at other types of booster linacs are necessary.

Fig. 3 is a drawing of a postaccelerator module stacking four equal spiral resonators. Always two resonators share one common middle flange carrying the grounded drifttubes. One operational module yields a total effective voltage of 1.3 MV (CW) at a synchronous phase $\phi_s = 20^0$. To each set of four spiral resonators belongs an external quadrupole dublet with a maximum field gradient of 3 kG/cm, 45 mm aperture and 15 cm

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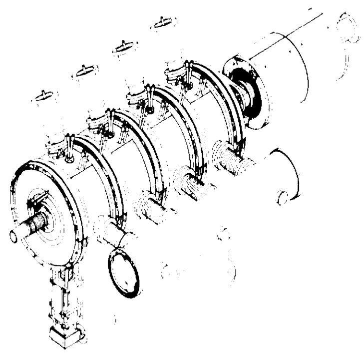

Fig. 3 Accelerator module consisting of four spiral resonators, quadrupole dublett and pumping line.

length per singlet. A vacuum better than 1 x 10^{-7} mbar is maintained by a cryopump (2 W, 20 K closed cycle refrigerator) with an external pumping line arrangement. The characteristic beam dynamics parameters of such a set up have been discussed in[1,3].

For the first 3 MV-stage of the Heidelberg booster three accelerator modules were manufactured in the institute's main work shop in 1977. Fig. 4 shows the first one during assembly. The four individual copper tanks can clearly be recognized; the module is complete up to the still missing coupling loops and one end-flange. The spirals are mounted, their surface is high quality electroplated. All other interior surfaces are brought to the finish visible by mechanical grinding and polishing.

The whole structure is already adjusted in the workshop and then transported to its actual location

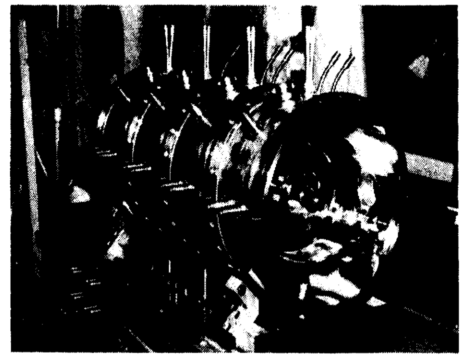

Fig. 4 Accelerator module during assembly

on prealigned support stands in the linac. This procedure has two advantages: it facilitates the assembly and gives the possibility to exchange complete modules in the case of a defect.

II. Layout of the accelerator and beam transport

The beam transport system and accelerator layout has been designed to fit the postaccelerator into the present MP-Tandem-accelerator building and to bring the postaccelerated beam back to the existing experimental area. Following the circled labels in Fig. 5 the path of the heavy ion beam in the Tandem-Postaccelerator combination is as follows: The bunched beam from the tandem (1) passes a chopper system (2) at 1/8 of the linac frequency, a 60^0 analyzing magnet (3), the postaccelerator foil stripper (4) and is then deflected with the desired charge state onto the axis of the booster. After a section of beam pipe, where the five modules of the final extension to 10 MV will be inserted, the beam enters the buncher (5) and after

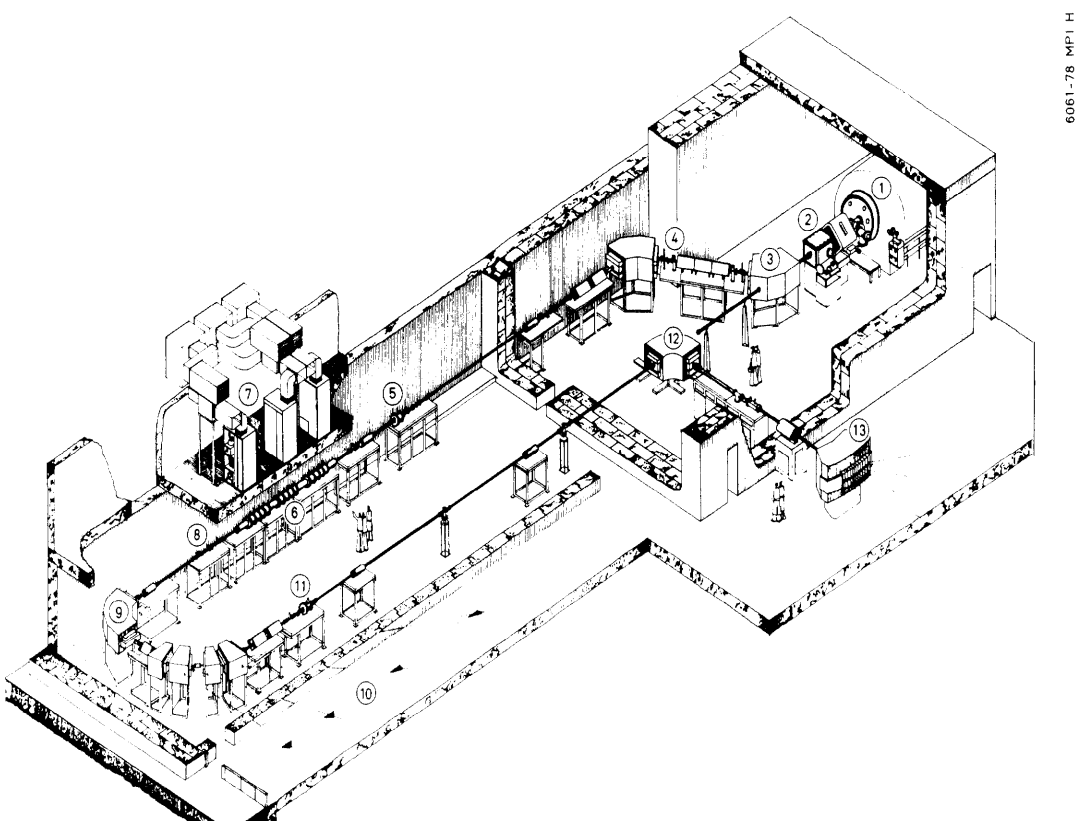

Fig. 5 Layout of the postaccelerator (3 MV-stage) and beam transport system. Numbers refer to the text.

5 m the first module of the 3 MV stage 6. The buncher is itself a spiral resonator that compresses the 1 nsec prepulsed beam to less than 250 ps necessary for proper beam matching. Linac and buncher can be seen in detail in Fig. 6. The backtransport of the postaccelerated beam starts with a 90^0 magnet 9 also

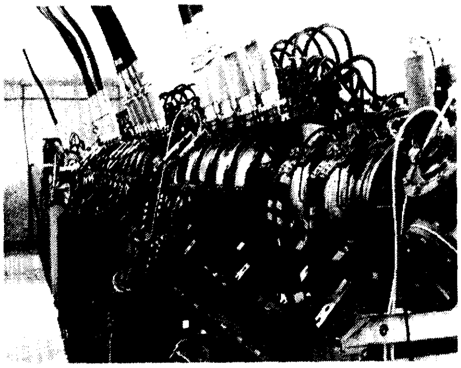

Fig. 6 View onto the three accelerator modules and the buncher resonator. Two of the twelve resonators are not powered in the 3 MV-stage of the machine.

used for determining energy resolution and calibrating the effective accelerating voltage of the cavities. The second 90^0 bend is subdivided into four smaller magnets giving the possibility to feed the beam to a new experimental area 10. Passing the debuncher resonator 11, the beam is then deflected by the 90^0 analyzing magnet 12 of the MP-Tandem - placed on a turntable and rotated into the shown position -, into the switching magnet 13 and thus to all existing experimental setups. The rf generators are installed on top of the radiation vault 7.

III. RF-generators and control electronics.

In the first 3 MV stage of the booster 12 commercially available FM broadcost transmitters with an output power of 20 kW CW are used to feed the cavities. They are of the same type operated in the power- and beam test in the years 1975-1976 and have proven to be reliable and rugged. For use as the rf-supply of the linac they had, however, to be modified considerably to meet the requirements of the computer control as well as to operate them from one common anode-power supply to run them in pulsed mode. Fig. 7 shows a view into one row of the transmitter gallery. The generators are set up in groups of four, one group belonging to one accelerator module. The 19" racks in the background house the driver amplifiers, the reference signal distribution, the regulation units for phase, amplitude and resonance frequency and the phase shifters necessary for each individual cavity as well as a CAMAC crate of the computer control. Details of the Computer control are described in a

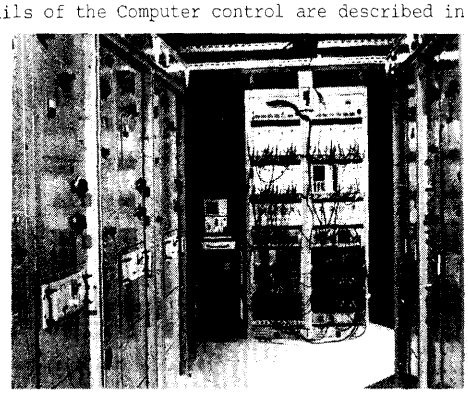

Fig. 7 View onto the rf-gallery showing transmitters and regulation and control systems.

separate contribution[4]. All the regulation units have been designed and manufactured in house.

IV. Operation experience with the postaccelerator

The Heidelberg postaccelerator started test operation in December 1977 and is in the state of full user available operation since May of 1978. Up to end of February 1979 9 testruns two days long on the average and 7 user beamtimes could be operated. Altogether 503 hours of user time had been scheduled from which for 414 hours a useful beam could be delivered to the experiment. These figures correspond to an overall availability of the combination MP-Tandem-postaccelerator of over 80%. Table II summarizes characteristic

Ion	q_{NB}	E_{MP} (MeV)	E_{PA} (MeV)	U_{eff} (MV)	I_{el} (nA)	$\Delta E/E$ (10^{-3})	ε_r (π mm, mrad)
^{12}C	6+	72	90	3.03	100	<4.3	--
^{32}S	14+	132	178	3.30	85	<5	3.1
	15+	132	181	3.28	30	--	4.2
	14+	108	152	3.15	50	~0,4	2.9 1)
	12+	140	178	3.13	40	<1	2.8 2)
	13+	150	190	3.11	15	-	- 2)
^{32}S	12+	140	206	5.52	30	-	- 3)
^{58}Ni	16+	177	225	3.01	30	-	3.2 2)

1) (140 ps→300 ps), 2) User Run, 3) 65 kW)

data of selected postaccelerated heavy ion beams as typical examples of the machine performance. The table shows that ions between ^{12}C and ^{58}Ni can be accelerated by the present 10 resonators with almost equal effective voltage, - column 5 -, which is in all cases above 3 MV. The measured energy resolution of less than $5 \cdot 10^{-3}$ (column 7), in some cases well below $1 \cdot 10^{-3}$ will be improved by one order of magnitude with the debuncher. The radial emittance ε_r is smaller than the projected value of 5π mm mrad indicating that the postaccelerator is longitudially and transversally properly matched to the tandem beam. Row 7 shows an example of the machine performance in pulsed mode. Running the cavities with a peak power input of 65 kW (1:4) resulted in a effective voltage gain of 5.52 MV. In the setting shown in row 4 a ^{32}S beam was gasstripped in the MP to a charge state of 8+ and further foil stripped before the booster to 14+. The final energy was 152.1 MV. Measured at the linac exit and 50 m downstream, the time halfwidth of the micropulse had only increased from 140 ps to 300 ps. From this an energy spread of $\Delta E/E \sim 4 \cdot 10^{-4}$ can be deduced. Beams of this quality have been rebunched in user runs to pulse widths of less than 70 ps[3].

V. Status of the further extension

The status of the further extension of the machine to its final 10 MV acceleration voltage is as of early March 1979 as follows: The production of the five additional modules started in August 1978 and is that far advanced, that the preassembly has begun. Supports, quadrupollenses and vacuumcomponents are delivered in separate charges between May and October. Two thirds of the regulation electronics and driver amplifiers as well as additional CAMAC equipment is in house. The time plan foresees a 4 months' shut down end of 1979 to insert the additional cavities into the beam transport. Normal MP-Tandem operation will not be affected.

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