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THE HEIDELBERG HEAVY ION POSTACCELERATOR

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Summary

The Heidelberg Heavy Ion Postaccelerator, a linear accelerator booster[1] for the upgraded MP-Tandem[2] is operational in its extended version since end of 1979. Yielding 9.7 MV in CW and 18.5 MV in pulsed mode (duty factor 0.25) it has considerably increased the mass and energy range of heavy ions for Nuclear Physics experiments at Heidelberg.

The high flexibility of the booster is guaranteed by using 32 independently phased spiral resonators[3] allowing operation of the machine in the mass range of A=10 to A=100 with almost constant accelerating voltage; although even ions as heavy as ^{197}Au have been successfully postaccelerated. Typical examples of postaccelerated beams are: 164 MeV ^{12}C, 332 MeV ^{32}S, 476 MeV ^{79}Br, 511 MeV ^{127}J and 640 MeV ^{197}Au. Longitudinal and transversal beam quality are tandem like with $\varepsilon_r < 2\pi$ mm mrad and $\varepsilon_l < 3.2\pi$ MeV ·deg., the debunched energy resolution being well below 10^{-3}. The overall availability of the postaccelerator together with the MP-Tandem was 83% of the scheduled user beam time in 1980.

I. The spiral resonator-postaccelerator

Development, construction and prototype tests of the normal conducting spiral resonator of the Heidelberg type have been described in Ref. 3. Fig. 1 shows a cut drawing of the structure to summarize the main features of this type of resonator. The dominant element in the figure - labeled 1 -, is a $\lambda/4$ line resonator wound as a spiral. The free end of the spiral, 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 $\ell = \frac{\beta\lambda}{2}$ Thus the structure has a very widebanded transittime factor 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 an inductive loop 3 extending into the resonator near the leg of the spiral. The resonance frequency is maintained by a capacitive tuning plate 4. Characteristic parameters of the resonators are listed in Table I. The resonators are stacked in modules of four. Always two resonators share one common flange carrying the grounded drifttubes. To each set of four spiral resonators belongs an external quadrupole dublet with a maximum field gradient of 3kG/cm, 45 mm aperture and 15 cm length per singlet. Altogether 8 such modules have been installed. (See Fig. 2).

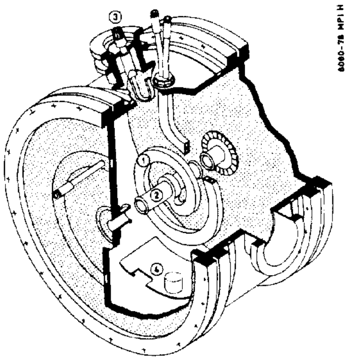

Fig. 1 Cut drawing of the Heidelberg spiral resonator. Tank inner diameter is 35 cm.

Table I. Parameters of the spiral resonators used in the Heidelberg postaccelerator

Operating frequency (MHz)	108.48
Quality factor Q	3500
Design velocity β_o	0.06-0.10
Shuntimpedance Z (MΩ/m)	40-30
Input power N_{cw}(kW)	20
N_p (kW)(25% duty cycle)	80
Effective voltage (ϕ_s= -20°)	
U_{cw} (MV)	0.3
U_p (MV)	0.6
(ϕ_s= Synchronous Phase)	

The beam transport system and accelerator layout can be seen in Fig. 3. Following the circled labels 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° analyzing magnet 3, the postaccelerator foil stripper 4 and is then deflected with the desired charge state onto the axis of the booster. The rebuncher spiral resonator 5 compresses the 1 nsec prepulsed beam to less than 250 ps necessary for proper beam matching. After 5 m the beam enters the first module of the RF-linac 6 which consists of 12 resonators with design velocity β_o = 0.06, 8 resonators with β_o= 0.08, and the 12 resonators of the 3 MV-stage[4,5] with β_o = 0.10.

The backtransport of the postaccelerated beam starts with a 90° magnet 9 also used for determining energy resolution and calibrating the effective accelerating voltage of the cavities. The second 90° 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° 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.

II. RF-generators and control electronics

The commercially available 20 kW FM broadcast transmitters⁺ which were initially installed for the 3 MV-stage had proven to be reliable and rugged but had to be modified considerably to meet the requirements of the computer control, to operate them from one common plate power supply and to run them in the 80 kW pulsed mode. Thus for the 22 additional resona-

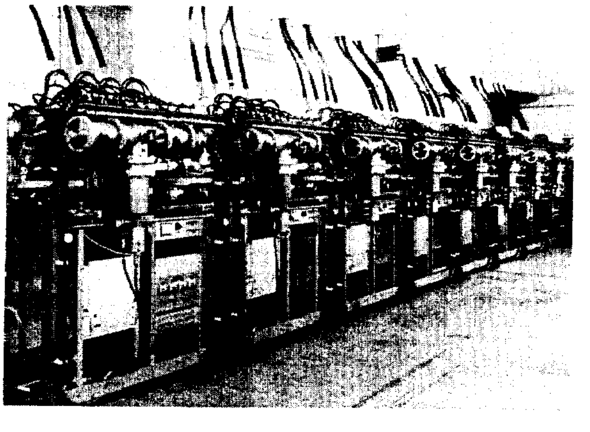

Fig. 2 View onto the eight resonator modules of the Heidelberg Postaccelerator.

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tors of the extended version newly designed transmitters++ compatible with the existing computer control were built. All these transmitters were acceptance tested at the factory using one original spiral resonator as a load. They show improved RF-characteristics especially in pulsed operation.

Fig. 4 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. Except the CAMAC crates and CAMAC modules all these electronic units were designed and manufactured in the institute.

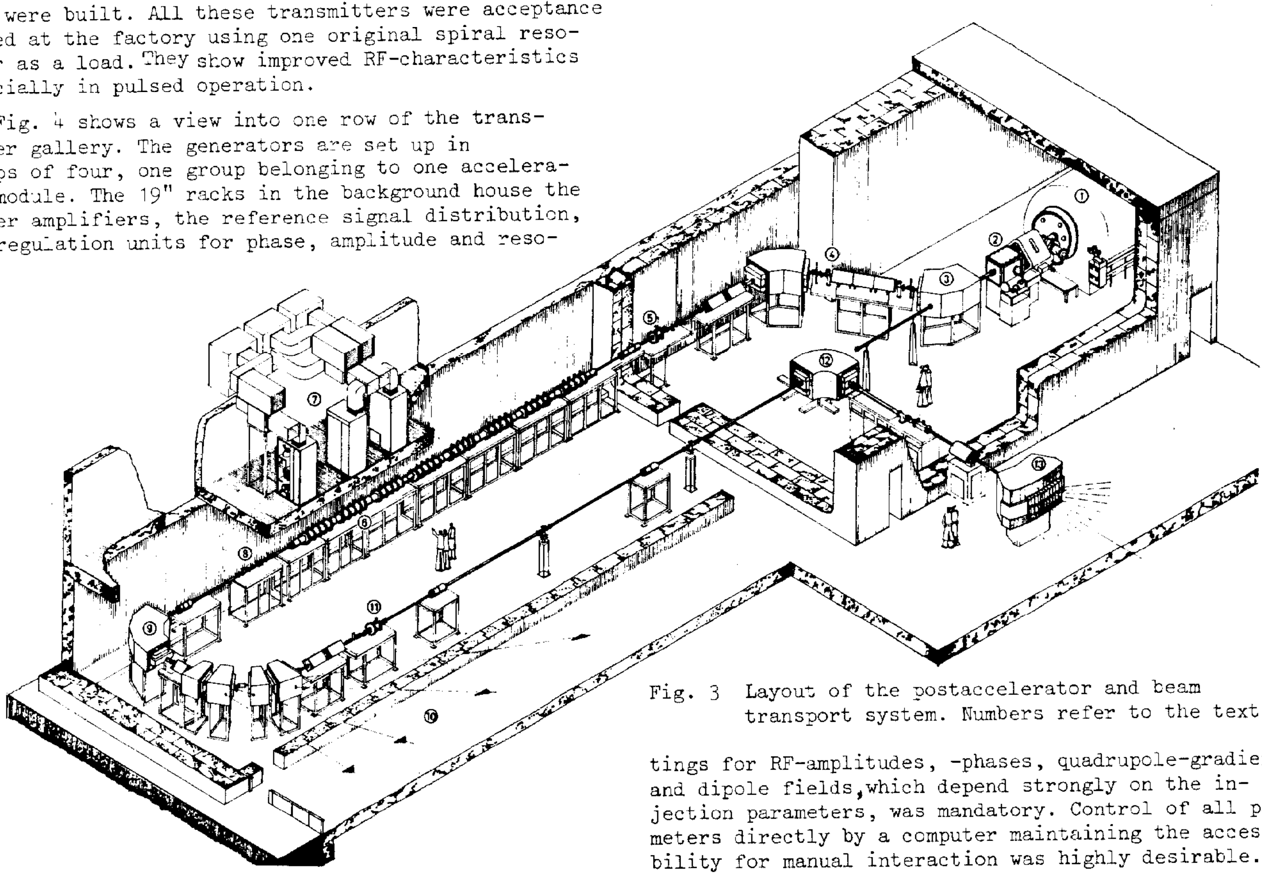

Fig. 3 Layout of the postaccelerator and beam transport system. Numbers refer to the text.

III. The computer control system

The use of indpendently phased resonators for an acceleration of a large variety of different ion species delivered by the electrostatic tandem injector demands for an efficient computer assistance of the operator. A computer program to calculate all settings for RF-amplitudes, -phases, quadrupole-gradients and dipole fields, which depend strongly on the injection parameters, was mandatory. Control of all parameters directly by a computer maintaining the accessability for manual interaction was highly desirable.

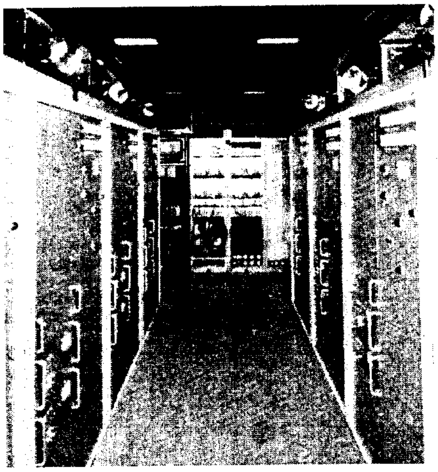

Fig. 4
View onto the RF-gallery showing transmitters, regulation and control system.

The concept of the computer control^{6} was based on the following general guidelines in order to limit the complexity of the overall system:

a) All remote control of the postaccelerator should be performed only via the computer.
b) The computer control system should not be used for closed-loop regulation of parameters or for operating safety interlocks.
c) The control system should reflect the modularity and expandability, which are the key features of the accelerator itself.

The hardware of the accelerator control is schematically indicated in Fig. 5. The system is controlled by a dedicated PDP 11/34 minicomputer equipped with 124k of memory, a floating point processor and standard peripherals.

All accelerator components and the operator's console are accessed via a single JY 411-CAMAC interface, which directly can drive a parallel CAMAC branch as well as a serial highway. The highspeed parallel branch is used for servicing the operator's console where various display units need to be updated rapidly. The serial highway runs a large loop of about 300 m total length from the computer through three storeys of a remote part of the building. Only one cable necessary for a byte parallel serial highway interconnects the different hardware components of the accelerator.

Basically, four standard types of highly integrated CAMAC modules are used throughout the accelerator, keeping the number of crates down to a minimum. These are 32 channel ADC's, 12 channel DAC's, specially designed control units with 24 relay contacts and 24 status flags and control moduls for one magnet power supply each.

The PDP 11/34 is operated fully under control of a

\+ Fa. Harris-Gates, Quincy/Ill.
++ Fa. Herfurth, Hamburg

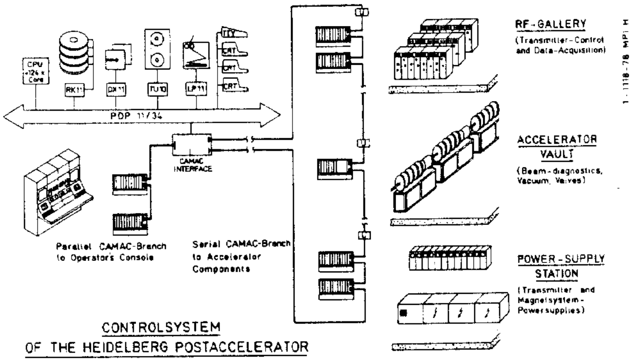

Fig. 5 Schematic diagram of the Heidelberg Postaccelerator control system.

multitasking operating system RSX 11M. The control software is largely subdivided into different smaller programs which are responsible for specific operations and can be run independently from each other in parallel. By this scheme the software development and maintainance was greatly facilitated. Tasks which have to perform larger numerical calculations are written in Fortran, whereas the control software is written in Assembler language.

The main effort was invested into the scheme of a data base which contains all information on the accelerator components, e.g. CAMAC addresses and commands, actual values, calibration factors and the names of the parameters. All tasks can access the CAMAC hardware only by using the information stored in the central data base, which is stored in the memory. Using a memory-resident data base and updating it 2-3 times per second by a DMA-task guarantees fast access and fast response.

By touch panel interaction the operator can perform simple operations like switching, changing of displays, connecting of parameters to one of the control knobs and protocolling of the settings. Furthermore, there exist a large number of different tasks which can be started via the touch panel to perform more complex operations. For instance the completely computer controlled start-up of all RF-generators can be done in about 3 minutes initiated by only one touch panel command.

Initial setting of the postaccelerator components is achieved by an interactive optimization routine which from basic information on the injected beam parameters optimizes the linac parameters for a requested output energy with respect to the beam acceptance. All focussing and beam handling elements as well as the RF-amplitudes and phases are set to the calculated values directly by that program. Only minor manual fine tuning and optimization with respect to beam transmission for the injection and extraction region is required afterwards, whereas the linac settings can remain unchanged.

IV. Operation experience with the postaccelerator

After a 3 MV-section of the postaccelerator already had been used for experiments between the end of 1977 and August 1979[5] the fully extended booster started operation with 30 resonators in the beginning of December 1979. Since March 1980 it is in the state of full user availability. During the rest of the year 16 user runs with 1363 h of beamtime had been scheduled. For about 1133h a useful beam was delivered to the experiments resulting in an overall availability of 83% for the complete Tandem postaccelerator combination. Table II summarizes characteristic data of some heavy ion beams postaccelerated in 1980.

Table II Final energies E_{PA} and currents I_{el} of postaccelerated heavy ion beams

Ion	CW mode				Pulse mode			
	E_{MP} (MeV)	q_{PA}	E_{PA} (MeV)	I_{el} (nA)	E_{MP} (MeV)	q_{PA}	E_{PA} (MeV)	I_{el} (nA)
^{12}C	84	6^+	129	600	84	6^+	164	15
^{19}F	96	7^+	144	120	------------------			
^{32}S	108	14^+	228	150	108	14^+	332	80
^{35}Cl	120	15^+	248	130	108	14^+	337	15
^{58}Ni	96	20^+	278	70	------------------			
^{79}Br	174	16^+	319	32	96	22^+	476	20
^{127}J	----------------------				96	25^+	511	17
^{197}Au	----------------------				156	32^+	640	3

All the figures of table II (except for ^{197}Au) have been taken with the 30 resonators available till September 1980. The measured final energies thus obtained are compared with the predicted values in Fig. 6 showing good agreement. The effective acceleration voltage with now 32 spiral resonators is 9.7 MV (CW) and 18.5 MV (pulsed mode).

The change of ion species and energy with a Tandem Postaccelerator combination should be as easy as with the Tandem alone in order not to loose important advantages of a Tandem. Due to the complete computer control of the Heidelberg booster this could be demonstrated. Changing the postaccelerator parameter and optimizing to 100% transmission of the linac is in all cases faster than changing the ion source.

The measured radial emittance of a 332 MeV ^{32}S beam of 1.5·π·mm·mrad indicating that the postaccelerator is longitudinally and transversally properly matched to the tandem beam. The time spread of the beam behind the linac was determined to be 250 ps. The measured energy spread of $4 \cdot 10^{-3}$ could be improved to less than 10^{-3} using the debuncher. Beams of this quality are rebunched by an additional spiral resonator in front of the target. Routinely a time resolution better than 100 ps was achieved in many user runs and is used for time of flight measurements in nuclear and atomic physics experiments.

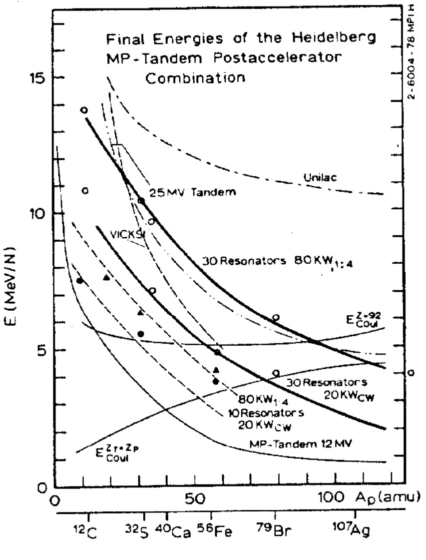

Fig. 6 Predicted and measured final energies of the Heidelberg Postaccelerator compared with the values of a 12 MV-Tandem, VICKSI (Berlin) and the UNILAC (Darmstadt)

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