STATUS REPORT ON THE UNILAC-PROJECT

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Summary

The paper reviews the beam parameters of the UNILAC and gives tentative figures for an early start-up phase at the end of 1974. Recently completed design work is reported and comments are given on the progress of component procurement and building construction.

Introduction

At the end of 1969 the GSI was founded near Darmstadt as a new laboratory for fundamental research, in particular in the field of heavy nuclei. The new institution had to start from scratch and it took more than one year until staff, office space and support facilities were available to attack the goal of this new organization, namely to build and to operate a versatile heavy ion accelerator.

In the mid of 1970 the decision was taken which type of accelerator the GSI was going to have and since then the members of the UNILAC study group slowly moved from Heidelberg to Darmstadt (1). Unfortunately several of the well experienced engineers resigned and remained at Heidelberg.

Mid of 1971 the remainder of the study group and the new staff members got reorganized in order to conform to the promoted phase of the project: research efforts had to be dropped and procurement of accelerator components was initiated. One year later, about 80% of the equipment was ordered from industry and today generally all activities seem to be in agreement with the time schedule. The linac tunnel will be available in mid of 1973 and the first beam, with reduced specifications however, will be awaited by the end of 1974.

Beam Parameters

The design aim for the maximum output energy versus mass number is shown in fig. 1. For uranium ions 8.5 MeV/amu will be obtained with a gas stripper and 10.2 MeV/amu with a foil stripper. The rf duty factor will be 25% for the heaviest ions and can be increased to almost cw for light ions. If the duty factor is kept small, higher energies are available for light ions. The lower limit for the variation range is about 2 MeV/amu for all particles. The undisturbed bunch structure of the beam will be available in the whole variation range for debunching purposes or for time of flight experiments, when additional rebuncher cavities are used down stream in the experimental area.

As a design aim for the beam intensity, few reference values should be mentioned:

mass number 70	about 10^{14}	particles/sec
mass number 184	about $3 \cdot 10^{13}$	particles/sec
mass number 238	about $2 \cdot 10^{12}$	particles/sec

These values are in agreement with the best presently available ion source data. No finite plans exist so far for a complete table of usable ion species.

The design aim for the beam quality is based on computer studies including reasonable tolerances for rf amplitude and phase and misalignments of accelerator components as well. Typical values for the bunch structure of the beam are: time resolution 0.15 nsec without and 1,20 nsec with debuncher, the energy spread is expected to be 0.3 % and 0.04 %, respectively. These values deteriorate slightly at the lower limit of the energy variation range. The radial emittance of the beam will be about 2 cm mrad including an assumptive emittance blow up by a factor of 5.

The above cited parameters are to be considered as design aim. Some are precalculated, others are of an assumptive nature including extrapolations of available data, but all should be understood as an optimum performance, to which a future experimental program should conform. Clearly some features may be improved on the expense of other ratings, for instance emittance and energy spread can be tuned at the expense of beam intensity.

However, for an initial start-up these values must considerably be reduced to account for risks in component performance and reliability and also to account for imperfect control on rf phase and amplitude, and magnet currents in the beam transport elements as well. It is indeed the typical situation of an universal heavy ion accelerator that tolerances and calibrations must be maintained within a large variation range of parameter settings. On the other hand, it is also typical that even for an underrated operation of the installed equipment and for an imperfect control of main parameters the machine is useful for certain experiments. It is therefore advisable to establish clearly a set of minimum beam parameters, which may be available to the users in an early phase of start-up, while the optimum performance is subsequently searched with increasing operation experience. These minimum parameters are shown in the following table and reflect the envisaged state of completeness at the end of 1974.

Element	Intensity in part/sec	RF Duty Factor	Energy in MeV/amu	Energy Resolution	Bunch Structure
Ne	$1.5 \cdot 10^{13}$	0.25	3.6 and 5.9 variable by ± 10 %	about 1 %	not available
Mg	10^{11}	0.2			
Ar	$3 \cdot 10^{12}$	0.15			
Kr	$3 \cdot 10^{11}$	0.1			
Xe	10^{11}	0.05			

The reductions result from the following facts or cautious assumptions:

a) source developement for a more complete variety of elements is limited by available man power, since priority was given to the preinjector installation;

b) mass numbers lower than 10 may eventually be difficult to accelerate due to unpredictable multipactor discharges at low rf fields;

c) the rf duty factor, or more generally, the rf power losses in the prestripper cavities may initially be subject to an important reduction accounting for a non predictable detuning of the cavities and difficulties with the rf drive loop;

d) mass numbers higher than xenon may probably not be available initially because of peak power limitations in the rf amplifiers for the Alvarez-structure;

e) the maximum output energy will not be available before the mid of 1975 due to the late delivery of the rf amplifiers for the single-gap cavity structure and the subsequent calibration procedure of cavity phase settings;

f) the reduced beam intensity is indicated by the facts that an overstressed source operation should be avoided initially in order to provide a stable beam for machine tests and in order to save on service man power which must be assigned to system improvements. Substantial beam losses may be encountered initially due to phase space matching deficiencies in the injection region and transition area between prestripper and poststripper accelerator;

g) beam quality in terms of energy resolution and time structure will be the most difficult feature to obtain and requires certainly a perfect and generous beam diagnostic system and an advanced understanding and control of the whole machine. This state of completeness may require more than one year of operation experience.

This certainly incomplete list of initial departures from the design aims seems overly pessimistic. But it tends to reflect the start-up difficulties with an universal and complex accelerator like the UNILAC and it leaves a clear and defined freedom for the users to fit their programs into the improvement phase of a machine. This improvement phase is linked to the time schedule as a straightforward consequence of the present project development.

Progress Report

The UNILAC project has reached a phase, in which almost 80 % of the accelerator components and auxiliary equipment are commissioned to industry and preparations for the assembly and installation phase are being initiated.

Fig. 2 shows a survey on the machine with the injection area on the left and extending into the experimental area on the right side. Alongside the accelerator tunnel with its concrete shielding walls runs a three-story building for the auxiliary equipment: The cooling system in the basement, the electronic racks and local control areas at the ground floor and the rf amplifiers on the first floor. The central control room with the control computer facility is located near the high energy end close to the experimental area. A small low energy experimental hall is foreseen near the stripping area, into which a fixed energy beam of 1.4 MeV/amu may be deflected off the main beam axis for low energy atomic and solid state experiments.

A more detailed view of the preinjector (2) and the low energy beam transport system is seen in fig. 3. The injector building is nearly completed and half of its space, which is provided for future ion source studies, will be made available for component assembly at the end of this year, six months ahead of the occupancy of the tunnel. The two high voltage generators with the equipment domes and accelerating column are on order and will be installed next spring. Isolating transformers will be used for the main power supply to the domes because of unsatisfactory experience with isolating-shaft motor generators in the present test-injector facility. Bids for the two-story faraday cages and light-link transmission systems with a 128 bit transmission capacity have been received. Specifications for the four inflection magnets and for a standardized set of beam-transport lenses have been written and sent out for quotation. The beam transport system is designed to provide a mass resolution of 250 for isotope separation, if required. The beam optical parameters conform to the prestripper acceptance of 10 cm mrad. The beam diagnostic elements and the prebunchers are presently under design and prototype manufactoring is underway. A destructive and a non-destructive emittance measurement device have been commissioned to outside laboratories. The first beam operation of the injector is scheduled for spring of 1974.

All components for the Wideröe structure are on order and the first tank sections will arrive early next year for subsequent copperplating treatment. By an enhanced effort the design and the model studies for the Wideröe were brought back to schedule and the installation and the debugging of the machine will proceed stepwise starting at the low energy end. The earlier plans for electrostatic quadrupole lenses inside the Wideröe drift tubes have been abandoned in favour of high gradient magnetic quadrupoles, the aperture of which had to be reduced from 3 to 2 centimeters for the first few drift tubes. Fig. 4 and 5 show a cross section of Wideröe tank one and tank four. Quadrupoles are only in the outer drift tubes, adjustable by the stem heads on top of the cavity. The inner drift tubes, standing upright on the inner conductor have no quadrupoles and are smaller in diameter to reduce capacitive loading of the resonant line system. In tank 1, fig. 4, the drift tube period is $\pi/3\pi$ in order to provide more space for the quadrupoles, while tanks 2, 3 and 4 are designed in the normal π/π mode as seen in fig. 5.

A full scale model of one stub line, necessary to support the inner conductor and to flatten the voltage distribution along the cavity, has been successfully tested under high rf power. All cavities will be ready to be installed into the tunnel next summer and alignment and field tuning procedures will follow then. The rf amplifiers are on order and will be installed end of next year. High power tests of the cavities will follow subsequently.

Fig. 6 shows a sketch of the stripper area between prestripper and poststripper accelerator. A prototype gas-jet stripper has been evaluated to obtain data for vacuum system design. Beam transport calculations are completed and the achromatic charge analysis system including vacuum chambers and power supplies recently have been ordered. A septum magnet and an adjustable slit system for selecting a parasitic beam out of the charge distribution of the stripped beam has been designed and submitted for quotation to outside manufacturers.

Two short accelerating devices of the helix type are foreseen in the beam path of the transition region: one as an energy matching element to compensate for energy losses encountered in the stripping process and a second helix conceived as a rebuncher to provide perfect matching of the beam bunches to the longitudinal acceptance of the poststripper. The successful operation of these elements is essential for low particle loss and for good beam quality. As a consequence, considerable effort is presently devoted to a rf probe system, which provides a control signal relevant to the bunch shape and the bunch phase referenced to the rf phase in the poststripper. The rather modest beam intensities of a heavy ion accelerator and unavoidable rf leakage of power amplifiers tend to impair the performance of a fast phase control for both matching elements.

The production of drift tubes and cavities for the Alvarez section (3) proceeds on schedule. Delivery of tank sections will commence early next summer. The electroplating of the inner surface of these bulky units may turn out to be a difficult venture. As the Wideröe cavities will be plated before, which are less critical in respect to the rf properties of the surface, it is hoped that sufficient experience will be gained with the plating process prior to the treatment of the Alvarez cavities.

Like in the situation of the cavity plating, it was equally impossible to find an outside manufacturer responsible for the development of the two high power, 108 MHz amplifiers capable of 1.8 MW peak and 0.45 MW average rf power for the Alvarez section. Hence the development was initiated as an inhouse effort based on previous experience with the satisfactory completion of two smaller amplifier prototypes for the single-gap cavity structure. The hardware for the big amplifier stages is on hand and two 1 MW plate power supplies are on order. A third unit is presently installed for system checkout and for debugging of the high power stage feeding into a resistive load. The program is slightly behind schedule due to a shipment damage to a prototype tube. Since this tube was built as a modified version out of a short-wave tube family, its high power performance at 108 MHz lies still ahead to be demonstrated. Further developmental effort may result both for the tube manufacturer and the amplifier designer. As an ultimate reason, provisions are made for a dual amplifier chain for each Alvarez cavity. Preliminary experience with paralleling two amplifiers into one single-gap cavity proved to be satisfactory.

The single-gap cavity structure will be installed as the latest section of the machine. The high power performance of one cavity unit has been studied over 2000 hours and redesign has been applied to several details. The cavity cylinders are on order and remaining sub-components will be commissioned in the next three months. The time schedule for this part of the machine is determined by the late delivery of the rf amplifiers, the last units of which are due in spring 1975.

A block diagram of the entire rf amplifier installation is shown in fig. 7. All units, except for the pulse generator, the frequency multiplier, directional probes and few drive-line components are on order. Some particular details should be mentioned briefly: A phase reference line is running along the whole accelerator and is operated in a standing wave mode. Hence, the rf phase at every position along the line is either 0 or 180 degrees, independent of thermal changes of the line length. The drive signals for the power amplifiers are coupled out of this reference line. The level of the drive signal is kept low, to about one watt, in order to minimize resistive loading of the resonant line. This line extends beyond the stripper region providing a 27 MHz reference signal for rf beam diagnostic devices along the whole accelerator. A second 108 MHz reference line, which is driven by a frequency multiplier extends from the stripper region down to the high energy end to provide the low level drive power for the 26 amplifiers in the poststripper section.

All amplifiers for small and high power output ratings are made up from standardized modules: a remotely adjustable phase shifter, a combined amplitude and phase controller, a 300 watt solid state preamplifier, a 22 kW driver and finally a power amplifier. The 27 MHz power stages are specified to deliver 0.52 MW for each of the four Wideröe cavities and the 108 MHz stages deliver 0.18 MW to the single-gap cavities and the rebuncher and debuncher cavities as well. For the Alvarez structure two additional 1.8 MW stages cascaded to one of the before mentioned 108 MHz amplifier chains are required. A phase signal is derived from the cavities and fed into the phase controller. Thus phase errors resulting from cavity or amplifier mistuning are eliminated and the cavity field is phase locked to the reference line via the adjustable phase shifter. The field amplitude in the cavities is adjusted by a transformer circuit included in the power amplifier stage. The rf plate voltage of the latter is stabilized to a constant value by the fast amplitude controller. (These control loops are not shown in fig. 7).

In order to reduce the number of circuits and components, common power supplies have been selected for identical amplifier stages. The four power amplifiers in the prestripper section are fed from one 1 MVA rectifier. Also each group of ten amplifiers for the single-gap cavities is fed from a common 1 MVA rectifier. Except for few small amplifiers for the re- and debuncher, the DC supply for all the power amplifiers is obtained from 5 nearly identical 1 MVA rectifiers, which are fed from the 20 kV ac line. It is recognized that this unconventional scheme of centralized power supplies will bring up particular problems for crowbarring circuits and for the sensing of screen currents. But it seemed to be the only way to keep the cost for the entire rf supply within acceptable limits.

Much design effort was devoted in the past year to the control computer system and a combined system was selected for the accelerator and the experimental installations. Fig. 8 shows a schematic of the entire concept subdivided into three stages. The main laboratory computing facility (stage I) may be linked to the control computer if required in future. The accelerator equipment and the users electronics will be operated from the console in the main control room via the Sigma 6 control computer with its standard periphery. By a specially developed linkage system preprocessed data are transmitted from and to the satelite computers (stage III). These small PDP 11 computers are located either in the control areas of each accelerator sub-section or close to the counting equipment in the experimental area. These front-end computers will not have much periphery except for a teletype and a display, if required. Program development is done at the central control computer only. A cross-assembler for the PDP 11 will be an important feature of the entire system. CAMAC interface modules will be used throughout for data transfer between the PDP 11 computers and the local electronic equipment. The Sigma 6 and 5 PDP 11 units have arrived recently and are being installed as a temporary facility for program development. A computer aided operation of the test injector and eventually for the rf amplifier test facility is planned for next year. Design work for a computerized multichannel analyzer, a field measuring device and an emittance measuring set-up is in progress.

Fig. 9 shows a photograph of the accelerator building dated end of september. The injection building on the far left is complete and concrete casting for the second story of the service gallery is in progress, the linac tunnel lies behind. On the right, the heavy shielding wall finally separating the experimental hall from the adjacent laboratories is nearly complete. In the foreground of the picture foundation work for the main laboratory building is presently started.

Fig. 10 shows a view from the east into the experimental area. The basement has just been covered by the heavy removable concrete beams. A concrete delivery truck marks the point where the linac tunnel joins the experimental area. At the right of the tunnel the steel frame work of the low energy experimental hall is seen with the injection hall behind. Except for the cooling plant and the main laboratory building all construction work is progressing on schedule.

References

1 Ch. Schmelzer, D. Böhne: GSI, A New Heavy Ion Research Facility Proceedings of the 1970 Proton Linear Accelerator Conference, p. 981

2 H. Krupp: The UNILAC Ion Source and Injection System, IEEE Transactions on Nuclear Science, Vol. NS-19, No. 2. P.69

3 T. Niewodniczanski, E. Malwitz: Mechanical Design Features of the UNILAC. This Proceedings.

More detailed information on the UNILAC project is contained in the "UNILAC Projekt Bericht" series, available from the GSI library, 61 Darmstadt, P.O. Box 541. Issue No. 0 describing the project in general and copies, No. 1 through 6 are issued as quarterly status reports.

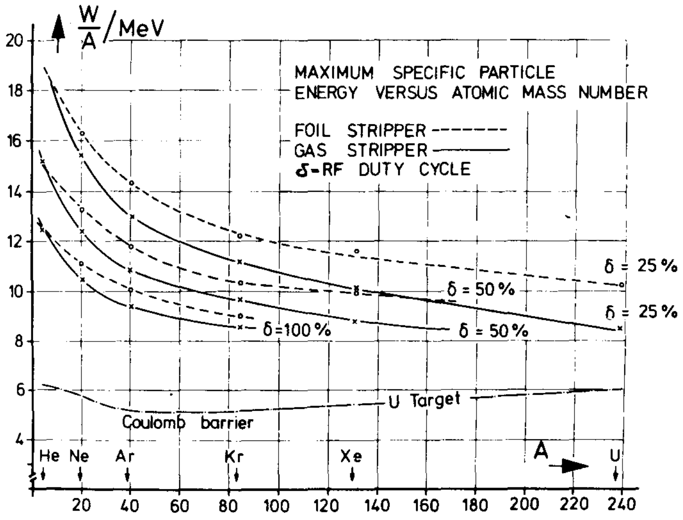

Fig. 1 Specific particle energy of the UNILAC in MeV/amu versus mass number and rf duty factor for gas and foil stripping.

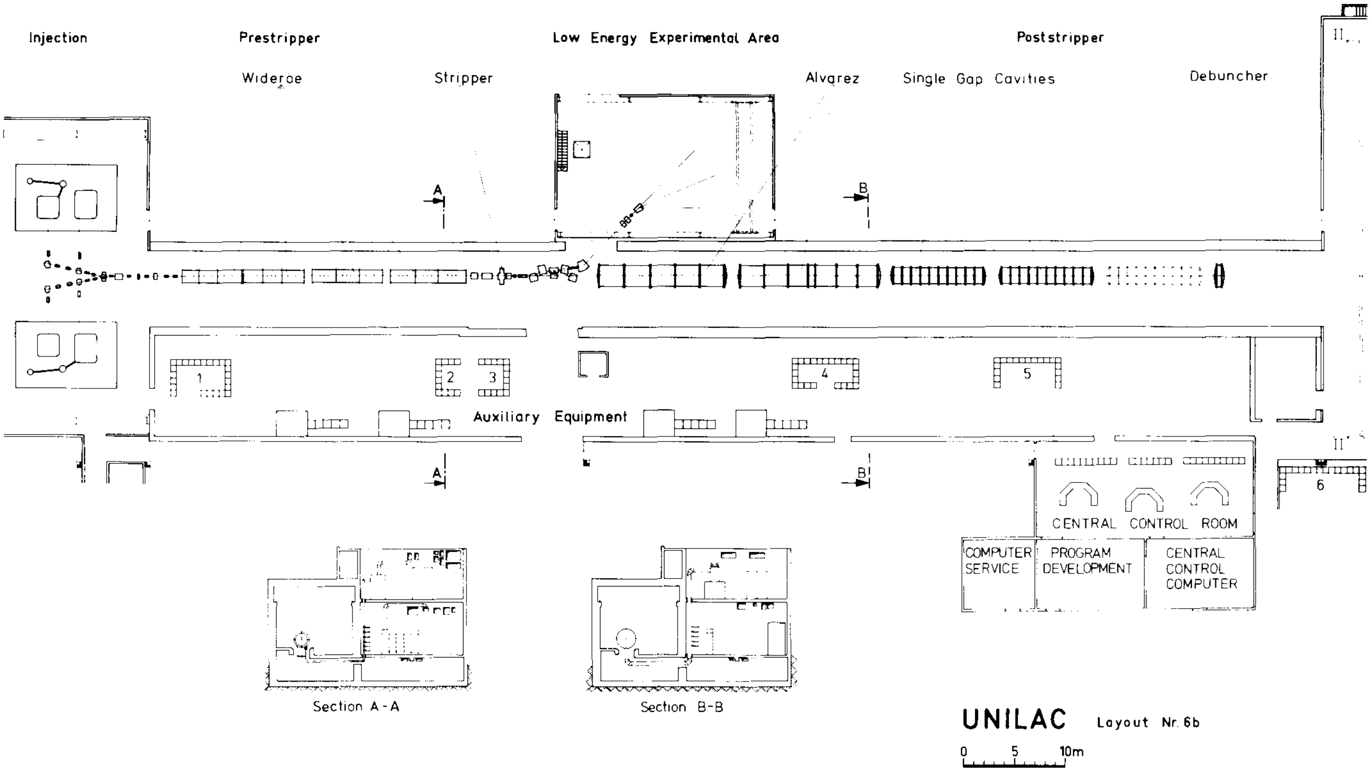

Fig. 2 Planview on the accelerator tunnel and equipment aisle

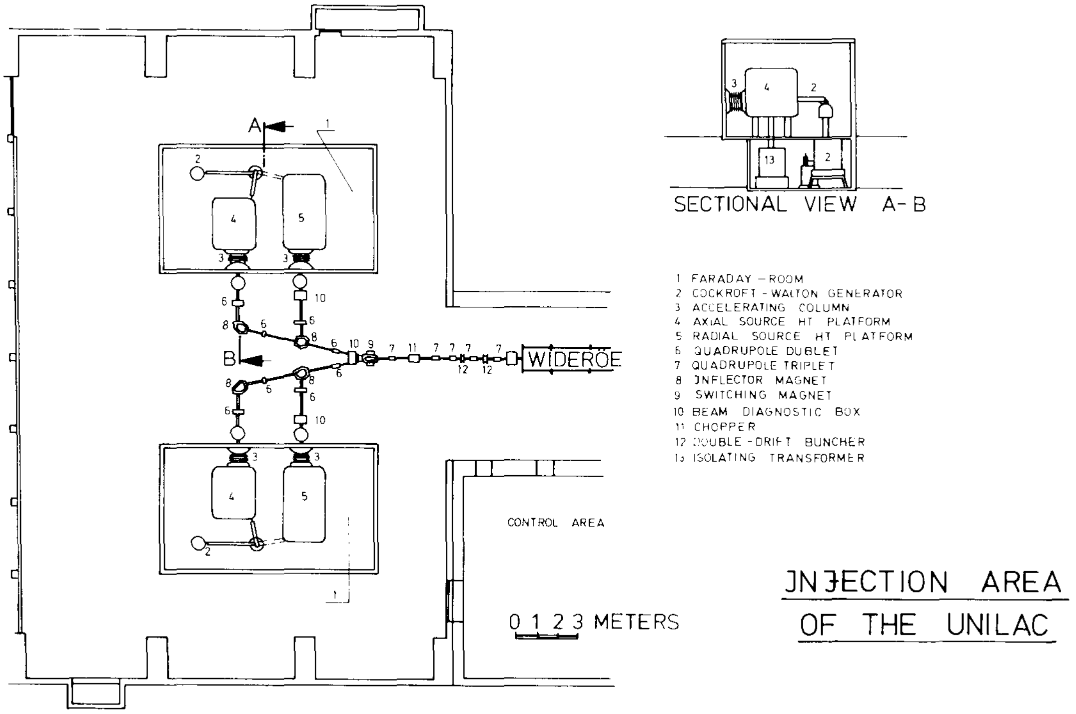

Fig. 3 Planview on the injection area with the low energy beam transport lines.

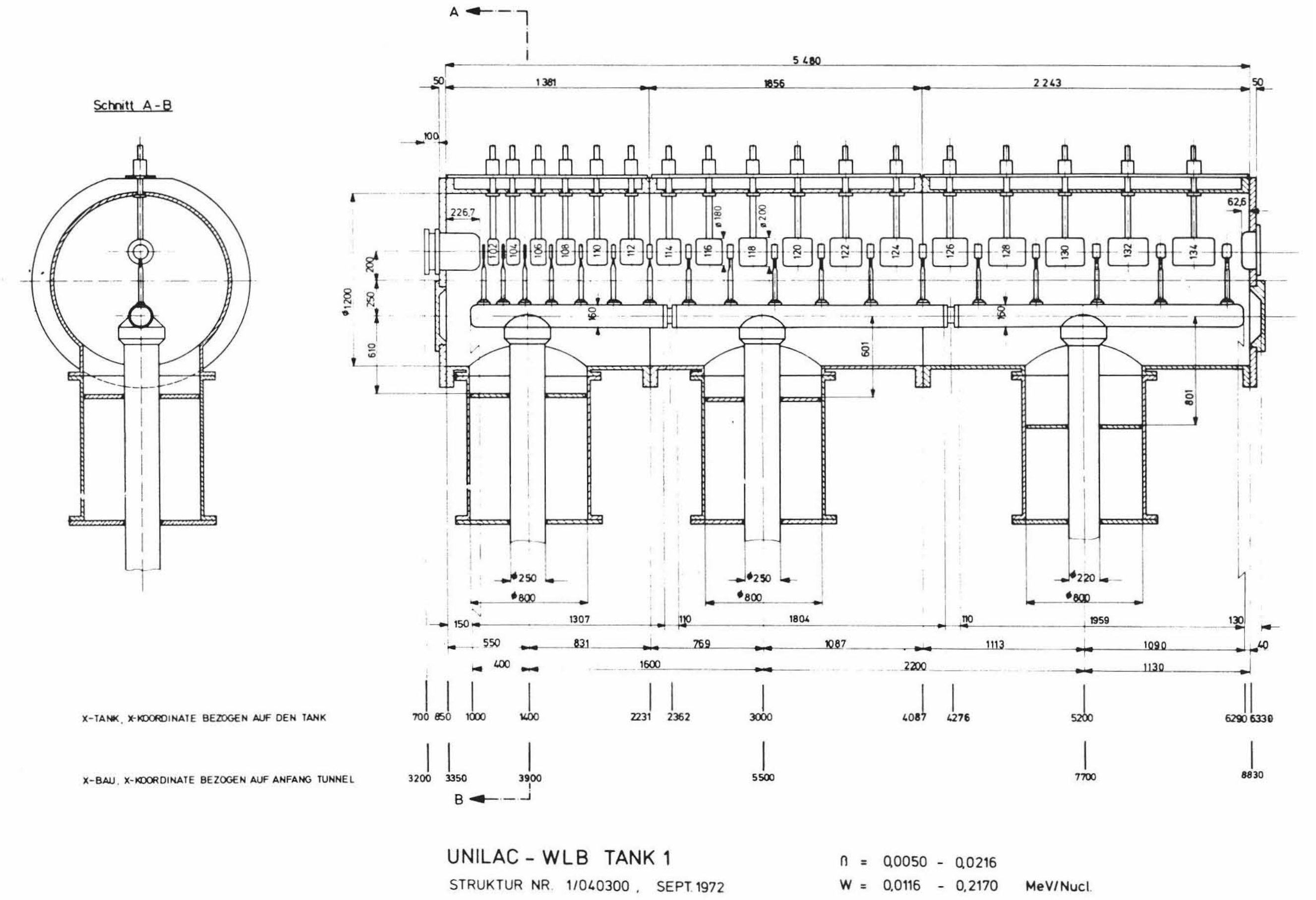

Fig. 4 Sectional view of Wideröe tank 1

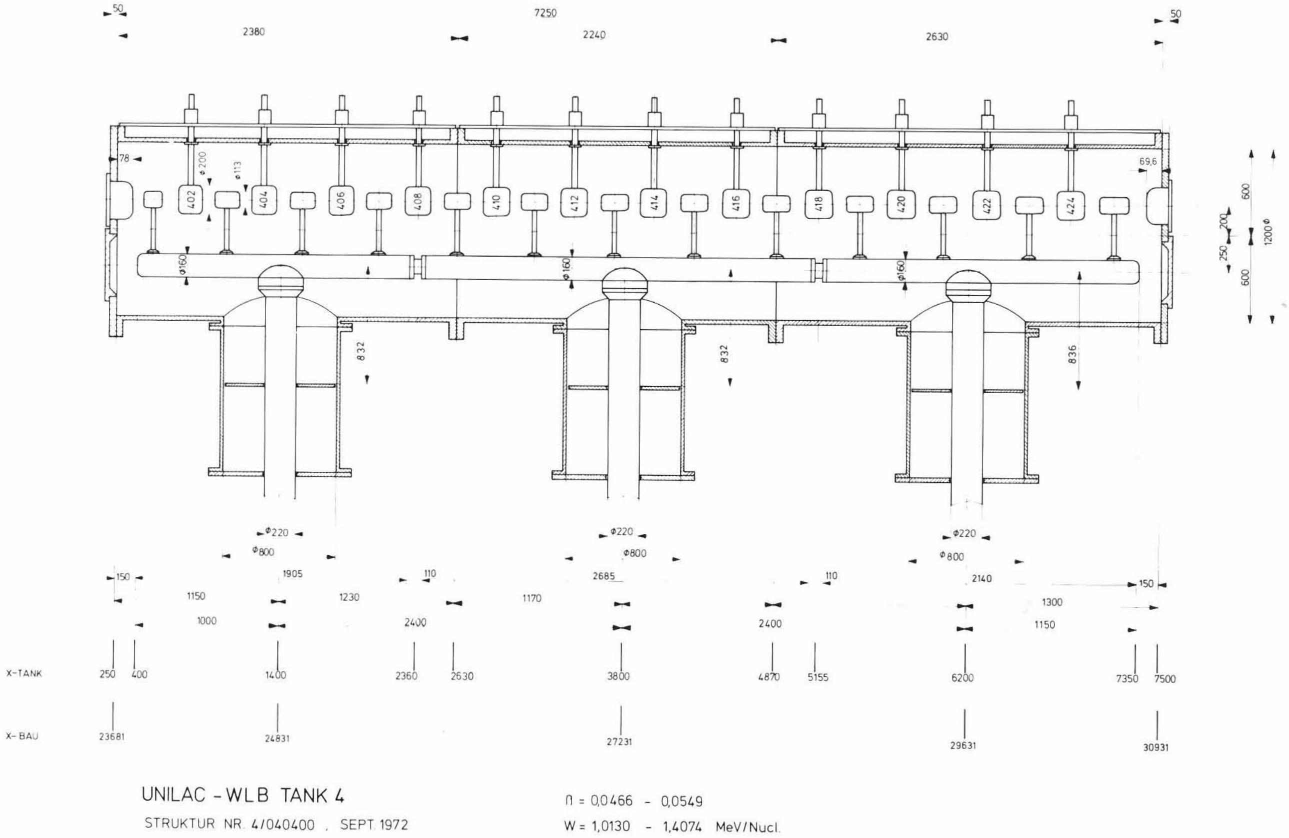

Fig. 5 Sectional view of Wideröe tank 4

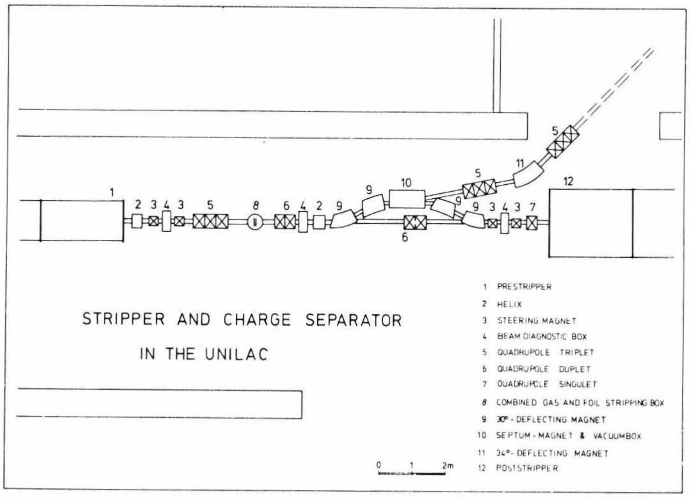

Fig. 6 Schematic of the stripper area between prestripper and post-stripper accelerator

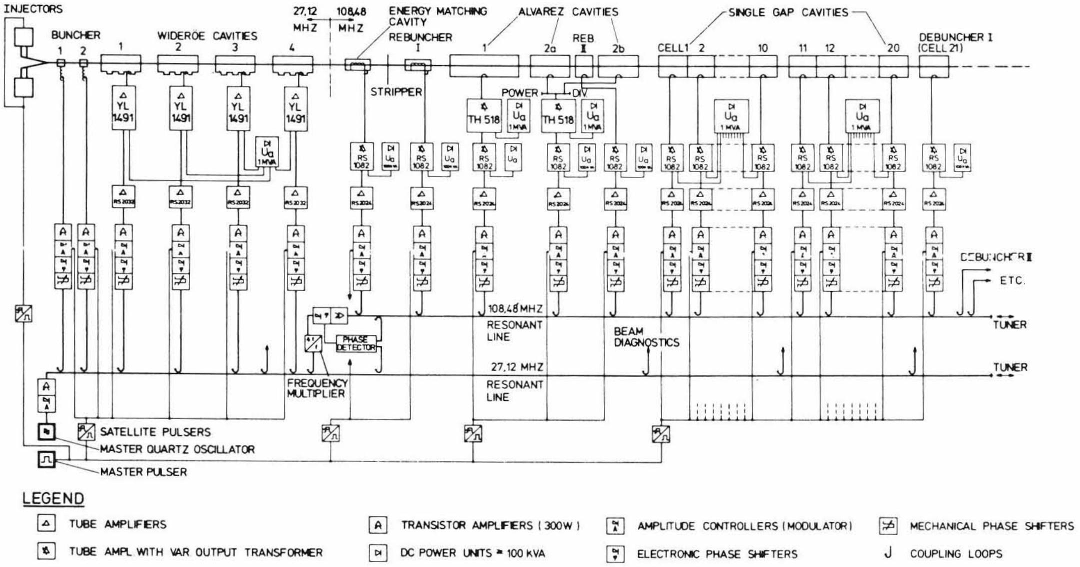

Fig. 7 Block diagram of the rf amplifier system

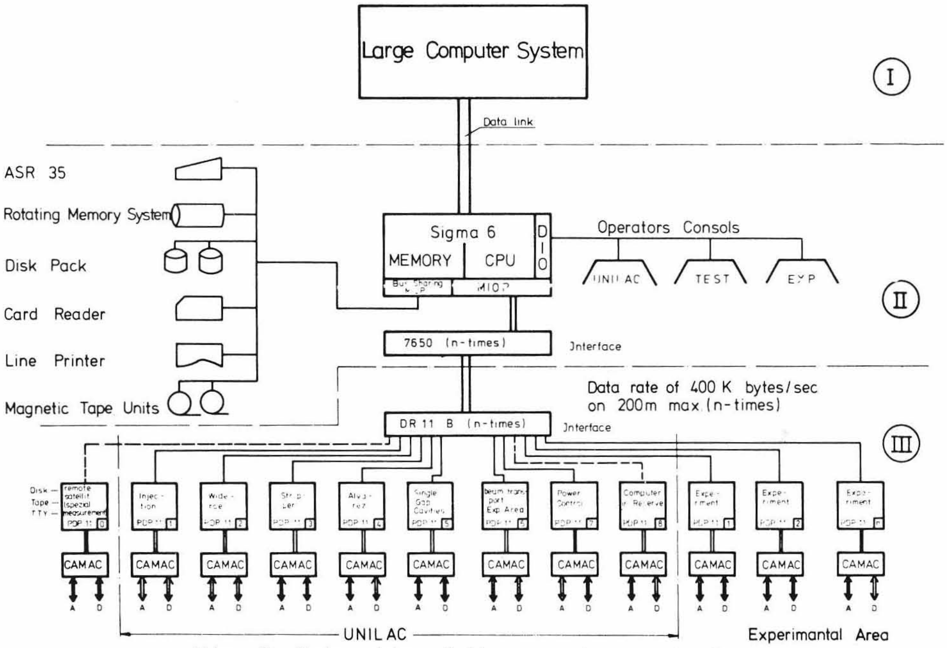

Fig. 8 Schematic of the computer control system

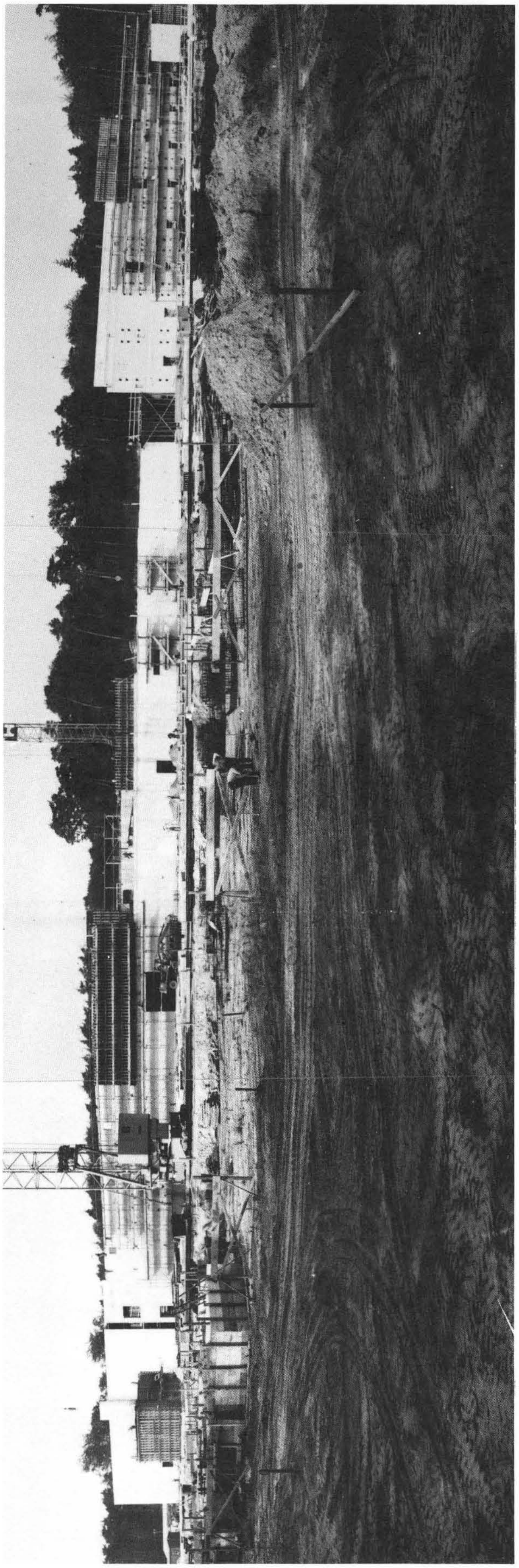

Fig. 9 The accelerator building under construction

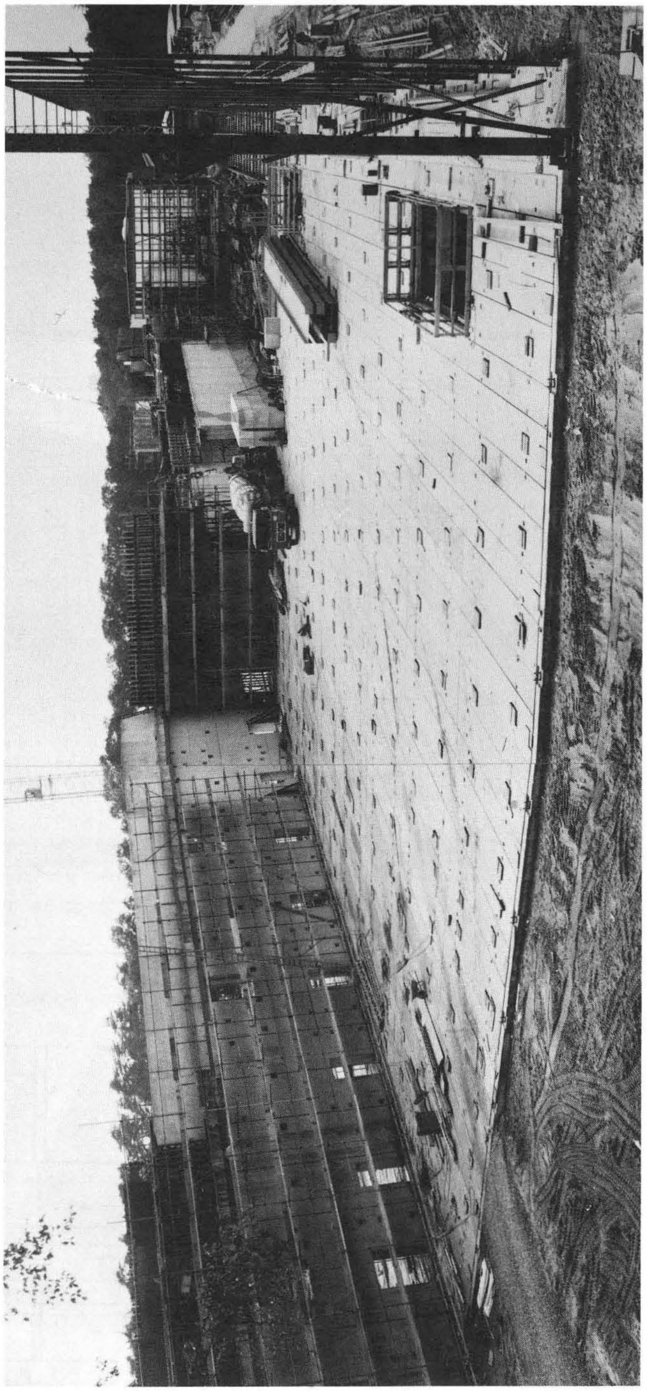

Fig. 10 View on the experimental area in the construction phase