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STATUS REPORT ON THE UNILAC

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Summary

A review on the first year of accelerator operation is given. Improvement activities, which have been initiated to bring the machine up to its design characteristics, are reported. Supplementary installations, devised to extend the design characteristics are briefly mentioned finally.

Introduction

The description of the Unilac is included in several conference papers ([1] to [9]) and will not be reiterated here. A schematic of the facility is found at the end of this report.

The Unilac was gradually completed in 1975 and commissioning took place in January 1976. At that date, still many subsystems had not performed properly and reliably. During the year 1976 the accelerator was brought to its design specifications except for the maximum energy. Since the majority of the proposed experiments did not require extreme performance characteristics in terms of energy, intensity, stability, beam quality and ion species diversity, the year 1976 was a successful period of data taking in the experimental areas, however.

Accelerator Operation

In the first year of routine operation considerable effort was devoted to eliminate imperfections of components and subsystems. During this period accelerator-physics experiments generally did not yield conclusive results and have been postponed. Machine tune-up tentatively started from pre-calculated values, but an additional empirically obtained optimization was indispensable. For this early running-in effort a computerized control philosophy was set aside.

The Unilac now is running 21 shifts per week without scheduled maintenance time. Minor inspections and repair activities are usually done at the occasion of ion source break down or other shut-off events. A scheduled shut-down time of 12 weeks in total is envisaged in 1977 for major alterations and improvements and for routine service as well.

The availability of the beam on the target is for medium heavy ions about 65 % of the total shift-time, 15 % are necessary for tune-up and the remaining 20 % account for break downs, predominantly caused by the ion source and the extraction system. The fraction of the tune-up and break down time has considerably decreased during the last year, because the beam time assigned to individual experiments became longer, one or two days for instance as compared to several hours as it was usual last year. This change seems to be important since break downs tend to occur predominantly during tune-up. In addition, the reproducibility of theoretically or empirically derived parameter settings became gradually more satisfactory. Retuning the machine for a new particle, different energy and different target station takes 8 hours, the change of energy or isotope for the same target station takes about 1 hour.

For very heavy ions, such as uranium for instance, the tune-up procedure takes longer for several reasons:

First, the sputter ion source requires a delicate running-in procedure including the optimization of the wanted and the suppression of unwanted charge states and isotopes.

Second, for the typically weak currents of very heavy ion beams, all nondestructive beam diagnostic principles are less applicable and the bunch signal of the capacitive pick-up probes disappears in the noise level, hence energy determination must be done by magnetic deflection, which is more time consuming.

Third, for the acceleration of particles with low charge to mass ratios, rf-amplifiers and magnet power supplies have to be set close to their maximum ratings and consequently trip off more frequently.

So far the accelerator was manually tuned by a crew of 2 or 3 operators per shift. Since no classical control-room was planned, the manual tuning was done in the 4 local control-areas in the equipment aisle, running in parallel to the accelerator tunnel. In the meantime all beam transport and beam diagnostic elements can be controlled via the computer system from the console in the central control-room. Parameter setting following theoretical values is generally successful and also optimized data can be saved in the computer memory and can be reused for tune-up.

Program improvements are in progress jointly with operator training.

The following list gives a survey on present accelerator performance:

Ion species:

Ar, Ti, Ni, Cu, Kr, Xe, W, Pb, U
additional 24 elements in preparation

Beam intensity:

^{40}Ar:	$6 \cdot 10^{12}$ pps	
^{132}Xe:	$2 \cdot 10^{11}$ pps,	source fed with natural Xe
^{136}Xe:	$2 \cdot 10^{12}$ pps,	source fed with pure ^{136}Xe; multi charge acceleration after stripper
^{238}U :	$2 \cdot 10^{10}$ pps	
	$6 \cdot 10^{10}$ pps,	multi charge acceleration after stripper

Energy:

3 - 9 MeV/u (xenon), variable
parasitic beam at 1.4 MeV/u

accuracy of energy setting	0.1 %
energy stability	0.2 %
relative energy spread	± 0.2 %
bunch width	0.3 ns
duty factor	40 % for Ar, 20 % for U

stripper: Foils up to $3 \cdot 10^{11}$ pps;
gas jet for higher intensities
debuncher not used so far.

Recent Accelerator Improvements

Injection

In the past year most experiments requested beams of noble gas elements. Therefore the duoplasmatron source was in use for about 85 % of the time. The beam intensities obtained from this type of source for the necessary charge states (e.g. Ar^{2+}, Kr^{4+}, Xe^{6+}) climbed to values that generally exceeded the limitations set by target life. The improvement of beam intensity by almost one order of magnitude since the start-up of routine operation resulted from proper adjustment of discharge parameters rather than from geometrical or technological modifications. Also the lifetime of the source went up with increasing operating experience and lifetime figures of about 100 h are sometimes recorded. However, occasionally quite short source life (of only a few hours) is observed. The reasons for it are not yet fully understood. The advantage of the duoplasmatron is its simplicity and its excellent emittance. It becomes more and more practice that after source change the accelerator needs only minor adjustment of one or a few lenses in the injection beam line. Two modifications of the duoplasmatron extraction system are in preparation: At first, the source will be removed from its present location inside the high voltage electrode of the preaccelerator column in order to provide space for a vacuum valve. Thus the vacuum can be maintained in the column during a source change and, hence, the presently necessary reconditioning time of the preaccelerator column can be saved. Secondly, the ceramic ball insulators in the extractor and einzel-lens system, which tend to develop shorts due to growing metal deposits, will be eliminated in favour of a well screened epoxy insulator cylinder.

The Penning source, which is installed in the second preaccelerator facility is now routinely in operation for metal ions. The metal is introduced in the anode cylinder by a plane electrode or a coaxial cylinder both at separated potential. Metal atoms are released by sputtering of the auxiliary argon gas discharge. The beam intensity from this source has also been raised by a factor of 10 in the past year by a proper tuning of discharge parameters and optical matching elements. However, this source requires a more refined tune up procedure and the peaking of the wanted charge state sometimes is a challenging undertaking for ion source experts. If once optimized, this type of source needs continuous control and retuning to avoid an intensity drop, or even a jump over from $^{238}U^{9+}$ to $^{185}W^{7+}$ ions which have the same charge to mass ratio. The Penning source is also used as a standby source for noble gas ions and in case of a duoplasmatron failure beam operation can be resumed after switch over and a modest retuning of the injector beam line. However, there is no advantage in terms of beam intensity for noble gases compared to the duoplasmatron source.

The isotope separation capability of the injection beam lines is used routinely for both source types. The equally provided achromatic tuning mode so far turned out to be of only little interest to the users. In case of ultimate intensity requirements or for rare isotopes with relative abundances below the order of percent, enriched material is used in the source.

The Unilac injection concept is now undergoing a major alteration. Originally two identical Faraday-rooms with both a duoplasmatron and a Penning source terminal had been planned. Both Faraday-rooms and DC-preaccelerator facilities have been built, but the duplication of both source types has been postponed so far for various reasons. One reason was the vague expectation that one of both source types might demonstrate a clear superiority independent of the state of aggregation of the source material. But thus far operating experience has substantiated the choice of different source types for gaseous and metallic elements and the development line of both types resulted in a more convincing specialization. A second reason was of a more technical nature. Both ion source terminals in each Faraday-room were provided with an individual insulating transformer underneath the equipment platform (see Fig. 1). This concept excluded an easy transformer replacement in case of a failure and prevented the installation of a filtering network between the transformer terminals and the source platform. The provision of a series inductance of reasonable dimensions proved to be advisable in order to protect the transformer from detrimental transients originating from high voltage break downs in the accelerating gap. One Faraday-room was recently modified and now has only one large equipment platform for both source types with their individual accelerating columns (see Fig. 2). Thus many of the terminal equipment can be used for both sources and only one insulating transformer is now necessary, being brought up to the floor level into an extension of the Faraday-room. If this modification will prove successful in future, the second Faraday-room will be modified in the same way and then a complete duplication of both sources will be available.

Accelerating Structures

Since the installation of the accelerator cavities two years ago, very little modifications have been applied to the mechanical components of the machine.

In the Wideröe structure the bellows of all 64 outer drift tubes have been changed recently. During the past year those water cooled bellows, made out of very thin copper sheet metal, developed leaks due to spot corrosion. They have been replaced by copper plated stainless steel bellows. Except for this problem, no further corrosion effect occured in the cooling system of the rf cavities, which include mild steel and copper components in the same water circuit. Also the copper plating on the rf surfaces has never presented any question of quality deterioration. The massive steel cavities demonstrated their excellent stability and alignment surveys of drift tube positions did not reveal detectable changes.

In the start-up phase of the Alvarez structure a discharge problem on the rf vacuum window in the coaxial power line occured. A rexolite disk in tank I was destroyed several times by heavy arcing on the vacuum and on the atmospheric surface. The released organic compounds spoiled the copper surface of the drift tubes which subsequently have been damaged by spark marks. Until the installation of ceramic dome windows and a complete clean up of the cavity the power level had to be kept below the discharge level. The ceramic dome windows work well now and only deficiencies in the rf amplifiers prevent from rising the power more than 80 % of the design level. The initial problem with the rexolite window has never become clear and the rexolite windows of tank II go on working without any trouble. An alternative approach to the coupling feed through with a ceramic disk window is in preparation but not yet tested.

The modification of all rf power lines in the linac tunnel is under consideration. It appears that the standard line dimensions are not adequate with respect to hold-off voltage in the environment of ionizing radiation. The power lines for the Wideröe cavities 3 and 4 had to be pressurized already to allow for a 50 % power increase for the acceleration of the U^{9+} charge state instead of the planned U^{11+} charge state. The power lines of the Alvarez and single-gap cavity structure also reveal traces of arc discharges and have to be replaced by a pressurized version if the rf power in the poststripper section will be raised in future.

The single-gap cavity structure now is routinely in use for energy variations between 3 and 9 MeV/u. For two reasons the maximum energy gain has not yet been reached in this part of the poststripper accelerator: At first, the cavity detuning under full rf power is for most cavities larger than the tuning range of the piston tuner control. The second problem, which still is not yet overcome, is the tendency of the ceramic dome rf windows to develop vacuum leaks. This problem, which never occured at the Wideröe structure, was already experienced in an early prototype phase and was eliminated then by a conductive coating on the vacuum surface of the domes. This coating apparently disappeared meanwhile and a mechanically more resistive coating has to be found. Both problems, the detuning and the ceramic puncturing is subject of a redesign program on a recently installed test resonator. The present rf end walls with additional expansion groves or a redesigned version made of thin copper sheet metal will be explored. Moreover, ceramic domes with different surface treatments of titanium and chromium oxide will be tested. If the latter approach should fail, an already tested loop device with a ceramic disk window (adapted from DESY) will be considered.

RF-Amplifiers

In the original design of the Alvarez section one single high power amplifier, rated at 1.6 MW peak power, was provided for each of the two cavities (see Fig. 3, left). During an intense test bench program one particular tube unit nearly reached the design goal, many other tubes having been destroyed by parasitic oscillations at lower power levels. Those oscillations, occuring between 0.7 and 1.9 GHz, resisted so far to all attenuating measures. The only way to get a satisfactory stable operation of the tube was a reduction of filament voltage, resulting in a reduction of power gain and saturation power level. Since half of the nominal power requirement seemed to be obtainable with most of the tubes, a straight forward approach was the duplication of the amplifiers (see Fig. 3, right). This presented no difficulty for tank II, which is separated into two individual cavities and which originally required a power splitting out of one amplifier. Now the duplicated amplifiers allow for an intermediate energy step at 4.7 MeV/u by switching off the second amplifier, and in addition this version provides a clear solution for individual phase and amplitude control of both tank sections. For tank I, however, both amplifiers have to be paralleled into a common load. For this purpose a second coupling loop was already foreseen in the original tank design. This mode of operation, which is in service since only recently, requires an almost perfect synchronization of the forward waves in both lines with respect to amplitude and phase and requires a coupling loop adjustment to 25 Ω rather than to the 50 Ω value of the line impedance. Since it is desirable to operate the cavity also from a single amplifier in case of a break down of the second amplifier, a quarter wave stub line, connected in parallel to the drive line, can be tuned to a proper admittance value, thus providing a match of the 25 Ω load to the 50 Ω amplifier output. - Not much operating experience with this system exists so far and no attempt was made to reach the design power level of 1.6 MW. It appears, however, that the synchronization is not simple to achieve and to be kept stable.

As part of the continuous effort to reduce the tune-up time of the poststripper for variable energy operation, a modification was applied to the timing system. It is now possible to run up an Alvarez cavity or any single-gap cavity to the preset power level in the intervals between beam pulses. If an energy change is desired, the pulsing of the necessary cavities is brought back to synchronism with the beam pulse. The precise energy setting is then accomplished by correcting the cavity phases according to bunch signal measurements and a computerized conversion into energy values. This timing scheme also provides the basis for a future energy variation from pulse to pulse.

Future Developments

In this chapter activities are mentioned, which are already initiated, but for which results can not be reported yet.

a) As part of a long term ion source development program, a so called "iron-free" duoplasmatron source was completed. It is intended to combine the homogeneous field characteristic of a Penning source (by using a solenoid coil) with the favorable extraction geometry of a duoplasmatron source. If this source proves to be successful, it may be a candidate for replacing the present double source concept.

b) In order to improve the reliability of the rf system of the Alvarez section, a complete test facility for high power tubes and associated equipment is in its final installation phase. The phenomena of parasitic oscillations will be investigated in cold probe and high power measurements without disturbing accelerator operation. A completely redesigned high power amplifier stage is also under consideration.

c) A series of capacitive bunch signal probes have been installed in the stripper section and at the high energy end of the machine. A microprocessor system is under development to provide an on-line energy measurement on a time of flight basis.

d) As an attempt to satisfy the considerable demand for beam time, a beam splitter has been designed and all components are presently under test prior to the installation of the system in the next shut-down period. Fig. 4 shows a schematic of the beam splitter. A large aperture quadrupole triplet widens the beam, which then is split off by a pair of two adjustable septum magnets into a left, a straight and a right going fraction. The intensity distribution between the three channels can be selected individually. A second pair of septum magnets deflect the left and the right going beam into the beam lines of the present switch yard. Thus two or three experiments can be run simultaneously, however, with the same ion species and energy.

e) An increasing number of experiments tend to request a well defined bunch structure at the target station while using the accelerator phase reference as start signal for time of flight measurements. Since the particle bunches deteriorate in the drift space between accelerator exit and the target place due to the energy spread of the beam, a debuncher-rebuncher system was conceived and is now partly installed. A single-gap cavity, positioned 15 m downstream of the accelerator serves as a debuncher and a short helix cavity in each of four different beam lines will then refocus the intrinsic bunch structure on the target. The performance of this system relies on an almost perfect energy stability of the beam and may require some improvements in the rf amplitude control circuits of the power amplifiers.

f) To extend the energy range of time of flight experiments to the detection of low energy reaction fragments, a micro pulse supressor is under consideration. A fast beam chopper device in the injection beam line is envisaged to increase the present 37 nsec bunch intervals by a variable factor. Further accelerator studies are planned to clear the question of the on-off ratio of beam intensity and of the total beam current between beam pulses. If this ratio will not exceed a factor of 10^6 for proper tuning of the machine, a chopper must be placed at the high energy end, resulting in an more elaborate and less flexible device.

References

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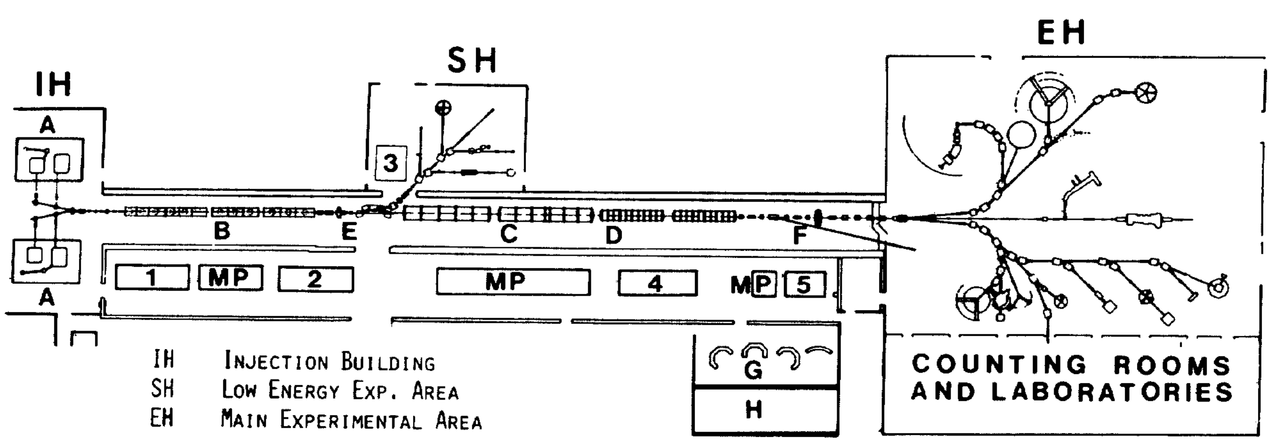
Planview of the Accelerator and the two Experimental Areas



IH	Injection Building
SH	Low Energy Exp. Area
EH	Main Experimental Area
A	Ion Sources and DC Preaccelerator
B	Wideröe-Accelerator
C	Alvarez-Accelerator
D	Single Gap Cavities
E	Stripper with Charge Separator
F	Debuncher
G	Main Control Room
H	Control Computer
MP	Magnet Power Supplies
1...5	Lokal Control Rooms

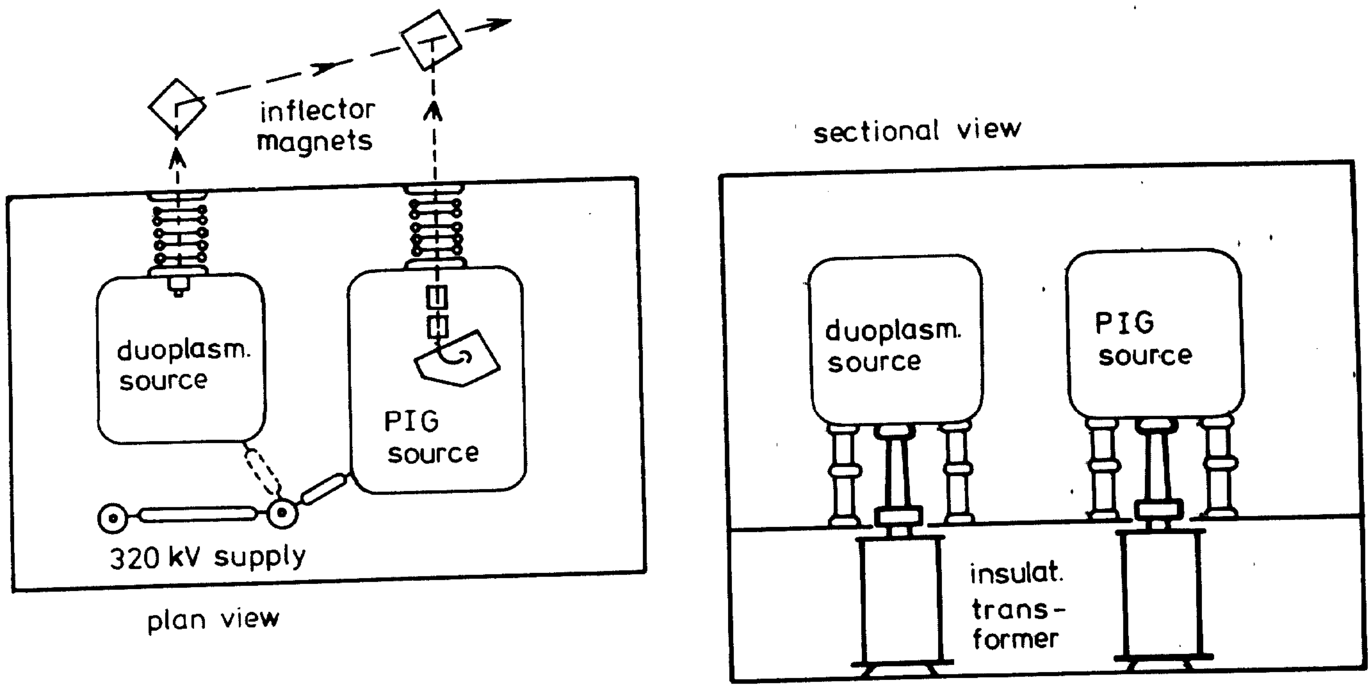


Fig.1: Original Version of the UNILAC Faraday Room

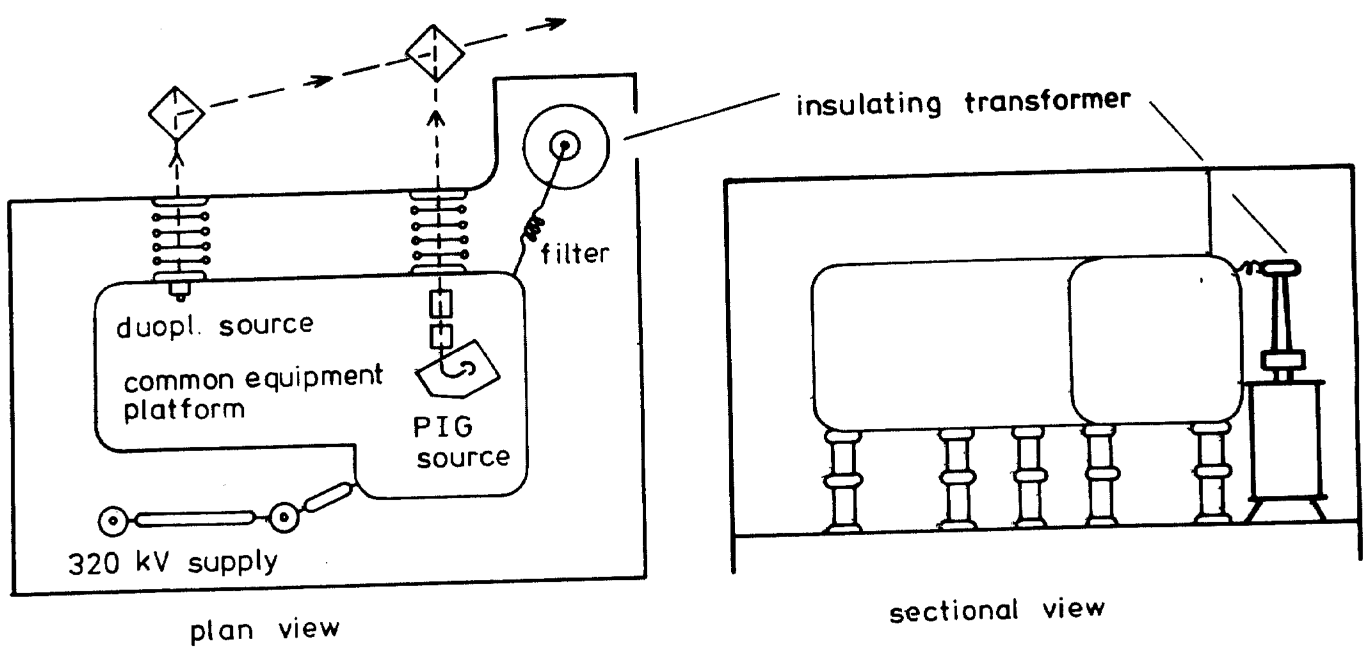


Fig.2: Modified UNILAC Faraday Room

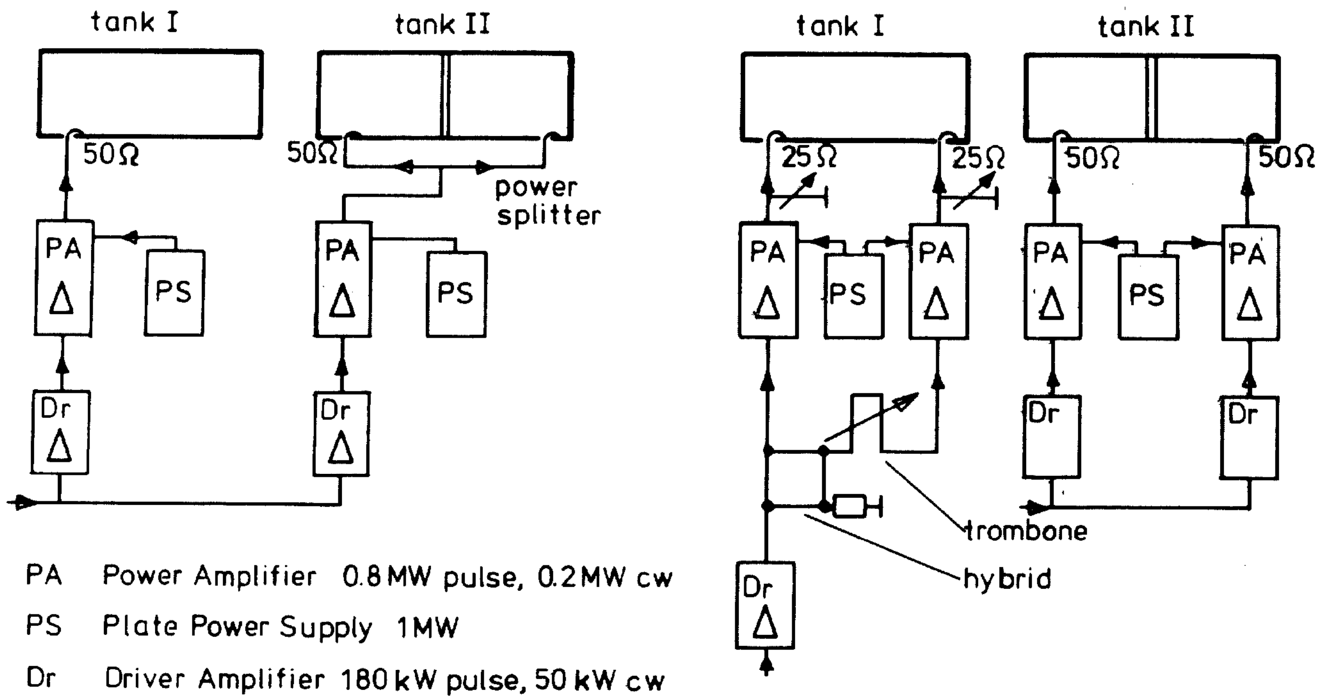


Fig. 3: RF System of the UNILAC Alvarez - Section
left: original configuration right: new configuration

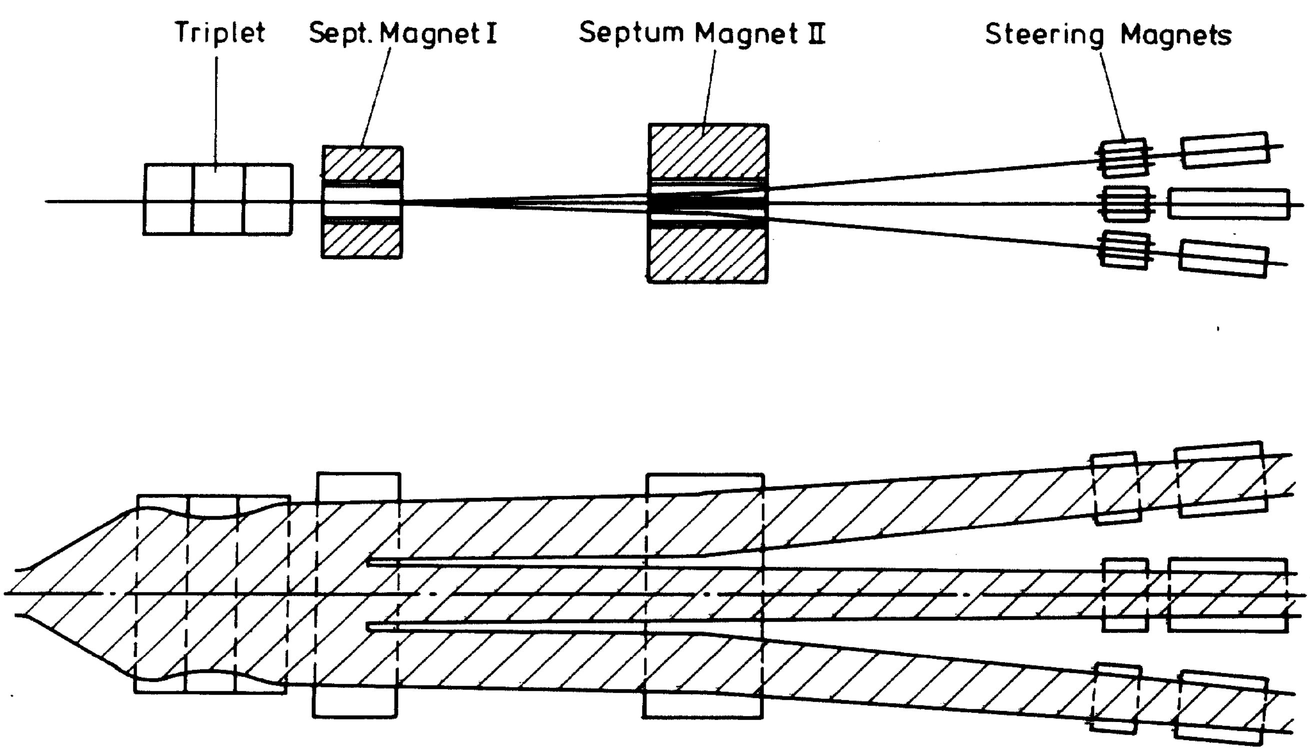


Fig. 4: BEAM SPLITTING SYSTEM