SOME ASPECTS OF THE

UNILAC BEAM DIAGNOSTIC SYSTEM

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Summary

A survey of the Unilac beam diagnostic system is given with special reference to the operational experience collected during the running-in period. Devices for measurement and display of beam profiles, energy, rf phases and amplitudes and rf matching procedures between the different stages of the accelerator are described. Some aspects concerning future developments and improvements are discussed briefly.

Introduction

Rather elaborate beam diagnostic systems are essential for multi-particle, variable energy linear accelerators like the Unilac. Beam parameters have to be monitored within a wide intensity range (10^9 to 10^{14} particles per second) and at specific particle energies between 11 keV/u and 10 MeV/u. The multi-stage rf accelerating system of the Unilac and its associated re- and debunching elements, in addition, demands precise phase measurements to obtain the high degree of beam quality necessary for a large group of experiments.[1]

The frequent changes of accelerating conditions, typical for multi-particle, variable energy machines, tend to decrease the overall operational efficiency of the facility and computer aided operation becomes almost essential. Therefore, the electronics associated with the beam diagnostic elements of the Unilac were designed, from start on for both, manual and computerized operation.

The development of beam diagnostic elements at GSI received much stimulation from other accelerator laboratories, yet the adaptation to the specific needs of the Unilac led often to considerable modifications and to special developments as well. Table I gives a survey of beam diagnostic elements either in actual operation in the Unilac, or in advanced developmental stage. The following remarks concentrate on beam profile measurements, fast pick-up probes and on phasing and energy measurements.

Beam Profile Measurements

From the viewpoint of first time operation of the Unilac and the present operation of the accelerator for experiments the harp system has proved extremely useful for tuning up, optimization and beam monitoring procedures even at rather low beam intensities. Therefore some more details will be given.

Fig. 1 shows a harp, removed from its pneumatic actuator. The harp itself consists of 2 x 16 tungsten-rhenium alloy wires, 0.1 mm thick and spaced by 1.5 mm. The wires are arranged in two planes for the measurement of the beam profile in x- and

TABLE I

Beam-Diagnostic Elements

Beam Parameter	Device	Specifications
Rough estimate of position	Movable slits	
	Segmented diaphragms	
	Sectorized Faraday cup	
Position and profile	Harp	Resolution 1.5 mm
		Sensitivity > 5 nA
		Aperture 40 mm x 24 mm
	Ionization beam scanner[2]	Resolution 0.5 mm
		Sensitivity (estimated)
		$5 \times 10^9 - 5 \times 10^{10}$ p.p.s. at 10^{-7} torr
		Aperture 50 mm x 50 mm
Current	Faraday cup[3] cooled:	Off-set current 1 - 10 nA
		Maximum power 6 kW
	uncooled:	Off-set current < 100 pA
		Maximum power 300 W
	Beam transformer	Sensitivity (S/N = 1) 500 nA
		Bandwidth 100 kHz
Micro-structure	Capacitive probe[4,5]	Sensitivity ≈ 5 μA peak current
	Coaxial Faraday cup[3,4]	Bandwidth 1.3 GHz
Emittance	Slit system with 32 detectors[6]	Angular range ± 16 mrad Angular resolution 1 mrad Resolution of position 0.1 mm Sensitivity 1 nA/detector
Energy, Energy spread	Time-of-flight system (Detector: capacitive probes, semi-conductors)	Resolution ≲ 1 ‰
	Pulse height measurement with semiconductors	Resolution ≲ 1 %

y-direction. Each wire is tightened by small springs made of durotherm, a material with good elasticity up to temperatures of about 650^0 C. The beam loss due to the interception of a harp is about 10 - 12 %. There is no suppression of secondary particles; on the contrary, electron emission gives some signal amplification. There is one operational amplifier for each wire, used as current-voltage-converter, optimized with respect to the cost and off-set current at a tolerable level. With the chosen amplifier (SG 3118 M), 2 nA on the wire can be measured within approximately 10 %, secondary emission included. In order to reduce the electronics necessary for about 70 harps, installed along the Unilac and in the experimental areas, relay switching units serve groups of 8 harps with one main signal processing unit.
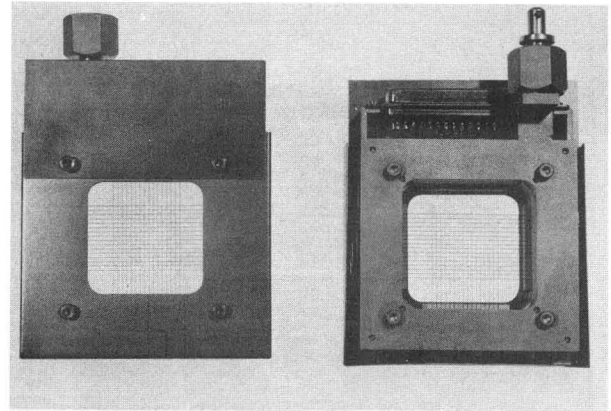

Fig. 1   View of a harp.

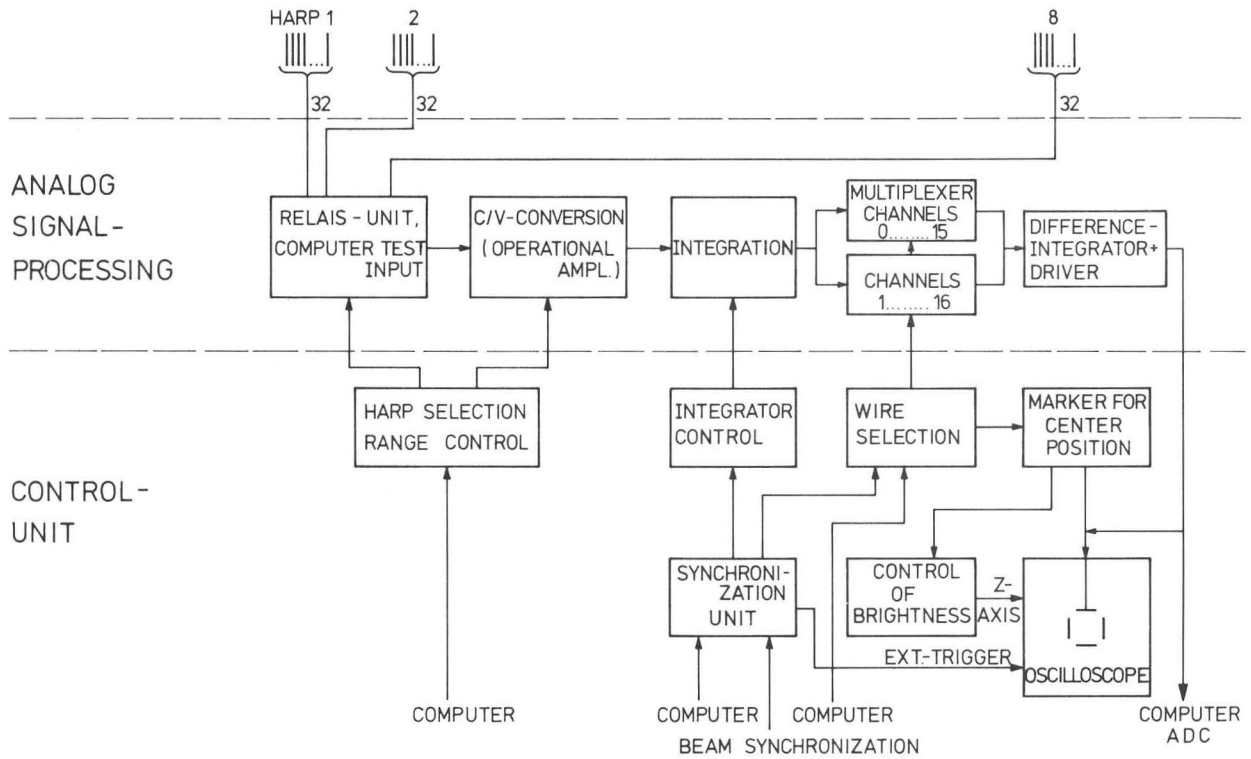Fig. 2 gives a blockdiagram for the harp electronics.

Fig. 2   Blockdiagram of harp electronics.

Fig. 3 shows a typical profile display. The original histogram is smoothed out by the difference-integrator.
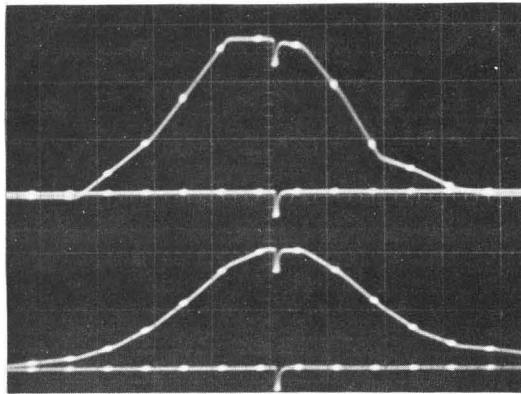

Fig. 3   Display of a typical beam profile in the horizontal (top) and vertical plane.

Microstructure Measurements

For the correct setting of rf phases, rf amplitudes and the matching of different accelerator substructures two probes for bunch signal detection are used: a coaxial type of Faraday cup and a nondestructive capacitive probe. Fig. 4 shows the coaxial Faraday cup without the pneumatic mechanism for plunging it into the beam line. The cup is made in 50 ohm-geometry and the reflection coefficient - measured with a 25 ps rise time TDR - is less than 10 %. The grid in front of the collector repels secondary electrons and shields against the longitudinal electric field moving in front of the bunch which otherwise would broaden the current signal.[3]

COAXIAL FARADAY CUP

Fig. 4   Coaxial 50 ohm Faraday cup (left). The beam entrance with radial grid (center bottom); isolator protection (top center); inner conductor with cooling water connections (left).

Fig. 5 shows a typical bunch signal observed on a 500 MHz oscilloscope with a prototype of the coaxial Faraday cup after signal amplification with a broadband-amplifier (HP 8774, BW = 1.3 GHz, gain 48 dB, noise 40 μV). In this case the grid in front of the collector was grounded.
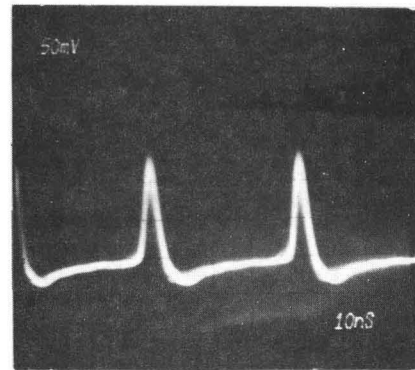

Fig. 5   Bunch signal behind the second Wideröe tank, measured with a coaxial Faraday cup (real time, 50 mV/div., 10 ns/div.).

For the proper tuning of rf parameters by observation of bunch signals, at present several capacitive probes are installed along the accelerator. The probes are made in a "coaxial" 50 ohm-stripline geometry[4] (see Fig. 6). Ground loops are avoided by isolating the probe from the beam pipe. The device is tuned to 50 ohms impedance by means of the segmented diaphragm in front of and behind the pick-up cylinder. In case of correct tuning the reflection coefficient can be as low as 5 %.
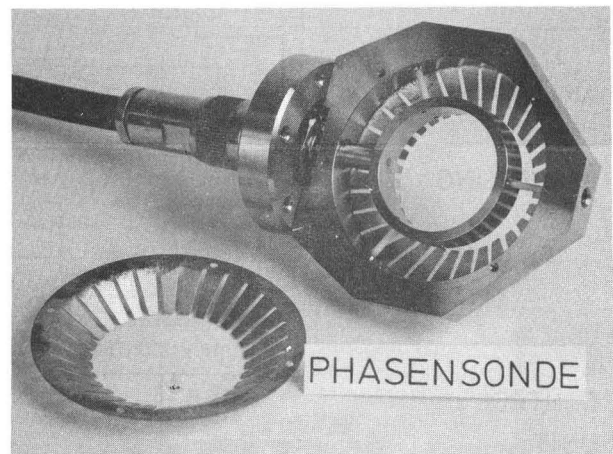

Fig. 6   Capacitive probe.

Because the influenced current on the pick-up electrode is proportional to the first time-derivative of the transverse electric field from the bunches, the signal is bipolar as shown in Fig. 7. In this picture the mean beam current was quite low (27 nA), but nevertheless it is possible to observe bunches and to set rf phases of the cavities to the correct time relation with respect to the bunch signal.
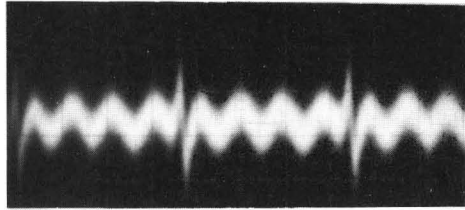
Fig. 7 Signal of the capacitive probe at low beam intensity, mean beam current 27 nA, at 15 % duty cycle, vertical 10 mV/div, gain 48 dB, horizontal 10 ns/div.

Measurements of the bunch position with respect of rf reference signals or the simultaneous observation of bunch signals from two or more probes have proved indispensable during the running-in period of the machine and for the present tuning-up procedure of the accelerator. For this reason five capacitive probes were installed along the machine up to now, and 8 more probes will added in the near future. Fig. 8 shows the positions of the probes along the accelerator. Later on more probes will be installed into the experimental beam lines in order to give the users information about the microstructure near the target.

The final concept of the signal processing system for the capacitive probes and the coaxial Faraday cups is now under development. It will allow the observation of all signal combinations which are needed for tuning-up the Unilac. A preliminary version of the signal processing system used at present is schematically shown in Fig. 9.
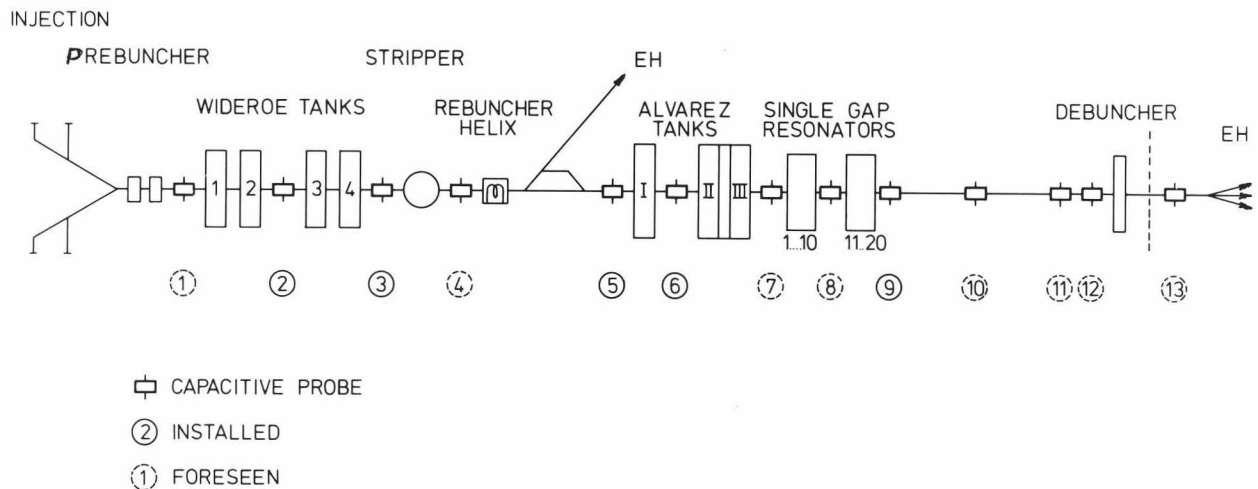

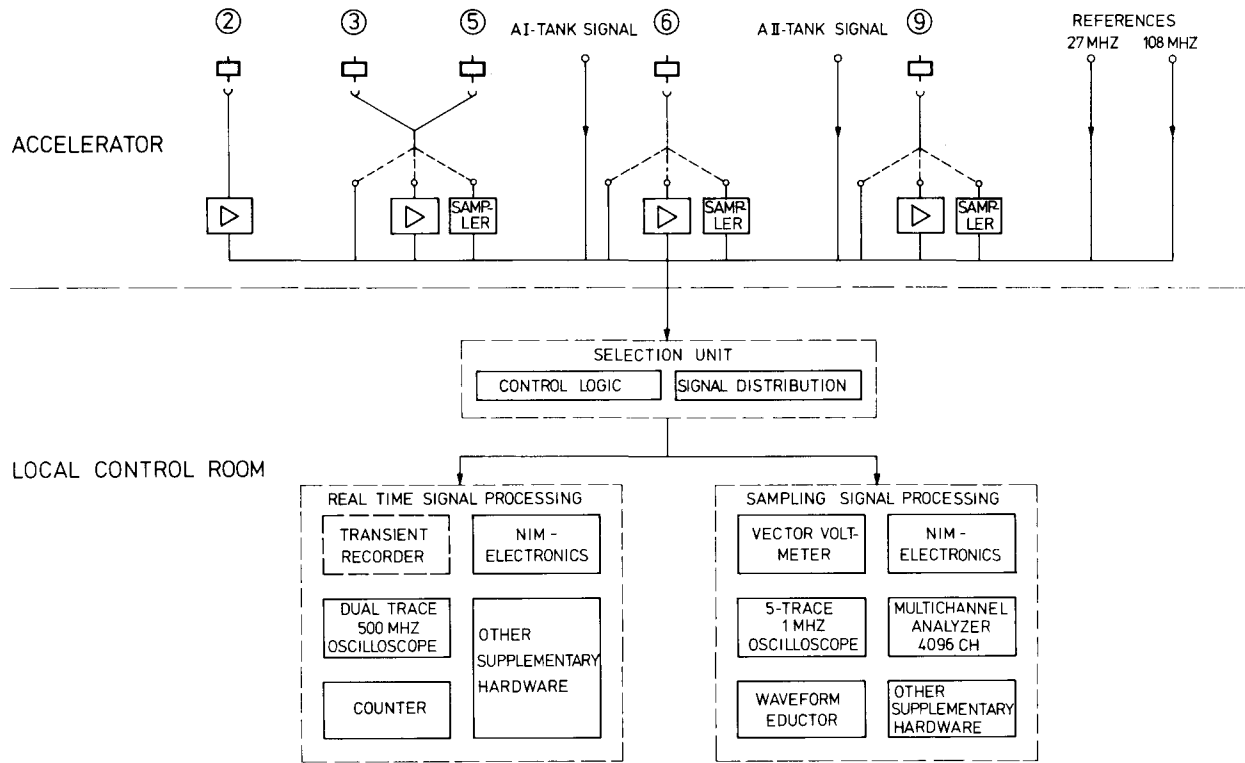Fig. 8 Position of capacitive probes.

Fig. 9   Signal processing for capacitive probes.
The selection unit allows simultaneous
observation of two signals.

The particle velocity can be measured with
a high accuracy by use of the signals from three
capacitive probes. The principle of the method is
illustrated in Fig. 10.

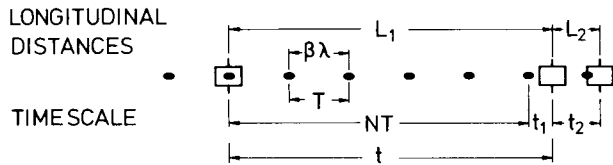LONGITUDINAL
DISTANCES

TIME SCALE

Fig. 10   Principle of time-of-flight measurements.

According to the definitions in this Fig.,
the velocity can be calculated from

$$v = L_1 / (NT + t_1),$$

where N is the number of bunches between the first
and second probe; t_1 is the measured time delay
between the both signals. The unknown integer number
N can be found exactly by a rough estimate of the
energy, which is easily obtained from the time-of-
flight measurement between the probes spaced by
$L_2 \lesssim \beta \cdot \lambda$. The desired accuracy for this measure-
ment is affected by the order of N, which itself

depends on the distance L_1, the particle velocity
and the rf wavelength. According to the parameters
of the Unilac, the required relative accuracy is
of the order 10^{-2}. The time difference t_1 can be
measured with a sufficient accuracy.

These measurements are foreseen at two po-
sitions along the Unilac (see Fig. 8): with probes
10, 11, 12 at the end of the linac and with probes
3 and 5 in the stripper region. Here the magnetic
analyzing system serves to determine N.

As an example, the main parameters in the
stripper part are as follows:

L_1 = (8025 ± 1) mm

λ = 11061.8 mm (T = 36.898 ns)

v_0 = 0.05491 x c (design value for Wideröe tank 4)

$\beta_0 \lambda$ = 607.406 mm $(\beta_0 = v_0/c)$

N   = 13.212

t_1 = 0.212 x T ≈ 7.82 ns

In Fig. 11 time signals from the probes 3 and 5 in the stripper region are displayed.
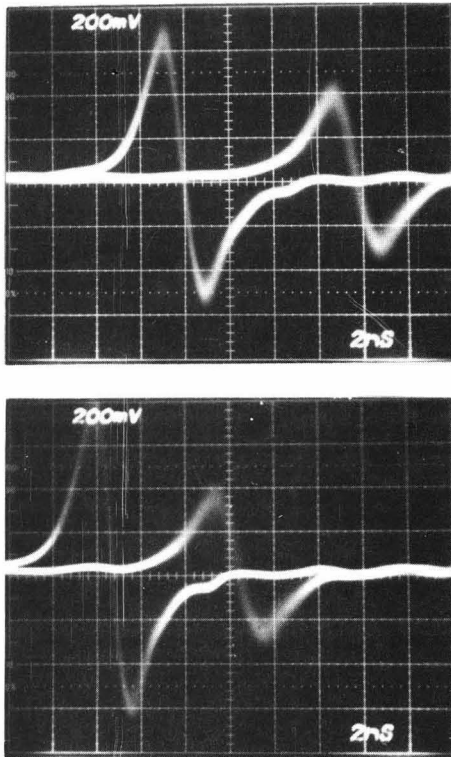

Fig. 11   Time-of-flight measurements behind the Wideröe accelerator (top: design velocity of tank 4; bottom: velocity 0.48 % higher).

The distance of the zero-crossings of the two traces measures t_1 and corresponds, in the upper picture, to the design velocity of v_0 = 0.05491 x c. The lower picture was taken for a 0.48 % higher velocity. It also can be seen that t_1 can be measured within approximately ± 200 ps corresponding to a relative error of ± 0.05 % in the velocity measurement.

Fig. 12 demonstrates the usefulness of this method. It shows the dependence of the output energy of Wideröe tank 4 from the rf phase difference between Wideröe tank 3 and 4 at constant rf amplitude. $\Delta E/E$ = 0 corresponds to the design energy at the end of tank 4.

This time-of-flight technique became a valuable tool for energy and phase matching between pre- and poststripper during normal operation.
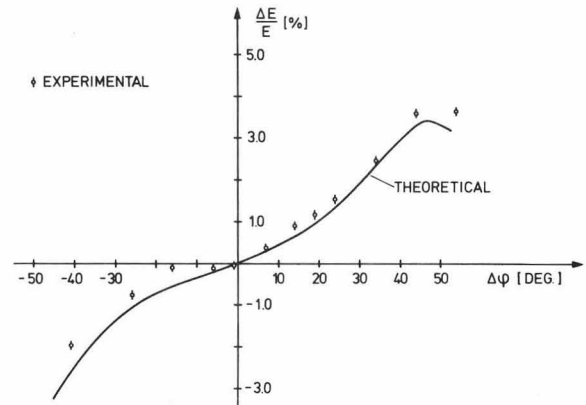

Fig. 12   Output energy of Wideröe tank 4 versus rf phase difference between tank 3 and 4.

The method is also used for the correct phasing of the rebuncher helix behind the stripper. The rf phase is set correctly for vanishing energy gain, i.e. the time-of-flight between the two probes does not change when the helix is switched on. An example for this - at present more or less standardized - procedure shows Fig. 13.
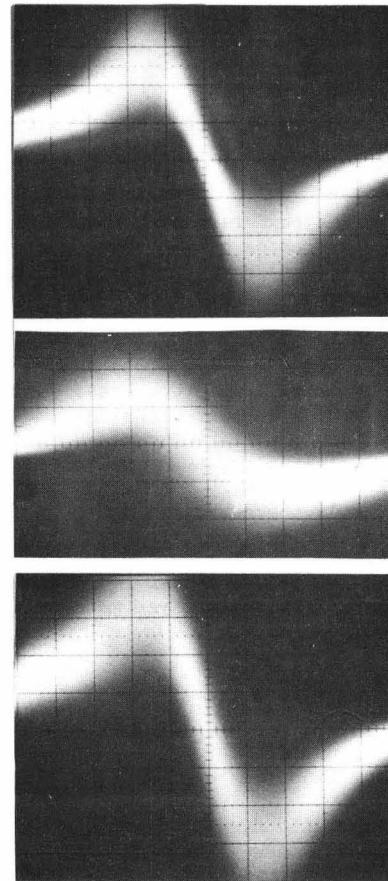

Fig. 13   Adjustment of the helix rebuncher. Top: signal straight behind the Wideröe, signals in front of Alvarez tank 1 without rebuncher (center) and with rebuncher (bottom).

The signal of probe 5 is also used for the tuning procedure of Alvarez tank 1. Since the distance between this probe and the first accelerating gap of the poststripper accelerator is quite small, the effect of small energy variations can be neglected in the time-of-flight between probe and gap; therefore the time relation between the bunch signals, observed with probe 5 and the rf signal from Alvarez tank 1 is assumed to be constant. For this reason the operators use the display shown in Fig. 14. for the correct setting of phase between prestripper and poststripper. The shown timing relation corresponds presently to a stable phase angle of -30^0 (design value) within approximately $\pm 8^0$.
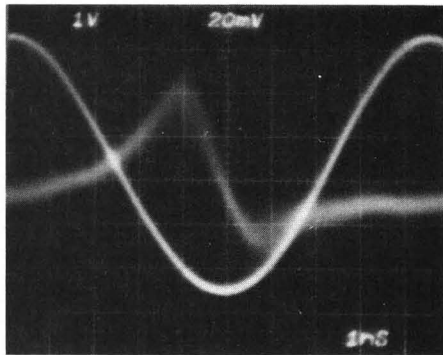

Fig. 14   Bunch position with respect to the rf-signal of Alvarez 1 (1 ns/div.).

Operational experience with the Unilac has shown, that the matching between pre- and poststripper is rather critical for the following reasons: the 15 m drift space between the two groups; the change of frequency from 27 to 108 MHz which reduces the longitudinal acceptance of the poststripper accelerator and the energy loss by the foil- or gasstripper. The described procedures, however, are fully sufficient for correct matching.

The time-of-flight techniques are also valuable for adjusting the 20 single gap cavities. Up to now we use only the capacitive probe 9 (Fig. 8). The procedure is as follows: firstly, the phase of each single gap cavity is adjusted for vanishing energy gain and in a second step the phase increment corresponding to the desired mode of operation is added.

Outlook

Further development of the Unilac beam diagnostic system goes along the following lines:

Destructive diagnostic elements will be replaced by the nondestructive types as much as possible. In case of the harps, a device based upon residual gas ionization is presently being tested. It needs no change of the electronic system.

A new nondestructive fast probe with increased bandwidth is under construction, which gives directly the longitudinal intensity distribution of the bunches.

Finally, a system displaying the particle distribution in the ΔE-, $\Delta \varphi$-plane is presently being installed using as detectors capacitive probes or semiconducting elements.

Improvements of signal processing and display of information go in parallel. Special care is given to produce simple reference patterns to speed up the tuning of the machine.

Acknowledgement

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References

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4   A. Nicklas, P. Strehl and H. Vilhjalmsson, GSI-PB-5-75.

5   J. Glatz, H. J. Keller and P. Strehl, GSI-73-1   (1973).

6   A. Ehrich, J. Glatz and P. Strehl, GSI-PB-3-74.

DISCUSSION

V. Elyan, RTI: Have you done any measurements by the ionization beam scanner? What is the space and time resolution of this detector and does it use crossed field for extraction?

Klabunde: The device is under test. The resolution is 0.5 mm and we use crossed E and B fields. The frequency range is 25 Hz to 1 kHz.