

## THE IH LINAC OF THE CERN LEAD INJECTOR

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### Abstract

The IH linac part of the new CERN Lead Injector consists of three tanks, which can accelerate Pb 25+ ions from 0.25 to 4.2 MeV/u. The total length is only 8.1 m. The RF power needed for the effective acceleration voltage of 33 MV is less than 1 MW.

Today this is the biggest linac based on the beam dynamics of Combined Zero Degree Synchronous Particles. Design and engineering work started in 1992. This paper presents experiences with the mechanical design and the performance of the structures with respect to RF and beam parameters during commissioning in spring 1994. A 4.2 MeV/u Pb beam was injected into the PS booster synchrotron in June 1994.

### Introduction

The new heavy ion injector at CERN [1] was designed and built in a collaboration of several institutions, mostly from CERN member states. It consists of a 14 GHz ECR ion source, a 101 MHz RFQ and three IH (Interdigital H-mode) accelerator tanks with 101 MHz (tank 1) and 202 MHz (tanks 2 and 3). The IH linac and part of the RF generators for the whole injector were the German contributions to this project.

The decision to use this IH type linac for the new CERN injector was taken after successful beam tests with a 1.4 MeV/u heavy ion linac at GSI in September 1991 [2], [3]. The final drift tube structure based on the "Combined Zero Degree Synchronous Particle Structure" [2] was agreed upon after beam dynamics studies at CERN and GSI [4]. The accelerating structure is divided into five drift tube sections, between which are housed magnetic triplet lenses. The first IH tank contains three drift tube sections and two triplet lenses. The three steel tanks were delivered to GSI early in 1993 and the copper plating completed in June 1993. Through to December the installation of the accelerating structure was completed as well as the RF tuning work and a full test assembly of the three tank array. At the same time the structure was tested for vacuum and the quadrupole lenses and the power supplies were accepted. Fig. 1 shows the tank ensemble during tests at GSI. January and February 1994 saw the delivery of the equipment to CERN, with installation, alignment and RF conditioning completed by April.

### Mechanics

The design and engineering of the three tanks were based on the GSI 1.4 MeV/u tank [3], [5]. The three new tanks were fabricated at the same company (Fa. Klein) as the GSI one, so there were no problems during manufacture. The two in-tank quadrupole triplets of tank 1 were also fabricated by the previous manufacturer (Fa. Bruker). They required again some attention in order to reach the specifications. A new feature of this linac was the combination of several tanks with a frequency jump between the first and the second one. Due to particle dynamics and to avoid intertank-rebunching, the tank distances had to be as short as possible, which led to a rather compact design of the intertank sections.

Much attention had to be paid to the alignment of the ensemble of the tanks, particularly the in-tank (tank 1) and the intertank triplets. The present mechanical design couples the tanks rather strongly to the triplets, making the independent alignment of tanks and triplets difficult. Alignment was performed with respect to the beam axis. Then the position of the alignment targets on the tanks were measured with respect to the CERN off-axis reference line. Total alignment errors could be limited to  $\pm 0.3$  mm for the in-tank and inter-tank triplets. The inter-tank triplets are equipped with steering coils which allow at least for partial compensation of beam steering effects due to lens alignment tolerances.

### RF Measurements

#### *RF-Tuning*

The tuning of the tank frequencies and gap voltage distributions was done for each tank in several iterative steps by successive mechanical matching of drift tube and gap lengths. In addition, the tank end undercuts had to be adjusted in parallel by properly sized tuning blocks to achieve the desired field distribution. Each tank has two capacitively acting plungers, one near the centre and one at the high energy end which are used to do the fine tuning. The finally achieved gap voltage distributions are shown in Fig. 2. The differences between the ideal and the measured voltage distribution are less than 5%.

The beam dynamics was then checked by the LORASR-code [2] with the final drift tube configuration and the measured gap voltage distribution. Not taking into account alignment tolerances, rms emittance growth of 20% in transverse and of 15% in longitudinal phase space was calculated for the whole linac structure.

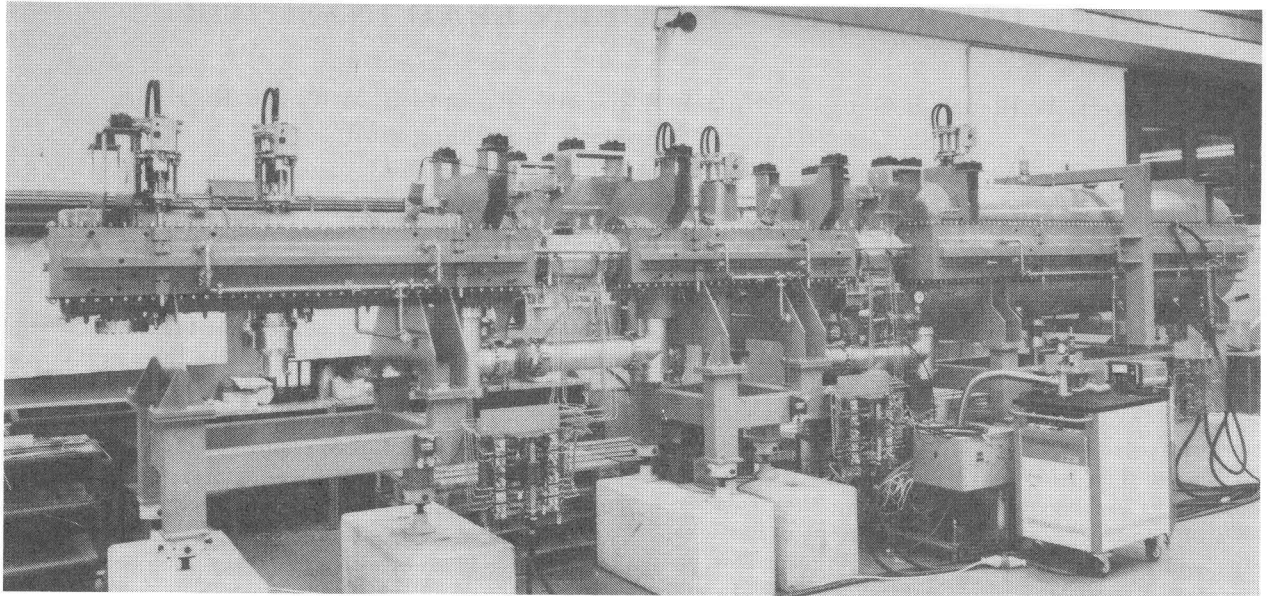


Figure 1: IH tank ensemble during tests and alignment at GSI

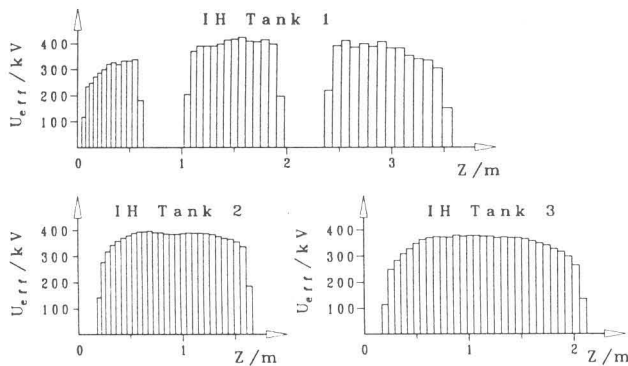


Figure 2: Distribution of the effective accelerating voltages in IH-tanks.

### Tank Parameters and Commissioning Experiences

The Q-values and the shunt-impedances of the tanks were evaluated by different means and for different cavity conditions. Some data still need confirmation. Table 1 shows the preliminary list of tank RF parameters.

RF conditioning of the three tanks could be achieved within a few days per tank, despite the low duty cycle of less than 1%. As it is preferred to have the linac area accessible for short interventions during operation, the tanks were covered by 5 mm lead shielding to reduce radiation by one order of magnitude. During RF-conditioning and during operation ( $\text{Pb}^{27+}$ , 0.06% duty factor), radiation profiles for the surface and at 1 m distance were established. These measurements agree well with the early estimates [5] scaled to the present mode of operation.

TABLE 1  
List of RF Parameters

Tank	1	2	3
Q-value	21200	12550	14370
$Z_{eff}^a / M \Omega / m$	244	165	152
$Z_{eff}^b / M \Omega / m$	216	153	141
$Z_{eff}^c / M \Omega / m$	212	153	125
$P_{RF} / kW$	220	370	345

<sup>1</sup>Q-value and  $Z_{eff}^a$  measured without incoupling loop.  
 $Z_{eff}^b$  measured with incoupling loop mounted (open).  
 $Z_{eff}^c$  corresponding to the forward RF power  $P_{RF}$  from the amplifiers, measured at the  $^{208}\text{Pb}^{27+}$  run.  
 The total effective voltage gain was 31 MV in this case.

### Results of Preliminary Test with Beam Instrumentation and Preparation of Beam Tests Medium Energy (250 keV/u) Transport

The beam from the RFQ is matched to the IH tank 1 by the Medium Energy Beam Transport (MEBT) [6]. In-situ diagnostics consists of a phase probe at the RFQ out-let, a Faraday cup and one profile detector per plane. In order to determine the beam characteristics of the RFQ and to optimize beam and buncher parameters for injection into the IH-structure a Temporary Measuring Line (TML) was installed in place of tank 1. It contained a bunch and velocity detector (BLVD) [7], which, along with the buncher allowed full measurement of the longitudinal phase plane using the technique described in [8] and measurement of the mean bunch energy. This greatly facilitated buncher tuning and provided excellent preparation of the IH-structure

beam tests. In addition a transverse emittance measuring device was installed in the TML.

### High Energy (1.8-4.2 MeV/u) Beam Transport

Two four-sector phase probes at the inputs of IH tank 2 and 3 respectively, allow measurements of bunch phase and position [9]. These however, suffer from 202 MHz noise which has yet to be suppressed. The transport and filtering region downstream of the three tanks contains the following diagnostic elements:

1. For the longitudinal phase space: Two phase probes, at 2 and 12 m downstream of tank 3, temporarily, at 1.1 m, the BLVD, as used earlier in the TML, at 5 m a magnetic spectrometer for both  $Pb^{27+}$  and  $Pb^{53+}$  (after stripping), and a second magnetic spectrometer for  $Pb^{53+}$  in front of the PS Booster.
2. For the transverse phase planes: Two sets of profile detectors for the horizontal and vertical plane, a complete emittance measurement device [10], and a second emittance detector in front of the PS Booster. Beam transmission was obtained from reading a current transformer, 3.5 m downstream of tank 3.

### First Results

After reinstallation of the tank 1 at the TML position the IH linac was brought into operation within 4 days. Acceptable performance (beam at sufficient current and quality for injection into the PS Booster) was reached by setting the IH linac parameters to values resulting from early simulations (LORASR, TRACE 3D), with some minor tunings according to first beam analyses. 60  $\mu A$   $Pb^{27+}$  were accelerated to 4.2 MeV/u from 70  $\mu A$  injected into tank 1 [11]. The BLVD measurements show only a minor longitudinal emittance growth, whereas the transverse emittance seems to grow considerably. Fig. 3 displays the longitudinal bunch shape of the 4.2 MeV/u beam. Table 2 gives some beam characteristics at the in and out-lets of the ensemble of IH tanks.

However, the parameter optimisation, the beam alignment and the tank fine tuning is yet to be done. It was postponed in favor of PS booster tests with beam, scheduled in June 1994.

TABLE 2  
Initial Beam Characteristics of the IH Tanks Ensemble

Parameter	input tank 1	output tank 3
Current ( $\mu A$ ) $Pb^{27+}$	70	60
W (keV/u)	250	4280
$E_{H,n}$ (mm mrad), 4 rms	0.32	1.2*
$E_{V,n}$ (mm mrad), 4 rms	0.38	1.1*
$E_{Long}$ (degr keV/u)	40	-
$\Delta\phi$ (deg) 2 rms/101 MHz	13-20	2.5 - 4
$\Delta W$ (keV/u) 2 rms	5 - 8	23 - 25

\*Preliminary data

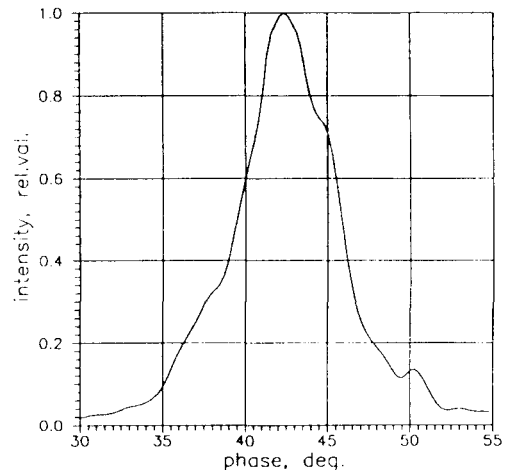


Figure 3: Longitudinal bunch shape in degree units (101 MHz), measured behind the 3 IH tanks with the BLVD ( $Pb^{27+}$ , 4.2 MeV/u).

### Acknowledgement

Much of our success we owe to our colleagues at CERN and GSI, responsible for alignment, mechanical support, vacuum, RF, who, in parallel to their other duties, achieved the installation and helped so much in the commissioning. The studies of the longitudinal phase space profitted to a great extend from A.V. Feschenko and P.O. Ostroumov's experience at INR Moscow, joining our team for several weeks.

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