The IH-Structure and its Capability to Accelerate High Current Beams

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Abstract

The interdigital drift tube structure is used successfully since about 15 years to postaccelerate heavy ion beams behind electrostatic tandem machines.

Recently the longitudinal and transversal acceptance of the original Munich cavity type was enlarged considerably and an improved type of IH cavity was developed and constructed at GSI, Darmstadt. It consists of subsequent structure sections for
- acceleration
- transversal focusing
- longitudinal focusing.

The 108 MHz GSI cavity contains three structure periods of that kind and accelerates the design ion 238U25+ from 300 keV to 1.4 MeV/u. The tank length is 3.5 m, the average inner diameter is about 0.63 m and the effective shuntimpedence is 320 MΩ /m.

Results from rf power tests and the status of the IH cavity for the new 1.4 MeV/u UNILAC injector are reported. Basic considerations and investigations about the designs for the acceleration of higher beam currents are described.

Introduction

Usually drift tube linacs are operated at negative synchronous rf phase, to provide longitudinal focusing. Quadrupole singlets are placed inside every n^{th} drift tube (usually n equals one or two) to form a quadrupole channel for transverse focusing.

Especially in the case of $\beta\lambda$ /2 - drift tube structures it is very economic to use a high resonance frequency and many gaps inside one cavity as well as to reduce the drift tube capacity by using small outer tube diameters. A big gain in this structure was achieved by introducing a modified beam dynamics :

An accelerating section consisting of typically 10 to 20 drift tubes without any transverse focusing elements is followed by a transversal focusing element and eventually by an extra rebunching element[1,2].

At GSI an IH cavity using that concept was constructed. RF power tests have started and beam tests will follow during 91. The required duty cycle is up to 50 %. In the early days of the IH structure it was a serious problem to get a flat gap voltage distribution along the tank axis, especially when the relative change of particle velocity was big. By combining the methods of g/L variation[3] and magnetic flux inducers[4] it is now possible to accelerate also protons efficiently even at 100 keV injection energy. Results from perturbation measurements and rf power tests at GSI are presented in ref. 5.

At present the beam currents out of sources for heavy ions are increased step by step. This gives the main motivation to develop an IH structure which can stand beam currents ranging from several emA up to about 100 emA. The computer code LORASR was developed and is optimized to

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investigate the ”Beam dynamics of combined 0° synchronous particle structures” including space charge.

A first idea of the high current capabilities of an IH structure was given at the Linac conference-88[2].

Basic concept

In contrast to the Alvarez linac structure the shunt impedence of the IH structure can be improved very much by reducing the drift tube capacity and rising the resonance frequency.

Slim drift tubes are used which contain no focusing elements. This allows at the same time to choose a high resonance frequency compared with other linac structures and to achieve a high acceleration field gradient (the ratio of gap length to period length is about 0.5). The transversal defocusing effect of the accelerating electric fields along each drift tube section is reduced by using a longitudinal beam dynamics as outlined in fig. 1 .

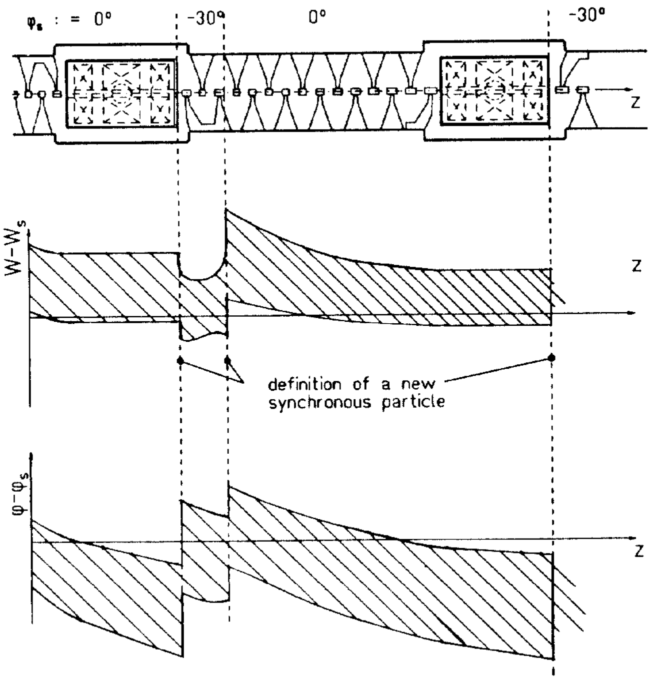

Fig 1 : Projections of the particle pulse to the W-z plane and ϕ-z plane along a typical IH-structure period.

- The drift tube table for each section corresponds to a 0° synchronous particle.
- The particle pulse is injected into each 0° - section with a surplus in energy and at rf phases around 0°.
- Towards the end of each accelerating section the particles are positioned at negative rf phases due to their high injection energy. The centre of the particle pulse makes less than a quarter oscillation around the 0° synchronous particle.(By making a section considerably longer the longitudinal beam transport becomes unstable).

Each accelerating section is followed by a transversal focusing element. This element should be as short as possible to keep the phase spread of the particle pulse low. The cross section of the beam behind the lense should be circular so that the aperture of the following drift tube section can be kept small.

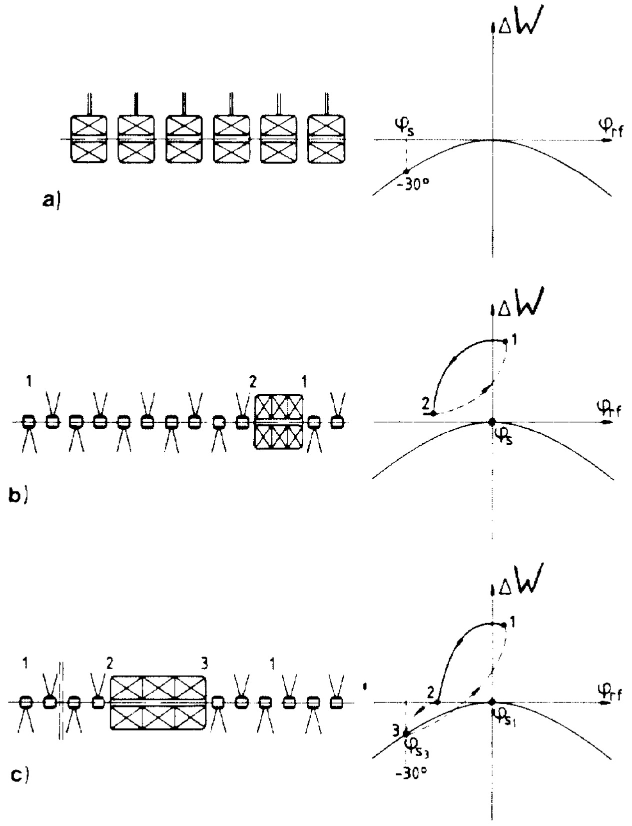

Fig. 2 : Scheme of drift tube structures and ’working cycles’ of the center position of the particle pulse relative to the synchronous particle.
a) Alvarez structure with ϕ_s= -30°.
b),c) IH-structures with combined 0° synchronous particle sections.

For the GSI cavity, quadrupole triplets with an optimized length ratio of the magnetic poles are used.

If the q/A value of the design particle is very low a few gaps with negative synchronous phase are needed behind a lense to rebunch the beam(fig. 1 and fig. 2c). The basic structure with ' short' lenses is shown in fig. 2b.

Actually the efficiency of this structure is limited by the present ' state of the art ' in magnetic lense construction.

As soon as higher magnetic fields can be achieved the efficiency of this structure will be improved a lot. An advantage of the IH structure is that the transversal dimensions of the internal lenses are not seriously limited.

Linac Construction

Each tank consists of three parts (as shown in fig. 3). The middle part must be fabricated with high precision as it carries the drift tube structure. The internal quadrupole triplets are contained in water cooled drift tubes, hold on ground potential and n$\beta\lambda$ in length. This lense position is attractive at low beam energy only, where the accelerating sections are short compared to the rf wavelength. The internal lense position was studied at the GSI IH - model first and tested recently with rf - power at the mounted cavity successfully. The ' thick ' drift tubes containing the quadrupole triplets are mechanically connected with the tank by bellows. They are adjusted precisely from outside the tank. At higher beam velocity it is sufficient to have lenses at the connections between neighboured tanks only. The IH - design study for the CERN lead linac [6] shows the concept of a long IH - structure (fig. 4) . The drift lengths around the magnetic lenses are minimized. The transverse phase advance σ_0 is about 120 degrees per triplet period. The efficiency of this structure is demonstrated in table 1. With a total no. of 106 gaps an effective voltage gain of 32.9 MV is provided.

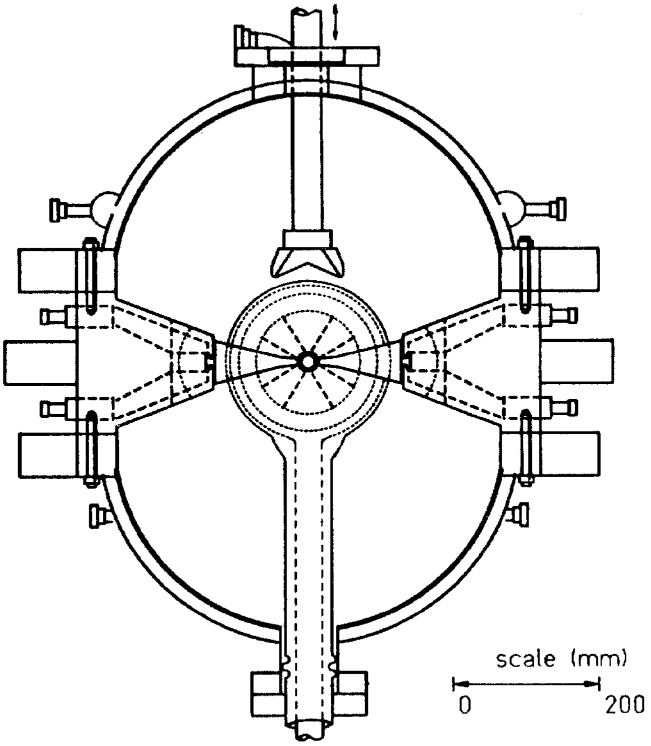

Fig. 3a) Cross sectional view of the GSI cavity.

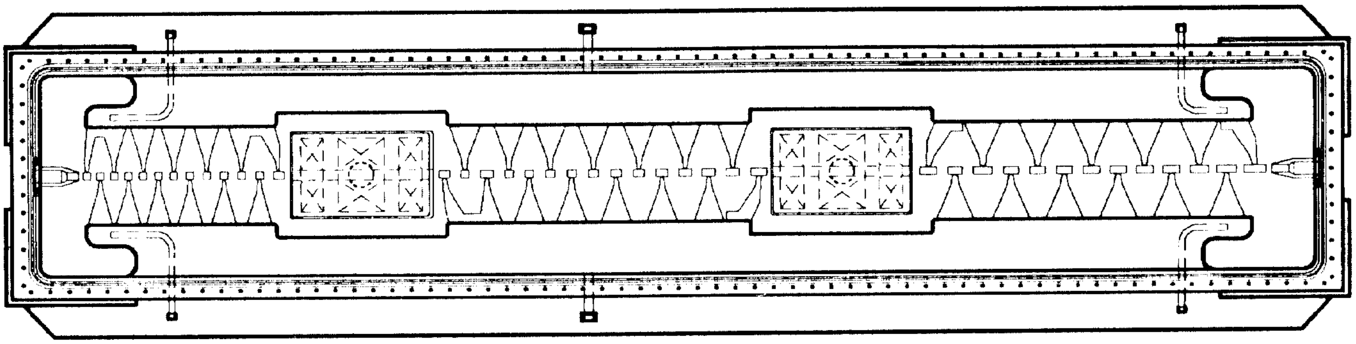

Fig. 3b) Top view on the middle part of the GSI-cavity.

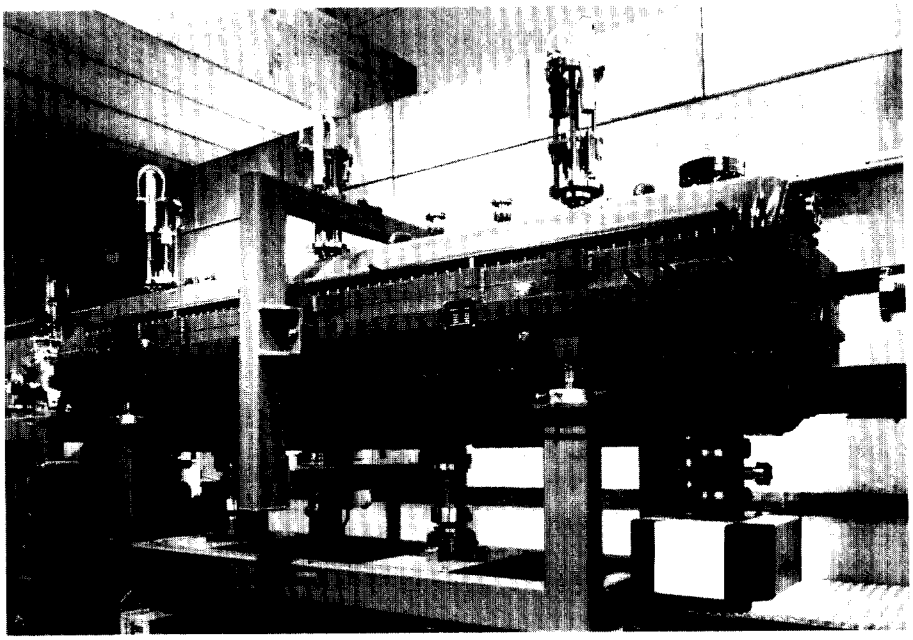

Fig.3c) View on the GSI cavity. Design particle $^{238}U^{25+}$, 0.3MeV/u-1.4 MeV/u, 50 % duty cycle.

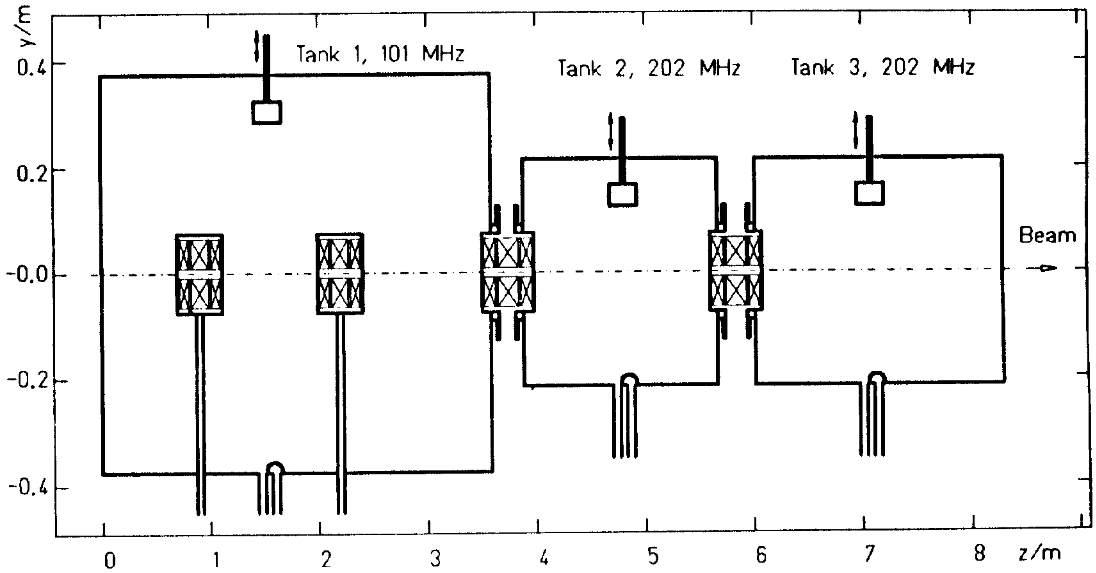

Fig. 4 : Scheme of the proposed CERN Lead IH-Linac.

CERN Pb-Linac ; Design particle $^{208}Pb^{25+}$, 0.25 MeV/u - 4.2MeV/u						
	length m	frequency MHz	eff.Volt. MV	shuntimp. MΩ/m	rf power kW	exit energy MeV/u
tank 1	3.60	101.28	12.045	285	142	1.7
tank 2	1.85	202.56	11.078	300	222	3.0
tank 3	2.30	202.56	11.389	209	270	4.2
Acceptance: $\alpha_{n,tr} \simeq 1.0$ π.mm.mmrad, $\alpha_l \simeq 0.6$ π.MeV.ns ; Duty cycle :<1 %						
No. of Quadrupole triplets : 4, No. of plungers : 3 ; Tuning range : ≃ 200 kHz.						

Table 1 : Characteristic parameters of the IH Linac proposal for CERN.

High Current Beams

In the previous sections a linac structure with a remarkable acceptance volume in the 6 dimensional phase space is described. The CERN Pb-Linac design shows that stable transport also in long IH structures is provided. Doubling of the resonance frequency at favourable positions along the linac causes no problems. These capabilities give the motivation to check the beam current limits of such a structure.

The calculations are done by the extended version of the LORAS - code. It includes the space charge action by a Particle In Cell (PIC) simulation method. Results from investigations done so far are promising.

Typical effects can be described as follows :
- By rising the beam current through a ' zero current-design structure ' particle losses occur in longitudinal direction towards positive rf phases first.
- The current limits can be increased considerably by rising the gap voltage in the percentage range. It is also helpful to readjust the rf phase relations between adjacent structure periods.
- The dependence of the current limits on beam energy, aperture and resonance frequency is like in negative synchronous particle structures.
-For the GSI 0.3 MeV - 1.4 MeV/u cavity an electrical current limit of about 10 emA is calculated for a $^{238}U^{25+}$ beam. In ref. 1 a two cavity design for $^{238}U^{20+}$ is described which can stand up to 70 emA and does accelerate the beam from 0.6 MeV/u upto 2.4 MeV/u.

For any application most care has to be taken in the design of the linac entrance part. For light heavy ions and moderate current intensities combinations of high voltage platforms ($V \sim 100$ kV - 200 kV) with IH structures are feasible. The main advatages of such a design are the economy in rf power as well as high acceleration gradients and the low fabrication costs.

At q/A values below 0.5 RFQ - IH combinations are much more powerful with respect to the current limits. The design beam current and the rf frequency mainly define the beam energy were the transition from the RFQ towards the IH structure is most efficient.

Acknowledgement

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