NOVEL DTL SECTION FOR ITEP-TWAC HEAVY ION INJECTOR

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Abstract

A novel 81.5 MHz H-type drift tube (DTL) accelerating structure with RF quadrupoles following RFQ in the new injector I-4 for acceleration ions up to energy about 5 MeV/u for ITEP TWAC facility has been proposed. It is based on a combination of a DTL structure and the resonator with magnetic coupling windows. Computer simulations show that it can provide some advantages in comparison with conventional IH-DTL structure. Results of both electrodynamics and beam dynamics computer simulations of the structure as well as a new approach for beam matching RFQ and the section are presented.

INTRODUCTION

The new high current ion injector I-4 for ITEP TWAC facility is under construction [1]. The facility consists of main synchrotron accumulator U-10 with 25 MeV proton injector I-2 and booster synchrotron UK with 4 MeV ion injector I-3. It runs presently in several operation modes accelerating protons in the energy range of 0.1-9.3 GeV, ions in the energy range of 0.1-4 GeV/u and accumulating nuclei up to Cu at the energy of 200-400 MeV/u [2].

The injector I-4 have to accelerate ions with charge-to-mass ratio Z/A = 1/3 up to the energy of W = 7 MeV/u with beam current up to I = 30 mA. These parameters are required to increase the intensity of the ion beam in UK ring to reach the terawatt level of stacked beam power in storage ring U-10.

The 81.5 MHz RFQ with output energy of 1.57 MeV/u as initial part of I-4 has been successfully commissioned in 2011 [3]. The initial design of the second section (IH-DTL) was completely revised and a new design of the section has been proposed. The main goal of the new design is to provide compact, efficient and relatively inexpensive part of the injector.

The design of the accelerating channel is based on a hybrid scheme [4, 5]. A new resonant structure based on four vanes with displaced magnetic coupling windows (MCW) [6] similar to existing RFQ was proposed for second section.

The paper presents results of both electrodynamics and beam dynamics computer simulations of the new structure.

HYBRID STRUCTURE

General Injector Layout

Hybrid structure combines accelerating gaps and RF quadrupole focusing. A simplified scheme of the structure and its placement with respect to the first RFQ section is shown in Figure 1. Focusing part is formed by vanes with quadrupole symmetry. Its length is $L_q = 3\beta\lambda/2$, so focusing gradient changes its sign three times while particle passes this length. It means that this part of the hybrid structure acts as a conventional triplet of quadrupole lenses. Required focusing strength of each cell is defined by distance from axis to vanes.

TWAC injector RFQ output beam parameters allow direct injection into DTL part of the hybrid structure without any additional focusing or RF elements for matching of transverse and longitudinal beam parameters. So the design doesn't assume use any MEBT between RFQ and second accelerating section.

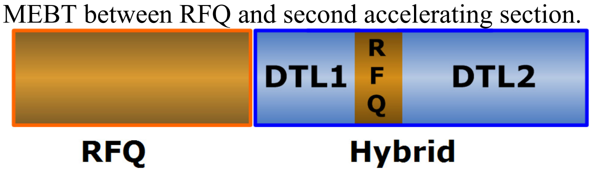

Figure 1: Simplified scheme of the hybrid structure.

Choice of the Resonator

Conventional IH and CH structures have twice lowered accelerating electric field in the space between the flanges and the tubes. In order to equalize the field distribution along the accelerating channel a new design of the resonator, using four-vane structure with displaced MCW like that was used for TWAC RFQ has been proposed. The displaced MCW structure has longitudinal electric field on the axis between the flanges and the vanes due to coaxial component of the operational mode. It allows equalizing electric field in end gaps of the CH and IH structures. Figure 2a and Figure 2b depict two 11- gap structures which have been simulated to evaluate RF parameters and choose most suitable design for second section. Varying the windows displacement and their dimensions allows very easy tuning both resonant frequency and field distribution along the structure. Normalized electric field distribution (E_{zn}) on the axis shown in Figure 3 is the same for IH and CH structures with displaced MCW.

Parameters of CH and IH structures with MCW simulated by OPERA-3d code are shown in Table 1.

Table 1: Structure parameters

Parameter	IH	CH
Inner diameter of the cavity, mm	760	880
Length of the resonator	1520	
Resonant frequency, MHz	81.5	
Frequency of nearest mode, MHz	105.1	106.2
Quality factor	17000	

ISBN 978-3-95450-125-0

Gap voltage, kV	600	
RF power losses, kW	180	320

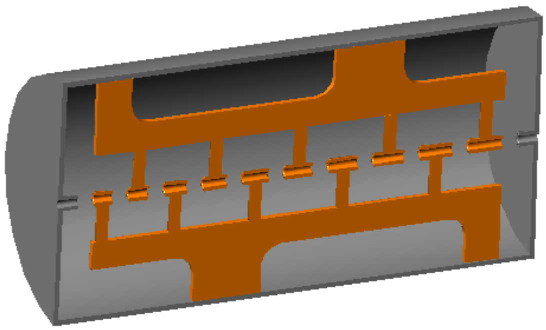

Figure 2a: IH structure with displaced MCW.

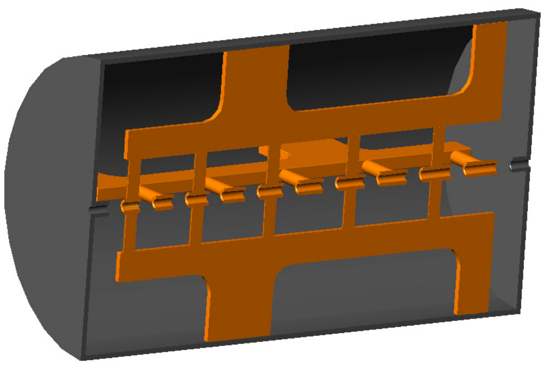

Figure 2b: CH structure with displaced MCW.

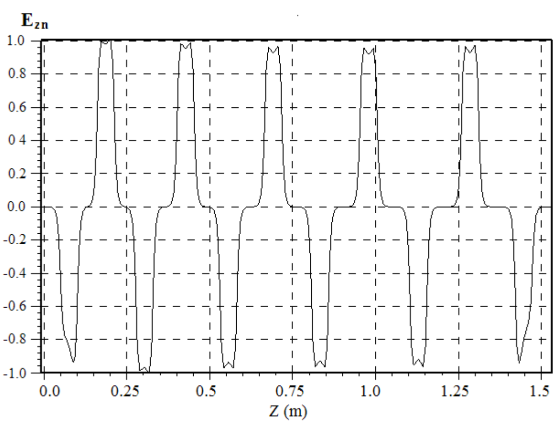

Figure 3: E_{zn} on the axis along the resonator.

IH structure has both smaller diameter and lower RF power losses in comparison with CH one. It is very important for CW operation. On other hand cross-bar structure has quadrupole symmetry that simplifies realization of the RF quadrupole focusing. Moreover, it excludes the necessity of compensation of dipole field component existing on the axis of conventional IH structure.

For low duty cycle operation (our case) excessive power losses are not very high price for listed above advantages of cross-bar cavity, taking also into account that this parameter can be improved by proper optimization of the resonator.

Second Section of the TWAC Injector

The MCW CH resonant structure with hybrid accelerating scheme was chosen for design of the TWAC second section. Its computer model is shown in Figure 4. Figure 5 shows simulated E_z field component on axis of the structure. It can be seen from Figure 5 that E_z amplitude is practically the same in all regular gaps except the gaps between drift tubes and RF quadrupole where it is two times lower owing to zero electric potential on quadrupole axis.

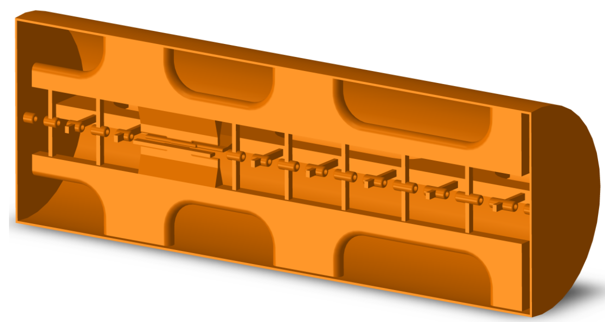

Figure 4: Computer model of hybrid accelerating structure based on four-vane cavity with MCW.

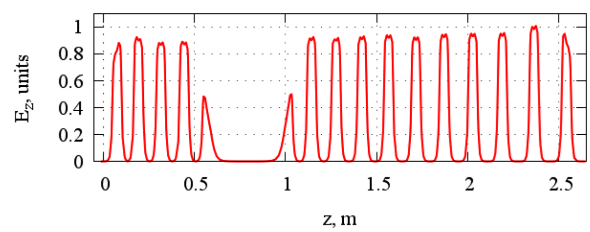

Figure 5: E_z component on axis of the structure.

Voltage V applied to RFQ vanes and drift tubes is the same in hybrid structure. It is limited only by acceptable surface field. Accelerating gap lengths are usually kept constant along the H-resonator.

Drift tube geometry is defined by several parameters. Aperture radius is determined by required transverse acceptance of the hybrid structure. Outer diameter of drift tube and rounding radius were chosen to minimize surface electric field. The gap length is optimized to achieve maximum transit time factor. Parameters of the accelerating channel are presented in Table 2.

Table 2: Parameters of the accelerating channel

Parameter	**Value**
Gap length, mm	50
Aperture radius, mm	12
Outer tube radius, mm	26
Inner curvature radius, mm	3
Outer curvature radius, mm	8
Maximum surface electric field MV/m	21
Gap voltage, kV	600

ISBN 978-3-95450-125-0

BEAM DYNAMICS SIMULATION

Simulation of beam dynamics in the hybrid accelerating structure was carried out by means of ITEP codes: PreRFQ, ALFIL and TRANSIT for 3D distribution of electromagnetic fields in accelerating channel. PIC solver was used for calculating particle interactions. Input energy of the second section is 1.57 MeV/u. Energy gain achieved in it is 3.33 MeV/u. Beam dynamics simulation was also carried out through the whole injector.

Simulated transverse envelopes at beam current I = 30 mA are shown in Figure 6. It confirms that RF quadrupoles provide beam focusing with the same efficiency as a triplet of conventional electromagnetic lenses.

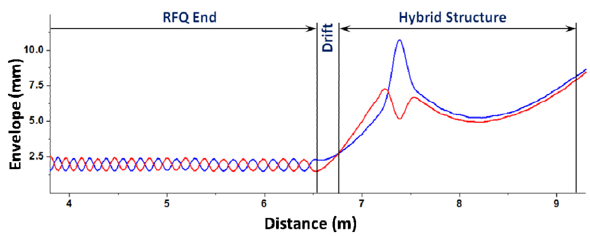

Figure 6: Simulated transverse beam envelopes. Blue line corresponds X plane, red – Y plane.

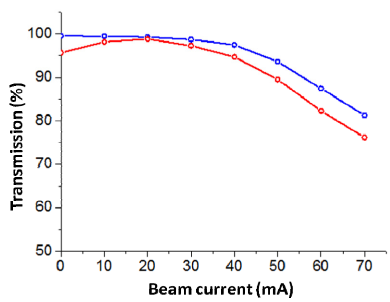

Figure 7: Calculated beam transmission in TWAC injector. Blue line represents transmission in RFQ, red line – for whole injector.

Figure 7 shows beam transmission calculated for TWAC injector linac. The transmission of the whole injector is very close to 100% for beam current of 10 – 30 mA and completely determined by RFQ section. There are only small additional particle losses in hybrid structure. Appearance some particle losses outside of the beam current range is owing to the fact that formation of longitudinal emittance in RFQ has been optimized for design beam current value I = 30 mA. Small increase of absolute value of synchronous phase in accelerating gaps can eliminate any additional particle losses in the hybrid structure.

Simulation showed negligible emittance growth in hybrid structure for both transverse and for longitudinal planes up to beam current I≅ 40 mA.

CONCLUSION

New CH-DTL section with hybrid accelerating channel following RFQ was designed for beam acceleration up to 4.9 MeV/u. Resonant structure with displaced MCW has some advantages in comparison with conventional IH and CH structures allowing very easy tuning both electric field distribution and resonant frequency.

The second section with hybrid accelerating structure allows direct beam injection from RFQ. So TWAC injector can be built without any additional MEBT.

Beam simulation carried out for whole injector shows that the new section provides acceleration up to energy required for injection into TWAC ring with transmission close to 100% for design beam current.

ACKNOWLEDGMENT

Authors thank Tatyana Tretiakova for adjustment of code TRANSIT for beam simulation of the section.

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ISBN 978-3-95450-125-0