COMPENSATION OF TRANSVERSE FIELD ASYMMETRY IN THE HIGH-BETA QUARTER-WAVE RESONATOR OF THE HIE-ISOLDE LINAC AT CERN

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AN INTRODUCTION TO THE HIE-ISOLDE PROJECT

High Intensity and Energy (HIE) ISOLDE is an ambitious project that aims to improve the intensity, energy and quality of post-accelerated Radioactive Ion Beams (RIBs) produced by the current RIB EXperiment (REX) at the ISOLDE nuclear facility at CERN. The design proposal includes an intensity upgrade of the proton driver beam, courtesy of LINAC4 at CERN, improvements in the target and ion source, and the HIE-LINAC: a superconducting (SC) upgrade of the normal conducting (NC) linac. The HIE-LINAC will employ independently phased SC cavities and solenoids to accelerate and focus the beam. Research and development has focused on the high energy section of the linac housing the high-β quarter-wave resonators, β= 11.3%, as shown in Figure 1. Ions with a mass-to-charge state in the range 2.5 < A/q < 4.5 will be accelerated.

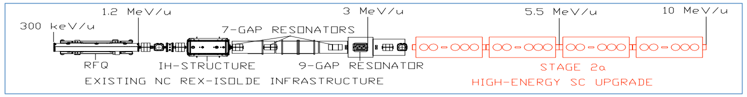

Figure 1 – The layout of the HIE-LINAC, showing the existing NC and the proposed SC infrastructure, along with beam energy.

TRANSVERSE FIELD ASYMMETRY

The cylindrical geometry of the quarter-wave resonator, as shown in Figure 2, introduces asymmetric (de)focusing forces around the beam axis, which can cause an effective emittance growth when the beam is rotated in the solenoid focusing channel. We consider two variants of the nominal cavity in order to improve the field asymmetry and to study the effect of cavity field asymmetry on the beam quality: a racetrack shaped beam port (RT) and a modification to the internal conductor (MOD DT).

NOMINAL CAVITY

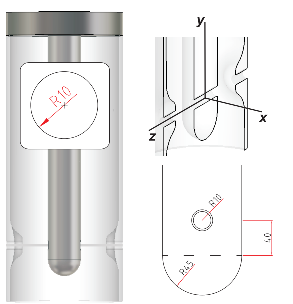

Figure 2 – The high-β (β= 11.3%) quarter-wave resonator, drawn in Microwave Studio.

CAVITY VARIANTS

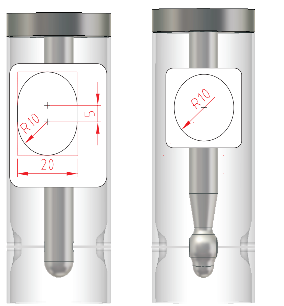

Figure 3 – The variants of the high-β cavity: with a racetrack shaped beam port (left) and with a modified internal conductor.

MOD DT GEOMETRY

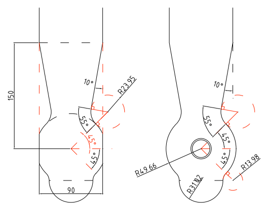

Figure 4 – The geometry of the modification made to the internal conductor. Dimensions are in mm.

THE DRIFT TUBE MODIFICATION

The conventional method for reducing the asymmetry of the electromagnetic fields on the beam axis is to use a donut shaped drift tube. The high-β cavity will be sputtered with a thin film of niobium and for this reason we designed a modification with a geometry that is symmetric about the resonator's axis, as shown in Figure 4, in order to facilitate the surface coating process. The modification effectively reduces the asymmetric rf defocusing forces, as presented in Figures 5 and 6. The cavity parameters are compared in Table 1.

Design Parameter	Nominal/RT	MOD DT
f (MHz)	101.28	
β_0 (%)	11.3	
Nominal Sync. Phase (deg.)	-20	
Design Voltage (MV)	1.8	
Design Gradient (MV/m)	6	
Active Length (m)	0.3	
Gap Length (mm)	70	
Cavity Diameter (m)	0.32	
Cavity Height (m)	0.785	0.807
U/E_{acc}^2 (mJ/(MV/m)²)	207	196
E_{pk}/E_{acc}	5.4	6.6
H_{pk}/E_{acc} (Oe/MV/m)	96	93
R_{sh}/Q_0 (Ω)	548	585
$\Gamma = R_{surface}.Q_0$	30.6	31.3
Cavity Offset (Steering Comp.) (mm)	2.2/2.8	2.2

Table 1 – A comparison of the cavity variants' parameters.

SINGLE PARTICLE BEAM DYNAMICS STUDIES

The asymmetry of the fields about the beam axis was analysed by tracking a single particle in the electromagnetic fields simulated for each variant in Microwave Studio. The dynamics of an ion with the lightest mass-to-charge state, A/q = 2.5, was studied at a synchronous phase of -20 degrees, as shown below, in Figure 5. The asymmetry intrinsic to each variant is compared in Figure 6.

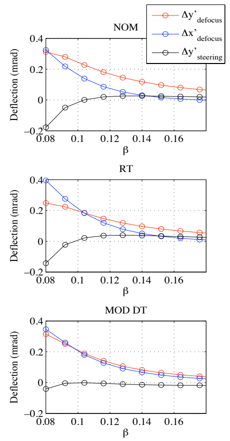

Figure 5 – The rf defocusing force and beam steering force experienced by an ion (A/q = 2.5, synchronous phase =-20°) at 1 mm from the beam axis in the high-β cavity. (Horizontal = x, Vertical = y).

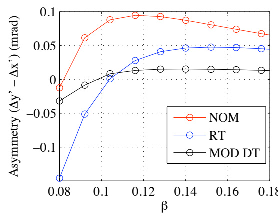

Figure 6 – A summary of the asymmetry intrinsic to each cavity variant. (A/q = 2.5, synchronous phase =-20°).

BEAM STEERING AND COMPENSATION

The presence of a transverse component of magnetic field on axis in the QWR results in a steering force exerted on the beam. To compensate this we offset the cavity from the beam axis, see [1], as shown by the black curves in Figure 5.

MULTI-PARTICLE BEAM DYNAMICS STUDIES

The beam dynamics in the high energy section of the HIE-LINAC was studied using the multi-particle tracking code TRACK [2]. The realistic field simulations from all three cavity geometries studied are shown below in Figure 7. We simulate beams with A/ q = 2.5 in a focusing channel with 90° transverse phase advance between solenoids, injected at an energy of 3.0 MeV/u, i.e. the intermediate stage. The splitting of the horizontal, x, and vertical, y, envelopes is apparent in the NOM and RT simulations where the phase advance in each transverse plane is different because of the asymmetry of the cavity fields. The MOD DT variant keeps the beam symmetric, making the linac more tolerant to mismatch from errors in the solenoid field and injection parameters. The emittance growth arising from rotation of an asymmetric beam in the solenoid channel can be observed in the structure of the emittance evolution for the NOM and RT simulations. However, this effect is only at the level of a few percent. The beam steering compensation is effective in all geometries.

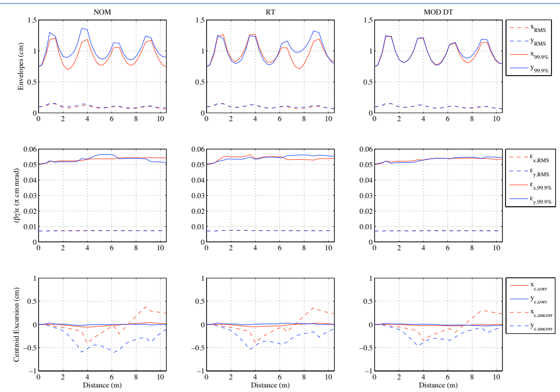

Figure 7 – The beam dynamics of the three cavity variants in the high energy section of the HIE-LINAC: nominal design (left series), racetrack design (centre series) and modified internal conductor design (right series).

CONCLUSIONS AND REMARKS

The racetrack shaped beam port reduces the beam asymmetry above an energy of 3.7 MeV/u (β = 0.09), with respect to the circular beam port. This coincides closely with the injection energy at the high energy section in the complete upgrade, which possesses the low energy superconducting section. The modification to the internal conductor keeps the cavity defocusing fields highly symmetric (less than 0.03 mrad difference), however, as a result of the modification, the peak electric field rises by over 20 %. It is clear that the MOD DT design will be less sensitive to mismatch because of the symmetric beam envelopes.

WITH SPECIAL THANKS TO... ISOLDE Collaboration Committee (ISCC)

The author would also like to thank Brahim Mustapha of ANL for making possible the realistic field simulations in the TRACK code.

More information can be found at: http://hie-isolde.web.cern.ch.

References:
[1] P. Ostroumov, K. Shepard, Phys. Rev. ST. Accel. Beams 11, 030101 (2001).
[2] P. Ostroumov, V. Aseev, B. Mustapha, http://www.phy.anl.gov/atlas/TRACK/