

STATUS OF THE IH-DTL CAVITIES DESIGN AND PROTOTYPING FOR THE ICONÉ PROJECT

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Abstract

CEA is committed to delivering a LINAC in the frame of the ICONÉ project, in order to accelerate an 80-mA beam of protons up to 25 MeV, with a duty cycle of 6%. The LINAC project is divided into five workpackages: Source and LEBT, RFQ, MEBT, DTL and HEBT. The initial acceleration and bunching will be provided by a 4-vane RFQ cavity. For the DTL part, two solutions with copper cavities were studied from 3.7 MeV to the final energy: an IH-DTL and an Alvarez DTL LINAC. This talk will present the design of the IH-DTL solution at 352 MHz. Prototypes of certain parts, including a small cavity, and a permanent magnet, are tested in 2025/2026. Results of these tests will be presented.

INTRODUCTION

The ICONÉ project [1] aims to develop a compact high-current proton linac for accelerator-driven neutron source applications within the HICANS framework [2-3]. The accelerator will deliver an 80 mA proton beam accelerated up to 25 MeV with a duty cycle of 6%.

A first global study of the RF components was presented in [4], including the main accelerating structures and the two DTL solutions investigated for the project. The present work focuses on the optimization of the IH-DTL cavities to improve the RF efficiency and reduce power consumption while preserving the required accelerating performance.

An IH-DTL prototype was manufactured and experimentally characterized through low-power RF measurements and Bead-Pull tests. Resonance frequency, quality factors, tuner sensitivity and EM field distribution were measured and compared with simulations, showing good agreement. The prototype is now awaiting authorization for high-power RF tests.

IH-DTL CAVITIES OPTIMIZATION

The IH-DTL cavities geometry definition was updated to improve flexibility and prevent imperfections in the geometry during the design and optimization process, enabling better control of the capacitive loading at the cavity ends and improving the accelerating field distribution. This updated parametrization, that affects more the tilt angle of the end stems, provides an efficient way to adjust the field profile without introducing additional structures such as girders [5], and was applied to the full set of cavities, whose results are presented in Table 1.

Table 1: Results of RF Simulations of the IH-DTL Cavities

Cavity	β	Acc.	RF losses	Peak E-	RF
		Gradient	[kW]	field	acceleration
		[MV/m]	[kW]	[MV/m]	consumption
					[kW]
1	0.09	1.40	11.6	10.9	28.1
2	0.0963	2.95	52.1	21.0	63.5
3	0.1058	3.50	76.0	24.1	82.7
4	0.1167	3.12	78.2	22.7	104.1
5	0.1289	3.40	100.1	25.0	128.1
6	0.1418	3.40	109.4	24.6	142.3
7	0.1548	3.40	120.2	24.0	156.9
8	0.1679	3.40	132.6	24.4	170.2
9	0.1810	3.40	146.2	23.8	185.2
10	0.1941	3.40	161.3	23.2	202.2
11	0.2073	3.40	178.6	23.4	219.5
12	0.2204	3.40	198.4	24.4	233.4
		Total	1364.7		1716.3

To further reduce RF consumption, a dedicated optimization was performed on representative cavities of the Linac, namely a middle energy cavity and the last cavity. The optimization focused on two main geometrical parameters: the tilt angle of the end stems and the outer radii of the drift tubes. The tilt angle was first adjusted to improve the field distribution along the cavity axis, followed by a refinement of the drift tube radii to reduce RF losses while maintaining acceptable peak electric field levels.

The optimized configurations show a consistent improvement in RF performance as shown in Table 2. For both cavities, the RF power consumption is reduced by 10%, while maintaining the required accelerating conditions. This improvement is accompanied by a moderate increase in peak electric field, which remains within acceptable operational limits. In addition, the optimization leads to a better control of the field distribution along the beam axis as illustrated in Figure 1. This approach can be extended to the remaining cavities if the IH-DTL solution is selected for the project.

Table 2: Results of RF Simulations Before and After Optimization

Cavity	Model	Q_0	V_{acc} @1J	RF losses	Peak E- Field	Kilp
			[MeV]	[kW]	[MV/m]	
6	Initial	11226	2.75	109.4	24.6	1.35
	Optimal	11407	2.89	97.6	26.0	1.43
12	Initial	12724	2.98	198.4	24.4	1.34
	Optimal	13453	3.07	178.1	24.8	1.36

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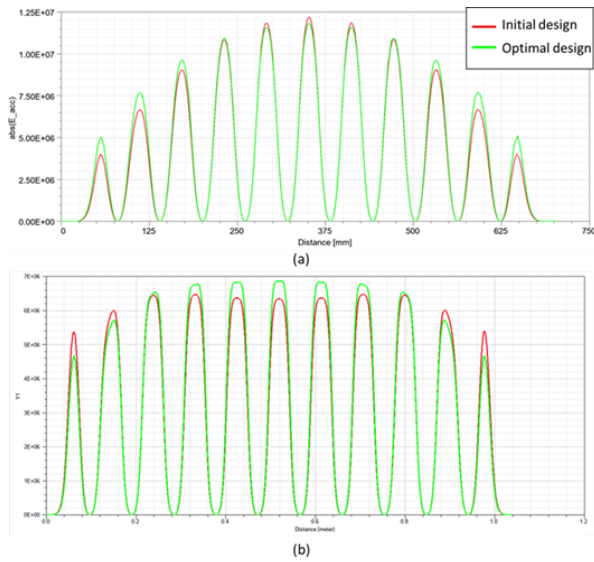


Figure 1: Accelerating field variation along (a) cavity 6 and (b) cavity 12.

IH-DTL PROTOTYPE

An IH-DTL prototype cavity was manufactured by Cinel (Italy), as shown in Figure 2, in order to experimentally validate the RF design. The prototype consists of a 10-drift tube cavity designed for an optimal velocity $\beta=0.09$, representative of the low-energy section of the Linac.

The experimental validation is planned in two stages, low-power RF measurements followed by a high-power RF test. At the present stage, only low-power measurements have been carried out. The following section presents the results of the low-power RF characterization of the prototype.

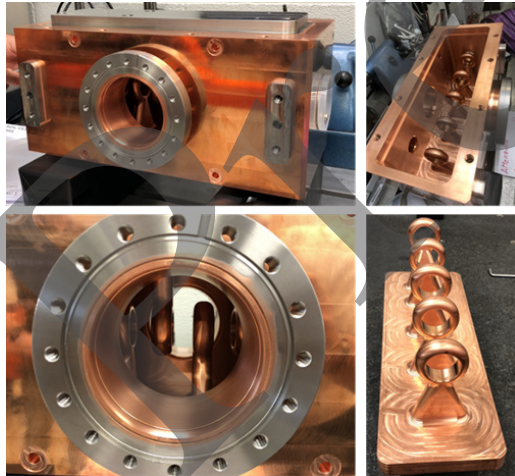


Figure 2: Design of the manufactured prototype.

IH-DTL Low Power Measurements

Low-power RF measurements were performed on the prototype cavity using a small input coupler and a tuner. After tuning, the nominal frequency of 352.2 MHz was successfully achieved. The extracted quality factors from measurements were $Q_0 = 6923$ and $Q_{ext} = 6878$, with deviations of about 7% compared with simulations, mainly

attributed to machining tolerances and the strong sensitivity of the RF fields in the tuner region. Figure 3 illustrates the variation of the distribution of the H-Field in the coupler – tuner plane considering the variation of the depth of the tuner inside the cavity.

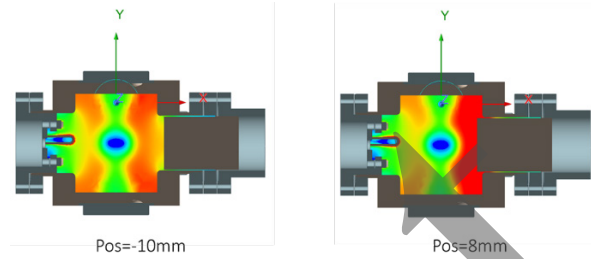


Figure 3: Distribution of the H-Field in the coupler-tuner plane in function of the depth of the tuner in the cavity.

A parametric study was then conducted by varying the tuner depth inside the cavity and comparing the measured resonance frequency and quality factors with simulation results. Increasing the tuner penetration leads to an increase in the resonance frequency while reducing the intrinsic quality factor, due to stronger field perturbations and the increase in surface losses induced by the tuner inside the cavity. For configurations adjusted to the same resonance frequency, the difference between measured and simulated Q_0 values remain within 5% to 9%, confirming the robustness of the electromagnetic model.

To maintain high measurement accuracy despite the cavity narrow bandwidth (~ 100 kHz), the data were acquired over two partially overlapping frequency ranges with recalibration after each shift in frequency span. This strategy provided high resolution, while also allowing consistency checks in the overlap region, with only a 1% difference observed between the two sweeps, thereby confirming the robustness of the measurement procedure. A comparison between simulated and measured Q_0 for a range of tuner positions at an equal resonance frequency is presented in Figure 4.

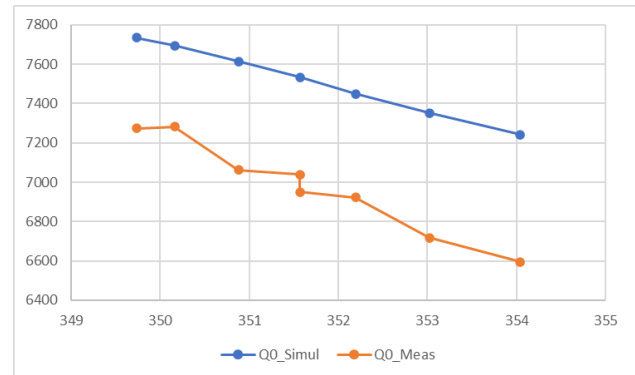


Figure 4: Comparison between simulated and measured Q_0 .

IH-DTL Bead-Pull test

The longitudinal field distribution inside the IH-DTL prototype was characterized using the bead-pull perturbation method based on the Slater perturbation theorem, which relates the variation of the cavity resonance

frequency to the local electromagnetic energy. The measurement relies on the phase variation of the transmission coefficient S_{21} , allowing the reconstruction of the field profile along the beam axis. A spherical lead bead was used as a perturbing element for the Bead-Pull test. Figure 5 shows the Bead-Pull mechanical measurement system mounted on the IH-DTL prototype cavity.

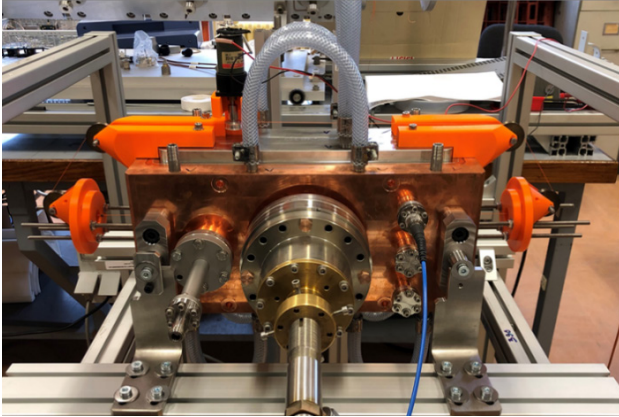


Figure 5: Bead-Pull mechanical measurement system mounted on the IH-DTL prototype cavity.

Measurements were first performed with the cavity tuned at its nominal frequency of 352.2 MHz. The field profile reconstructed exhibits a very good agreement with simulations. The positions of the maxima and minima are accurately reproduced, and the discrepancy on the peak values remains below approximately 1.5%. This confirms both the validity of the measurement method and the accuracy of the RF design.

A second measurement with the cavity intentionally detuned by fully retracting the tuner, resulting in a resonance frequency of 349.3 MHz. Despite this significant frequency shift, much larger than the cavity bandwidth, the overall shape of the field distribution remains consistent with the tuned configuration, though less uniform with reduced peak amplitudes. The maximum deviation reaches approximately 5%, highlighting the impact of detuning on field flatness and energy distribution along the cavity. Figure 6 illustrates the comparison between measured and simulated field distribution of both tests.

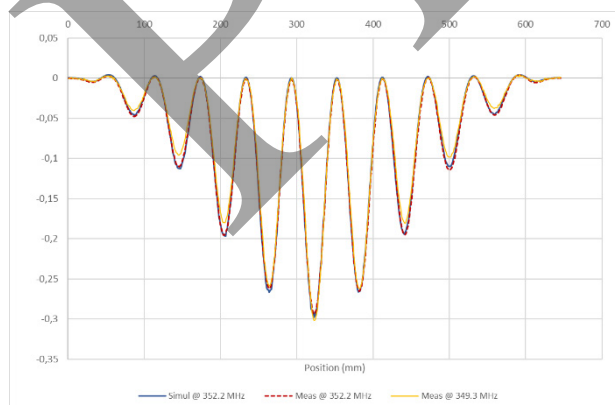


Figure 6: Comparison of measured and simulated EM Field distributions along the cavity beam axis.

PERMANENT MAGNET PROTOTYPE

In parallel to the RF tests of the IH-DTL prototype, a prototype of permanent magnet Halbach configuration was done. The magnet was built by YX Magnetics (Switzerland). It was made from NdFeB material. The permanent Halbach magnets will focus the beam along the IH-DTL line.

Tests were performed with the quadrupolar test bench of the Soleil Synchrotron. More information about the magnetic test bench can be found in [6].

The result is a deviation of the gradient lower than 0.1% on the beam axis. The requirement was 0.5% on the integrated magnetic field. This test qualifies the prototype.

Figure 7 compares the expected gradient at different position, integrated along the beam axis, and the measured integrated gradient. The 0 position corresponds to the beam axis at the geometric center of the Halbach magnet. The negative and positive positions correspond to a bottom-to-top sweep with the magnetic measuring device, and the same integration in the beam axis direction.

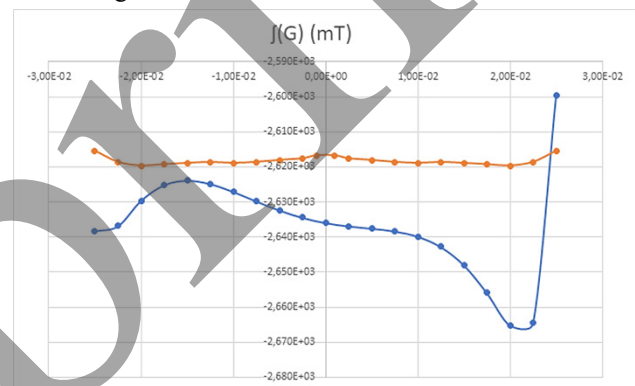


Figure 7: Integral of the magnetic field gradient on different positions. Orange: Expected gradient. Blue: Measurement on the Halbach prototype.

For further investigation, a second prototype will be made with SmCo material, in order to compare performances.

CONCLUSION

In conclusion, the optimization of the IH-DTL cavities has led to a noticeable improvement in RF efficiency, with reduced power consumption while maintaining the required accelerating performance. The experimental validation performed on the prototype through low-power RF measurements and bead-pull tests shows a good agreement with simulations, confirming the reliability of the design and the field distribution along the beam axis. The upcoming high-power tests will represent the next key step to fully validate the cavity behavior under operational conditions.

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