DESIGN AND IMPEDANCE OPTIMIZATION OF THE LNLS-UVX LONGITUDINAL KICKER CAVITY

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Abstract / Introduction

Performance evolution of parameters achieved during the electromagnetic design of the longitudinal kicker cavity for the LNLS UVX storage ring is presented. The effort on the electromagnetic optimization process of the heavily loaded cavity has been made to reach the required electrodynamic parameters of the kicker. The results for three different geometries are compared and a good compromise between the longitudinal shunt impedance and the effect of the longitudinal Higher Order Modes (HOM's) on beam stability has been found.

INTRODUCTION

The initial intention of implementing a longitudinal feedback system was using the present light source as a bench test for SIRIUS, the next Brazilian 3rd generation synchrotron light source. More recently some drawbacks of the RF phase modulation appeared:

•During the commissioning of the fast orbit feedback (FOFB) [2] the negative effect of the huge synchrotron oscillations was clearly observed; aliasing of the synchrotron sidebands produced low frequency noise in the BPM readings. A fine tuning of the FOFB clock signals had to be done in order to reduce the noise produced by the aliasing. The system tuning needs to be done in every event that provokes a change in the amplitude or frequency of the synchrotron oscillations;

•The studies to implement a low-emittance optics for the LNLS UVX storage ring also highlighted the need of bunch-by-bunch feedback systems. Large vertical instabilities showed up during the tests limiting the beam size reduction. The tests with beam indicated that huge longitudinal instabilities can prevent the transverse feedback systems of working properly. This may be the main reason for implementing a longitudinal bunch-by-bunch feedback system.

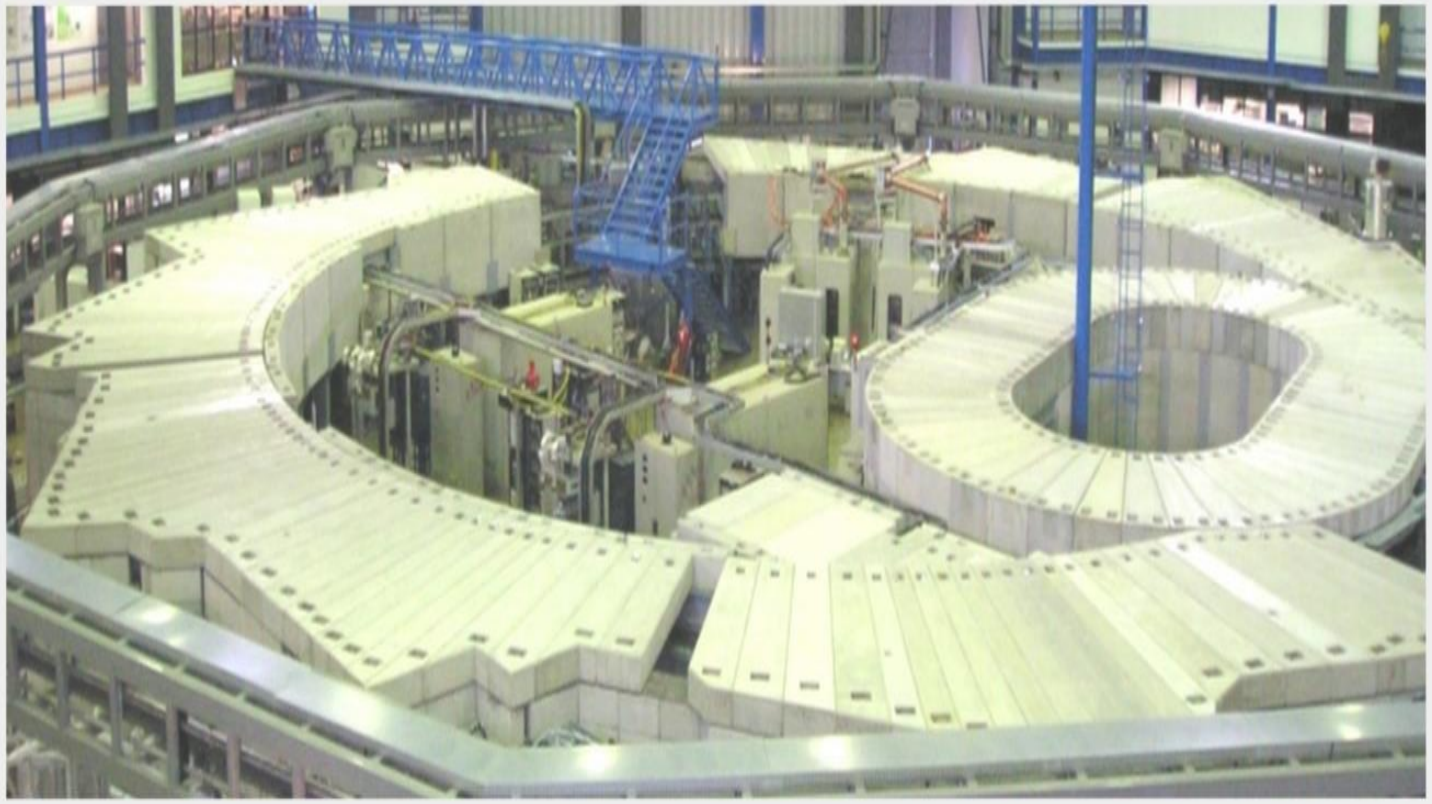
This paper presents the evolution of the performance parameters achieved during the electromagnetic design of a longitudinal kicker for the UVX storage ring. The presented design is based on the worldwide reproduced waveguide overloaded cavity kicker developed originally at DAΦNE in 1995 [3] and improved at Pohang Light source (PLS) [4]. Three different geometries are compared along this document aiming to propose a good compromise between the longitudinal shunt impedance and Higher Order Modes (HOM's) content.

Basic LNLS UVX Ring Parameters

The UVX ring is not equipped with a full-energy booster. Every 12 hours the ring is ramped down, refilled to 250 mA, and ramped back up. The energy ramp goes from 490 to 1370 MeV in about 40 s. The main LNLS storage ring parameters are presented in the Table below

Main storage ring parameters for UVX at High Energy (1.37 GeV)

Parameter	Value	Unit
Nominal Energy, E_0	1.37	GeV
Circulating current, I_{av}	250	mA
Circumference, C	93.2	m
RF frequency, F_{RF}	476.066	MHz
Harmonic number, M	148	--
Bunch length (sigma), σ_S	11	Mm
Horizontal tune, ν_x	5.27	--
Vertical tune, ν_s	4.17	--
Synchrotron frequency, ω_s	25*2π	Krad/s
Momentum compaction factor, α	0.0083	--
Energy spread, $\Delta E/E$	0.281	%
Horizontal damping time	7.8	ms
Vertical damping time	7.5	ms
Synchrotron damping time	3.7	ms

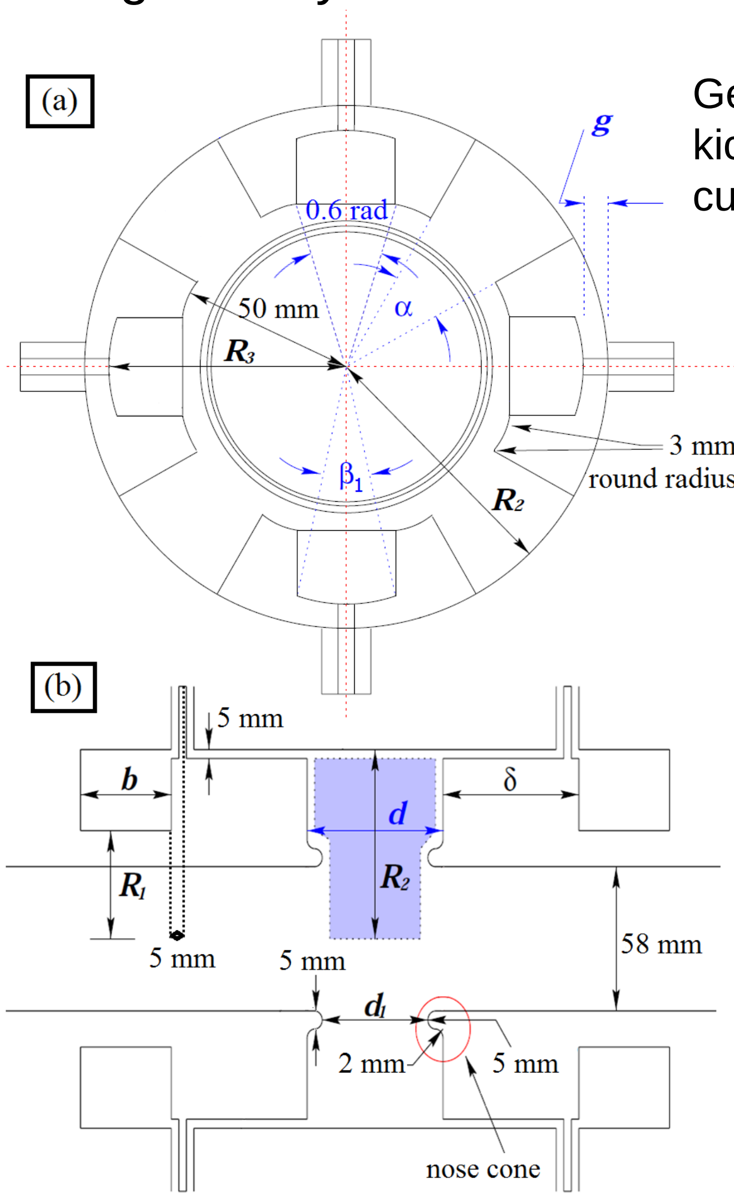


Electromagnetic Project

The LNLS longitudinal bunch-by-bunch feedback system is equipped to modulate the correction signal at 2.5*F_{RF}. Based on this, as well as on Coupled Bunch Mode Instabilities (CBMI's) theory, the chosen center frequency for the longitudinal kicker was the 2.75 multiple of RF frequency, i.e., with the fundamental mode centered at this frequency, all possible CBMI's can be covered within a ½ F_{RF} (238 MHz) bandwidth (BW). Attending the center frequency and BW requirements, the initial goal was to achieve the higher shunt impedance as possible with several geometry parameter sweeps. HOM's analysis, together with CBMI's growth rate (GR) calculations were also considered in the study, where our goal was to achieve a conservative GR, under 10% of UVX storage ring damping rate (DR). The table below summarizes the main design goals of the electromagnetic project:

Parameter	Value
Center Frequency (11/4 F_{RF})	1.31GHz
Bandwidth (1/2 F_{RF})	238MHz
Max. desired CBMI GR	10% of DR

The kicker parameterization pattern presented in the Figure below follows the same one employed by PLS for electromagnetic modeling [4]. The entire design process can be divided into stages that can be represented by three different geometries, whose parameters are shown in Table 3. Geometry 3, depicted in Figure below, was chosen as the final geometry since it attends the presented requirements.



Geometry sketch of the longitudinal kicker [4]. a) Axial-cut view. b) Side-cut view

Geometric parameters for the three kicker models considered for UVX

	Parameter value (mm or rad)		
	G. 1	G. 2	G. 3
R2	84	82	84.7
R3	79	77	79.7
α	0.42	0.42	0.2
β	0.25	0.25	0.39
d	74	67	52.8
δ	50.2	55	42
b	52.3	52.3	25

EM Project – Design Process

CST Microwave and Particle Studio [5] were used for the electromagnetic simulations. Geometry 1 was a re-scaled PLS design. The design procedure has followed the sequence:

1. Several parameter sweeps were performed after in order to set the shunt impedance curve, with maximum amplitude and with minimum required BW. The shunt impedance is defined by

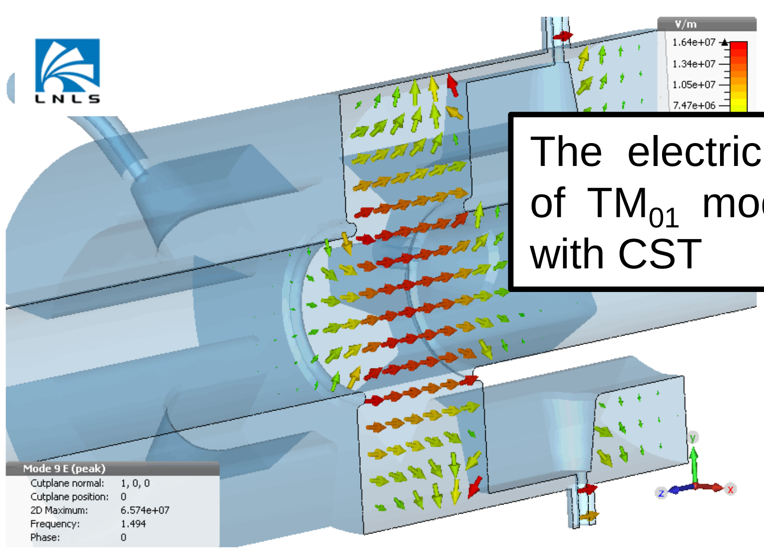
$$R_{shunt} = \frac{|V_{gap}|^2}{2P}$$

where P is the kicker total input RMS power

and V_{gap} is the gap voltage defined by

$$V_{gap} = \int_{-L/2}^{L/2} E_z e^{j\left[\omega \frac{z}{c} - \phi_E(z)\right]} dz$$

where L is the kicker length and $E_z(z)$ and $\phi_E(z)$ are the longitudinal E-field magnitude and phase, respectively, along beam axis.



The electric field pattern of TM_{01} mode calculated with CST

2. After dimensioning the geometric parameters to obtain a satisfactory R_{shunt} curve, the HOM's content of the cavity must be carefully analyzed. With the obtained coupling impedance spectrum, the CBMI's GR can be calculated in order to check if it is below the desired 10% DR factor. This work will show results only for the longitudinal analysis, once that for the also simulated transverse case, no concerns have appeared for any of the 3 geometries described. The CBMI's GR were calculated according to the Wang formalism [6], resulting in the Eq. 3 below for the longitudinal case, at zero chromaticity:

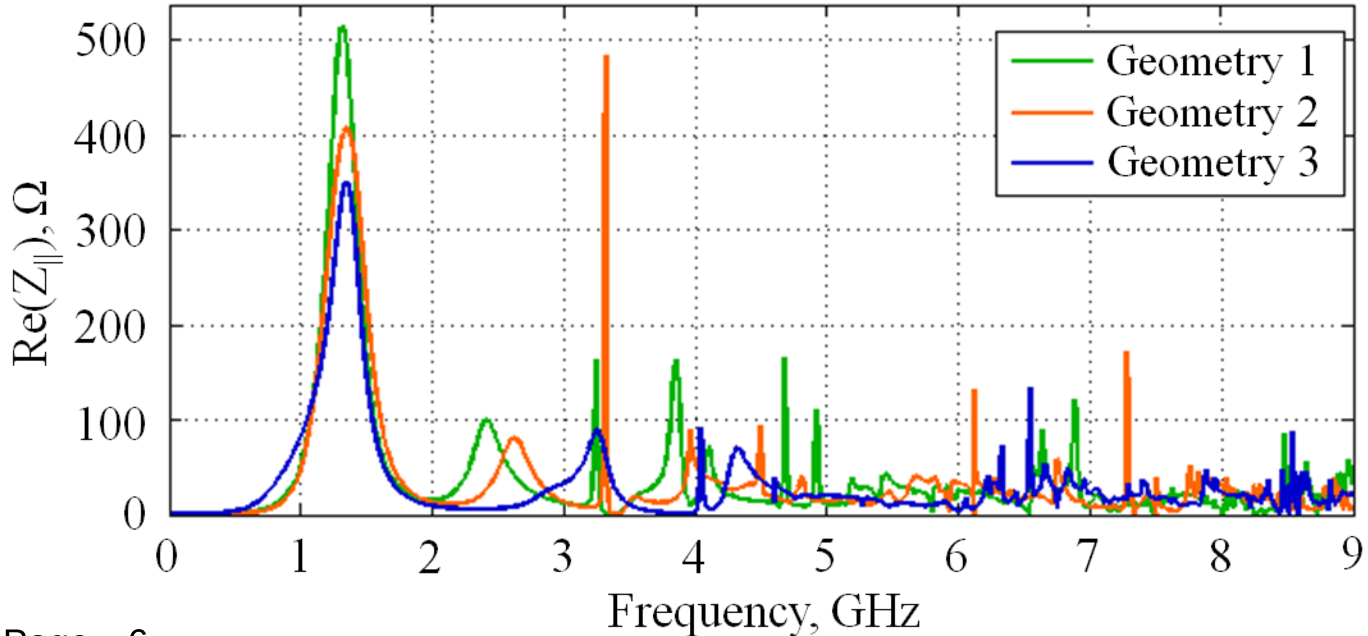
$$\mathrm{Im}(\Delta\omega) = \frac{1}{\tau_\mu} = \frac{I_B M \omega_0^2 \alpha}{4\pi (E_0/e)\omega_s} \sum_{p=-\infty}^{p=+\infty} (pM+\mu)^2 e^{-(pM+\mu_s)^2 \left(\sigma_s/R\right)^2} \frac{\mathrm{Re}\, Z_\parallel (pM\omega_0 + \mu\omega_0 + \omega_s)}{(pM + \mu + \upsilon_s)}$$

for the dipole mode a=1 and for Gaussian bunches with uniform filling. The related parameters follow the notation of UVX parameters Table. Additionally, $I_B = I_{av}/M$ is the average bunch current, $\omega_0 = 2\pi F_{RF}/M$ is the revolution frequency and $R = C/2\pi$ is the average ring radius.

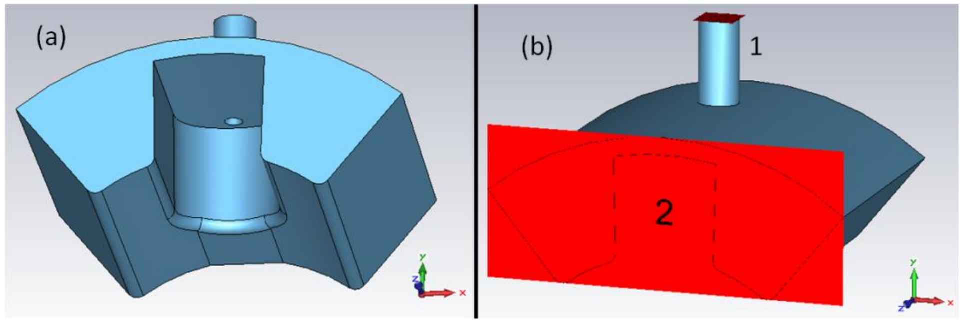
3. If the designed cavity did not attend an acceptable GR value: solutions that implied changes in geometry parameters were preferred. However, since modifications in geometry also change the shunt impedance curve, the steps **1** and **2** must be redone.

EM Project – Geometries Optimization

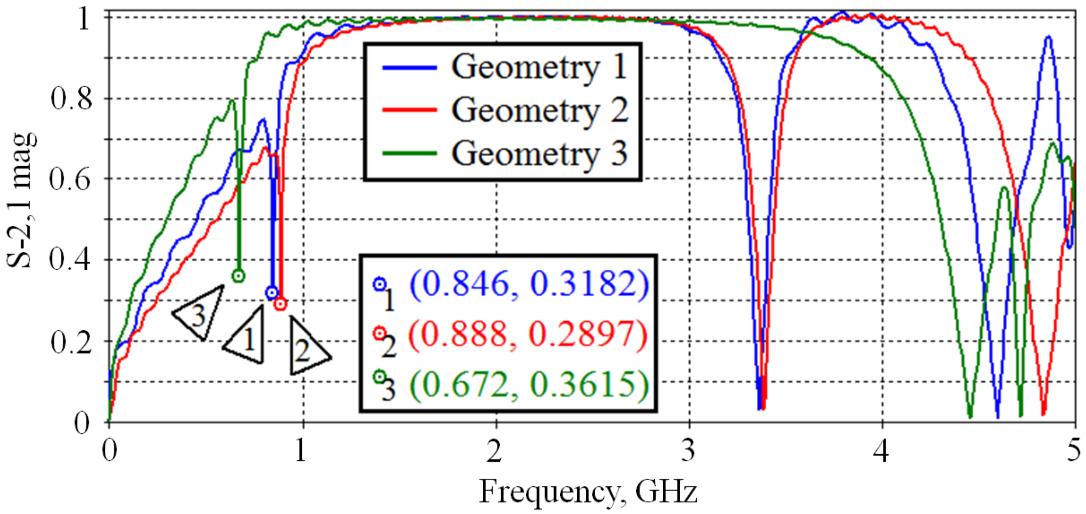
Below we can see the coupling impedance of the three geometries. The process has started with Geometry 1 being the one that came up from rescaling and adapting PLS design. However its CBMI's GR was found to be 20% of synchrotron DR. The own fundamental mode was exciting the fastest CBM. From Geometry 1 F_c = 1.31 GHz, we found that if we apply a 40 MHz center frequency shift on the fundamental mode, the CBMI's requirements would be reached. This shift was then applied onto Geometry 2 with the changes listed in Geometry Parameters Table, also leading to wider bandwidth and lower coupling impedance, generating higher growth rates though (~25% of DR). In this case, the longitudinal mode L3 at frequency 3.32 GHz is trapped and excites the fastest CBM. Therefore we started working with the possibility of damping L3, which later led to Geometry 3. The calculated fastest CBM excited by this final geometry has its GR in the order of 9.7% of the synchrotron DR.



Comparing blue and orange lines from previous Figure, we can see how strongly the L3 mode was damped. For doing this, we considered three options: a) introducing ferrite; b) inserting loop antennas; c) or performing a fine optimization of the ridged waveguide:



The optimization was done aiming the reduction of the waveguide cutoff frequency:

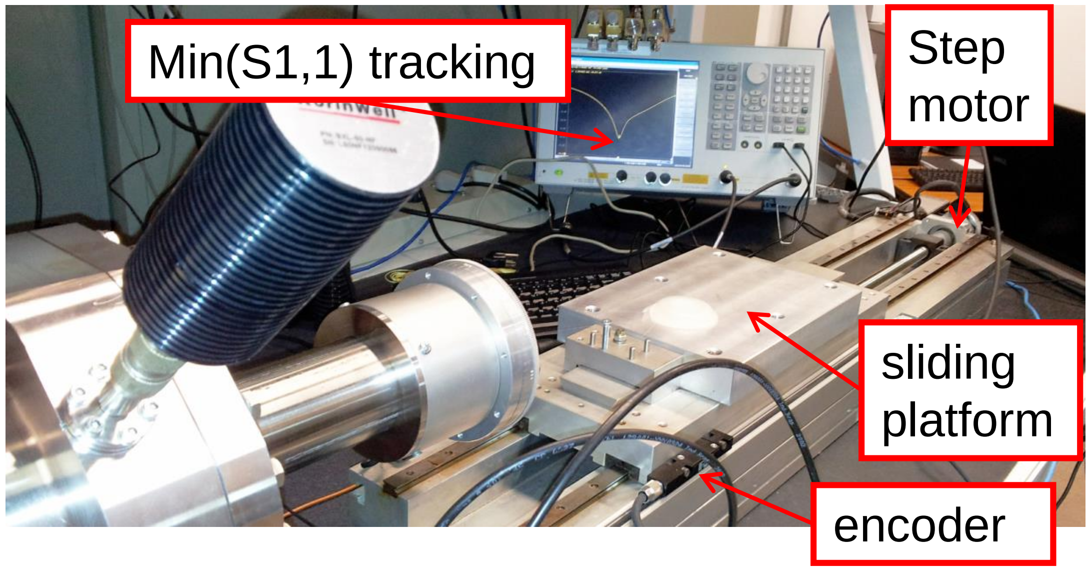


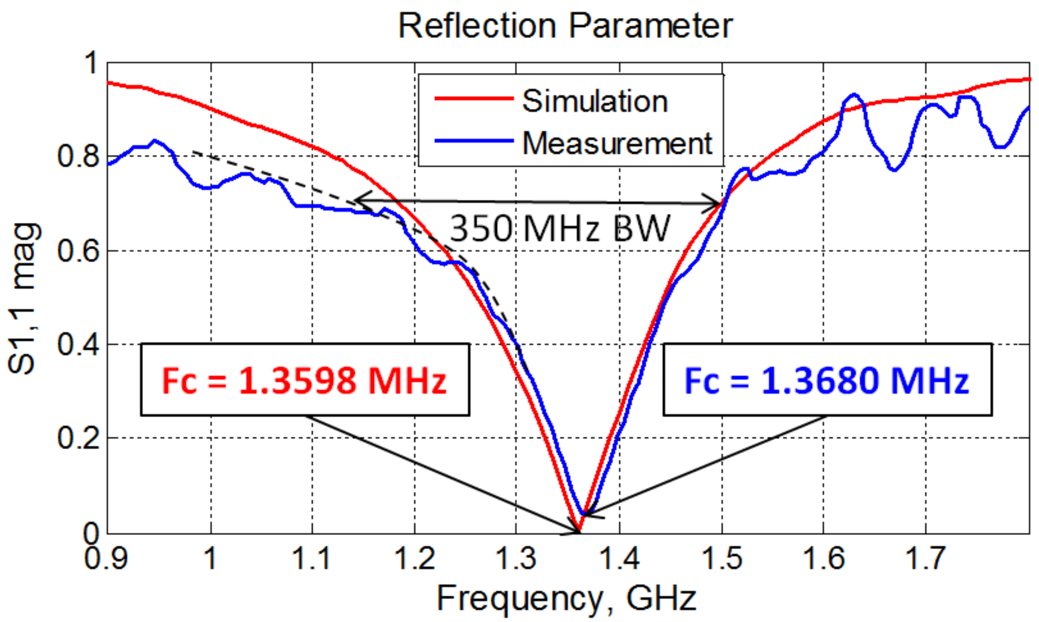
After the optimization, the remaining parameters of the global kicker structure (that do not interfere on the waveguide geometry) were readjusted: 700 Ω shunt impedance, 1.35 GHz center frequency, a 300 MHz BW. The BW was set larger than requirements in order to compensate the +40 MHz center frequency shift.

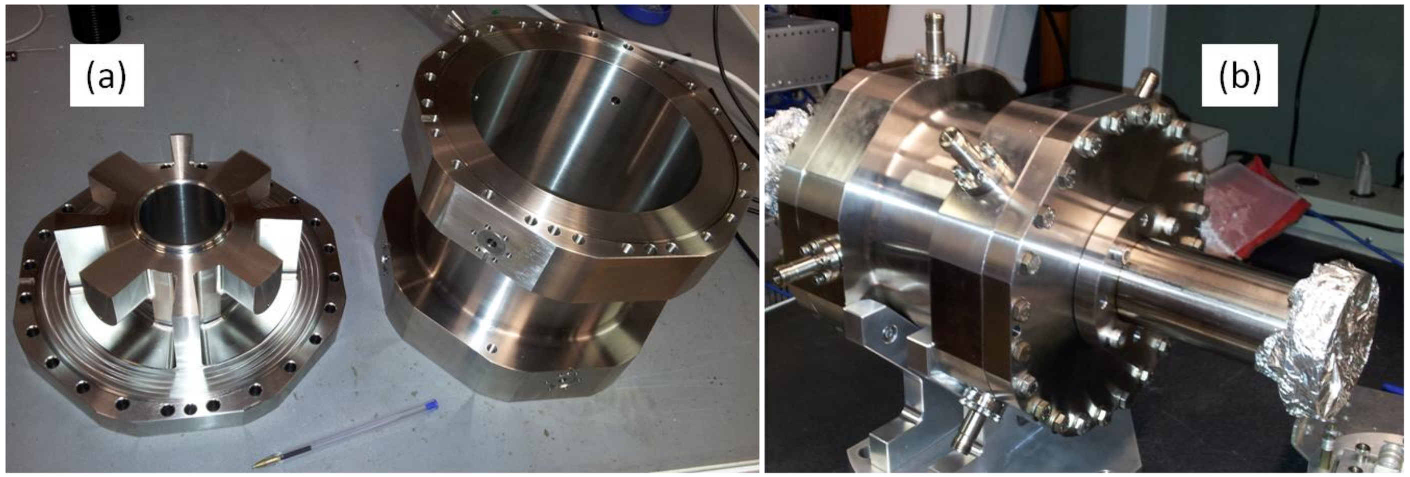
EM Characterization

• S1,1 parameters were not only calculated by simulations but also measured by simultaneous excitation of the four feedthroughs on the same side. On simulations this can be easily done by taking advantage of quarter symmetry. For the measurements, Port 1 of the network analyzer was connected to a 4-way splitter that feeds the downstream ports. The upstream ports were matched with 50 Ω loads. The plot shows the comparison between simulation and measurements. We can observe an 8.2 MHz deviation in center frequencies and a 30 MHz difference on BW's.

• One important point to be highlighted here is the difference between the parameters obtained from Rsh and S1,1 curves on simulation: later gives a BW=320 MHz and F_c=1.36 GHz, against BW=300 MHz and F_c=1.35 GHz from the former. Therefore, in order to calculate the shunt impedance by the measured data, a 330 MHz BW was considered, i.e., the 20 MHz difference was considered for measured S1,1 BW.







Bead-pull method (6mm radius metallic bead):

simulation	measurements
Q = 4.49	Q_{loaded} = 4.15
R_{shunt} = 700 Ω	R_{shunt} = 700.7 Ω

CONCLUSIONS

The LNLS longitudinal kicker geometry has been modified during the optimization process. To be more specific, the ridged waveguide geometry has been optimized from reflection and transmission coefficients point of view in order to improve the kicker coupling impedance. It is already installed in the storage ring and the BBB longitudinal feedback system is in commissioning phase.

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