Investigations on Low Energy Electron Beams: Experimental Setup, Diagnosis, and Dynamics

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Abstract

We present theoretical and experimental results concerning low energy electron beams. The experiments were performed with DIADYN, a laboratory installation suited to study electron beam properties in functioning regimes similar to those from irradiation installations used in applications. DIADYN includes a vacuum electron source, a beam channel consisting of two axially symmetric magnetic lenses, as well as two beams profile monitors. Our previous investigations [1, 2] were focused on the non-destructive beam diagnosis at the source exit and on the beam dynamics in the transport channel. In the present work we concentrate on hardware adjustments of the electron beam channel, that will lead to a better matching between experimental and numerical results.

B Introduction B

In a low energy beam channel with axial symmetry, consisting of magnetic lenses and free spaces, the root-mean-square (rms) beam radius, *R*, is governed by the equation [3, 4]:

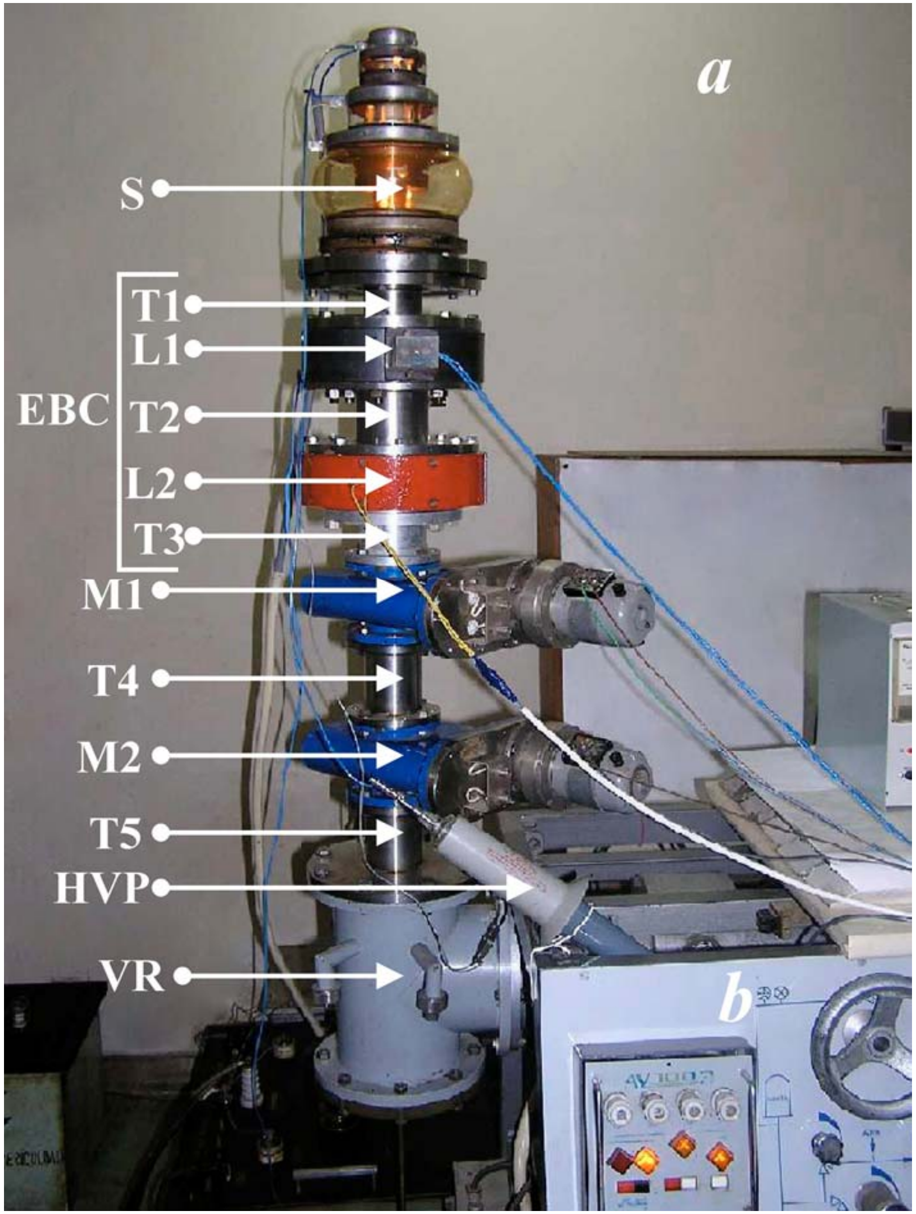
$$\frac{d^2R}{dz^2} + \frac{\eta B^2}{8U} R = \underbrace{\frac{1}{4\pi\varepsilon_0\sqrt{2\eta}} \frac{I}{U^{3/2}} \frac{1}{R}}_{T_{spch}} + \underbrace{\frac{\varepsilon^2}{R^3}}_{T_{em}} \qquad (1)$$

where I = beam current, U = beam acceleration potential, ε = rms beam emittance, B = axial magnetic field, η = electron charge-to-mass ratio, ε_0 = dielectric constant.

As indicated by recent results obtained with low energy medium current electron beams (LEMCEBs, cf. [1]), in order to have adequate control of the experiments one needs: (1) a good knowledge of the beam parameters, (2) a well designed electron beam channel (EBC), and (3) a fair understanding of the beam dynamics. In using DIADYN we have concentrated so far on the conditions (1) and (3). We developed the Modified Three Gradient Method, MTGM [1], for the non-destructive beam diagnosis, and investigated several beam regimes, by numerical simulations and experimental cross-checks.

Work presented in [2] emphasized the importance of condition (2) and made clear that DIADYN needs hardware adjustments of the EBC. These adjustments, in the meanwhile implemented, help preventing the current loss between the electron source and the beam profile monitors, as well as observing the paraxial approximation implied by Eq. (1).

Experimental Setup



The beam system, (**a**), and part of the vacuum system, (**b**), of the installation DIADYN. The beam system consists of:

- A pulsed Pierce diode electron source, **S**, providing 4 μs beams, at 100 Hz, with *I* and *U* in the ranges 0.05–1A and 10–50keV.
- The electron beam channel, **EBC**, made up of the magnetic lenses **L1**, **L2**, and the field free spaces **T1**–**T5**.
- The vacuum room, **VR**.
- A beam monitoring unit, including two beam profile monitors **M1**, **M2**, and a sliding Faraday cage (parked inside VR).

Also shown is the high-voltage probe, **HVP**.

D Beam diagnosis and dynamics D

A proper experimental determination of the beam radius at two locations, M1 and M2, as function of the L1 lens power, R_M=f(U_{L1}), is a key element for the success of MTGM. For each lens power the beam profile at the two monitors is read on the oscilloscope. The beam crossing duration and the known scanning velocity of the profile monitor provide the beam radius. A dedicated fit program uses R_M=f (U_{L1}) and Eq. (1) to find the beam parameters at the source exit.

Once the beam parameters are determined, one can investigate the beam dynamics. With two magnetic lenses, as in the DIADYN setup, it is possible to vary at the same time both the position and the radius of the image cross-over.

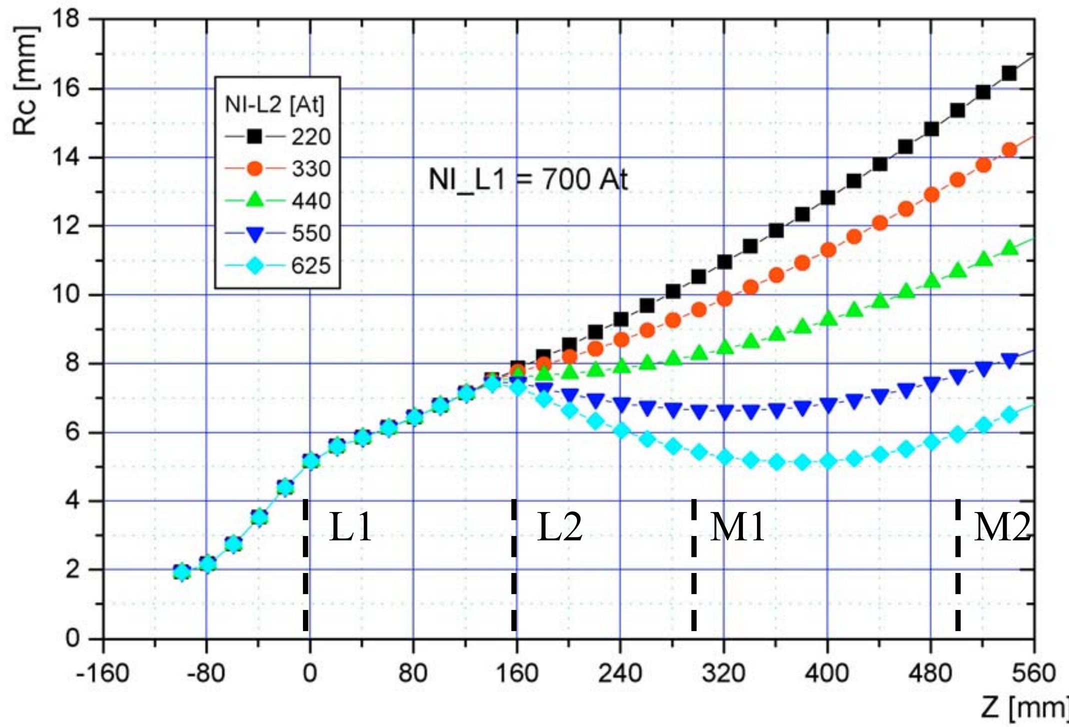
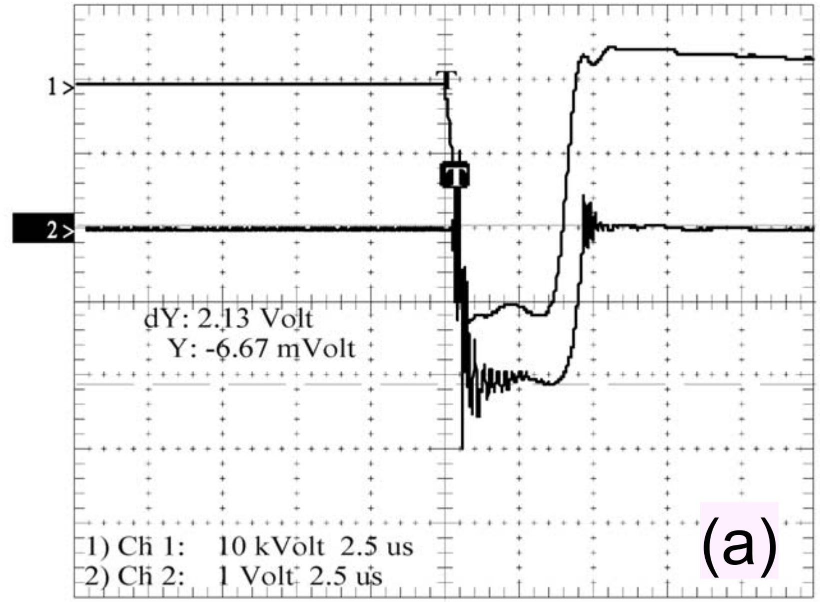


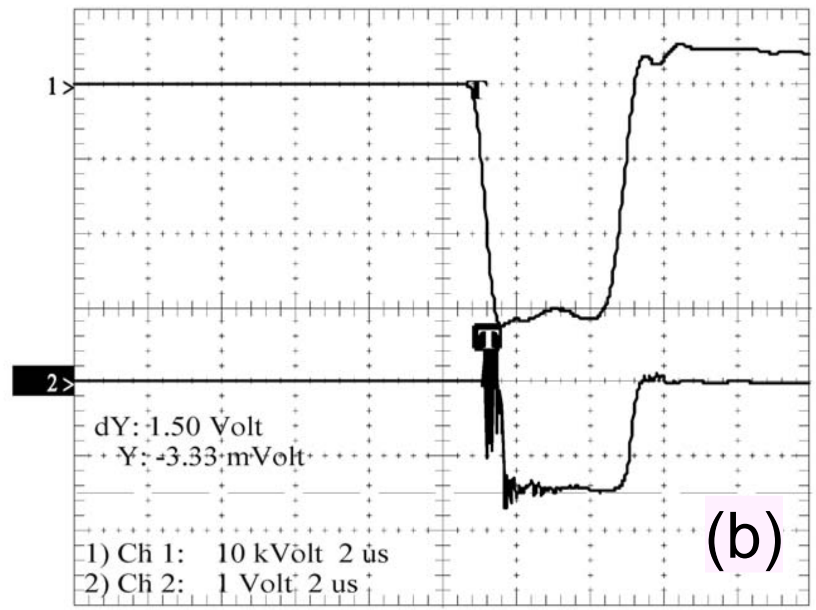
Illustration for the use of L2. The beam evolution through the transport channel is shown for a selection of L2 powers, corresponding to different NI_L2.

Beam Transmission

Since the agreement between experimental and numerical data was not always good, we suspected that in certain functional regimes part of the beam current was lost along the EBC. In order to check if this was true, we compared the current extracted from the electron source with the current transmitted to the monitoring unit. The beam current was measured with a Faraday cage, able to slide along the EBC axis, and parked inside VR during nominal operation.

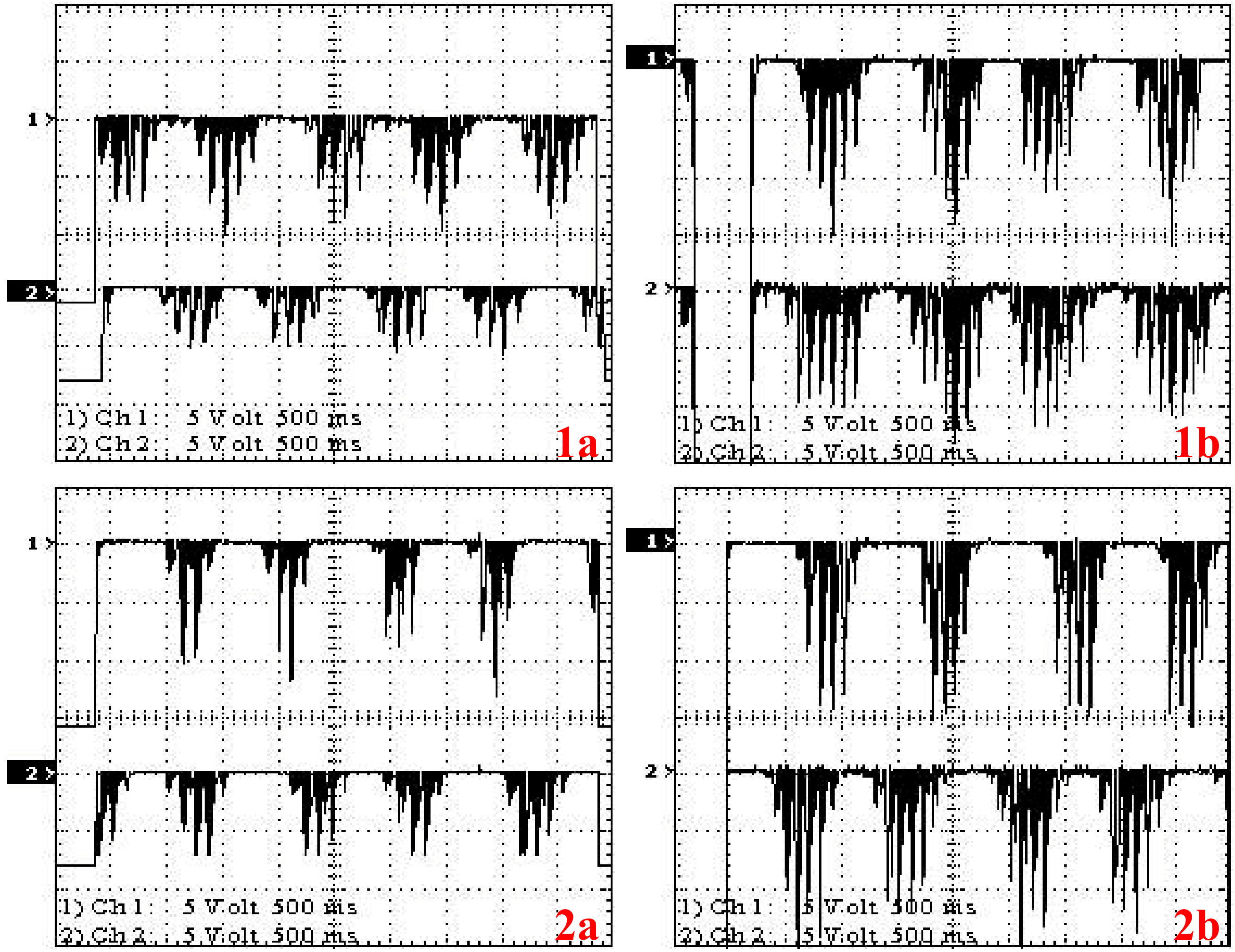
Here we present oscillograms of the beam current in the section T2, upstream from L2 (a), and in the section T4, downstream from M1 (b). The current is measured on a 10 Ω resistor, therefore $I_{b1} \approx 0.21$ A in case (a), and $I_{b2} \approx 0.15$ A in case (b). The first channel of the oscilloscope shows the high voltage, $U \approx 31.7$ kV. In case (b) about 25% of the beam current is lost.





Beam Transmission

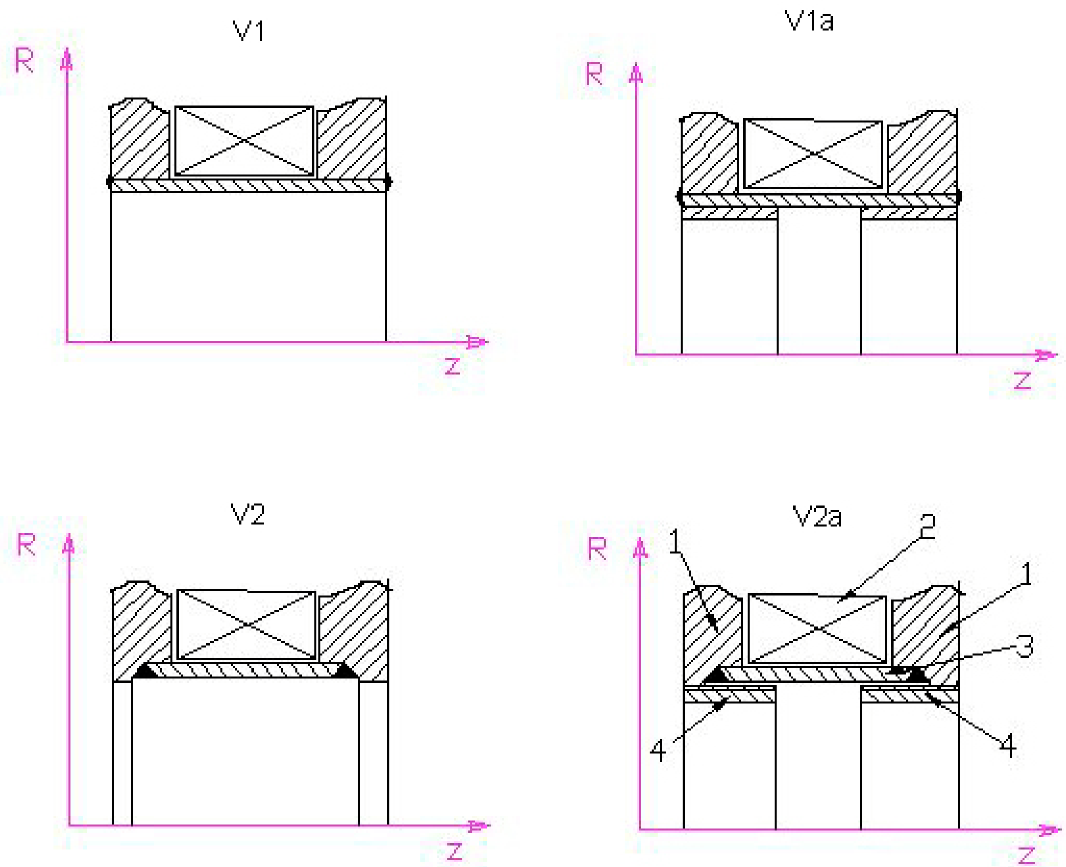
The beam profiles shown to the right pinpoint the location of the current loss between M1 and M2, at a centering diaphragm for the Faraday cage. Each oscillogram shows the beam profile at M1 on channel 1, and at M2 on channel 2. Profiles for two L1 lens powers are presented, corresponding to the applied voltages U_{L1} = 2.3 V (1a, 1b) and U_{L2} = 2.6 V (2a, 2b).



In the left column (1a, 2a), where the centering diaphragm is mounted between M1 and M2, the current loss is visible in the decrease of the pulse height. In the right column (1b, 2b), where the diaphragm was removed, the pulses at M1 and M2 have about the same height.

L2 Design

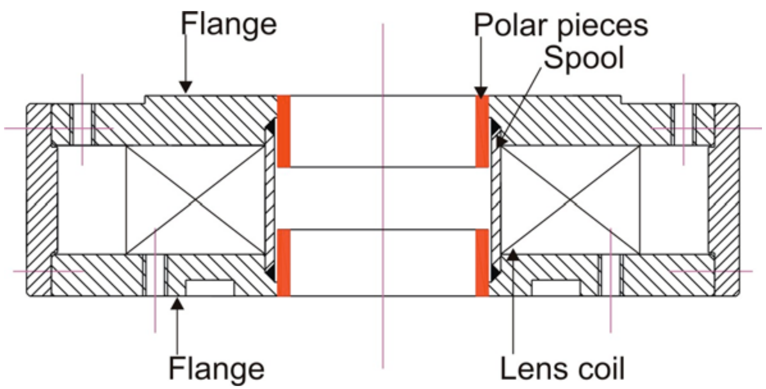
The new lens L2 was designed to have better electrono-optical properties by: (1) enlarging the spool, which enables a larger paraxial region, and (2) enhancing the field confinement, through lateral flanges and soft iron polar pieces. A key tool used in the design phase was the simulation program FER1CH [5], based on a finite element code, which allows the calculation of the magnetic field for axially symmetric lenses. FER1CH requires information on the geometry of the lens, the magnetic properties of the materials, as well as the current (in ampere-turns) and area of the winding.



Four possible design solutions for L2. The parts are indicated in the bottom right sketch: 1 – soft iron flanges; 2 – coil winding; 3 – stainless steel spool; 4 – soft iron polar pieces.

L2 Execution

1



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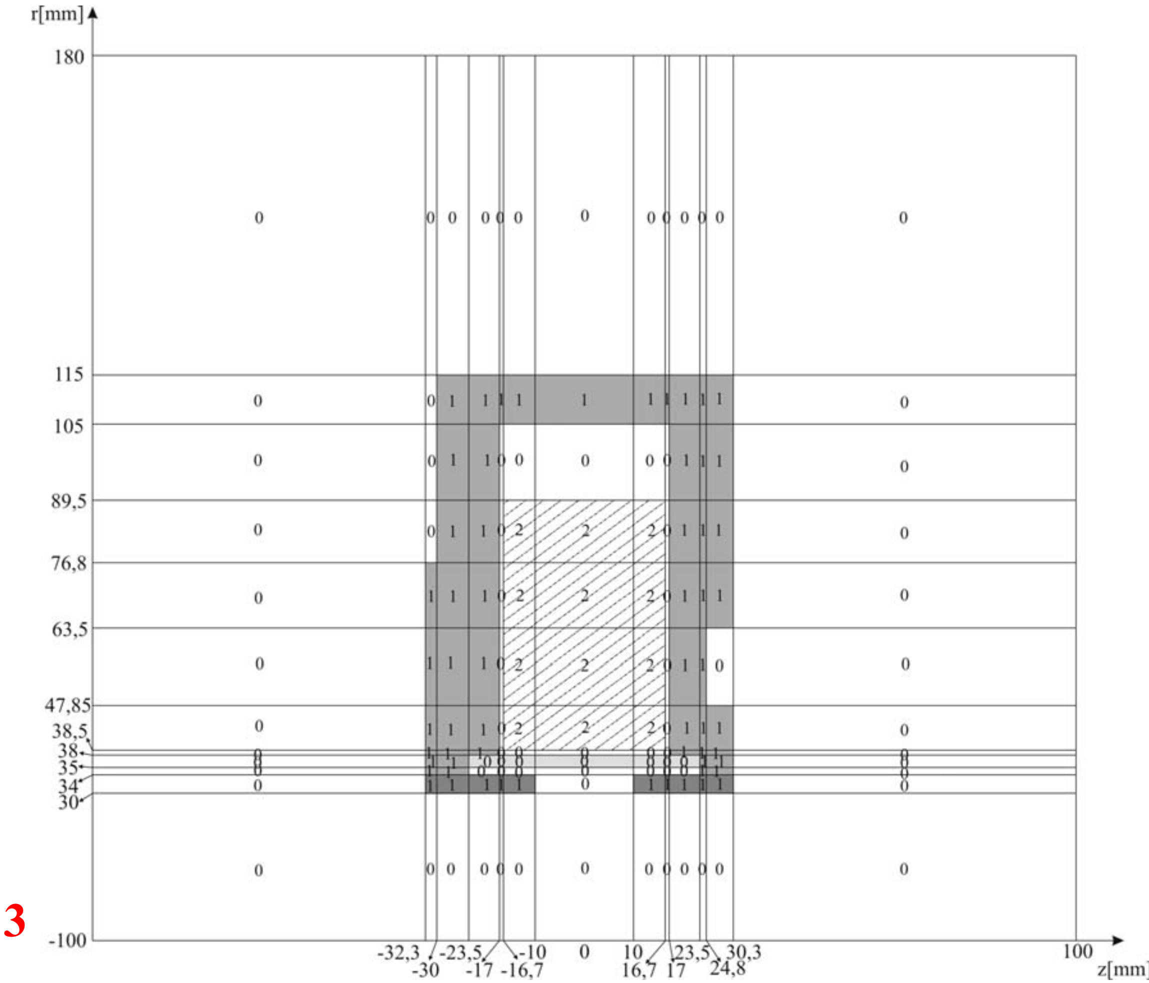
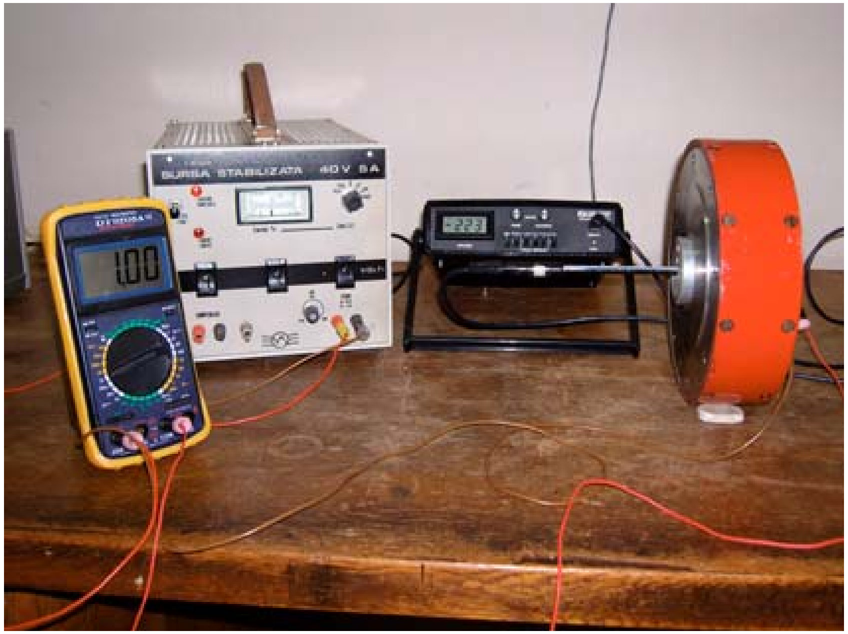
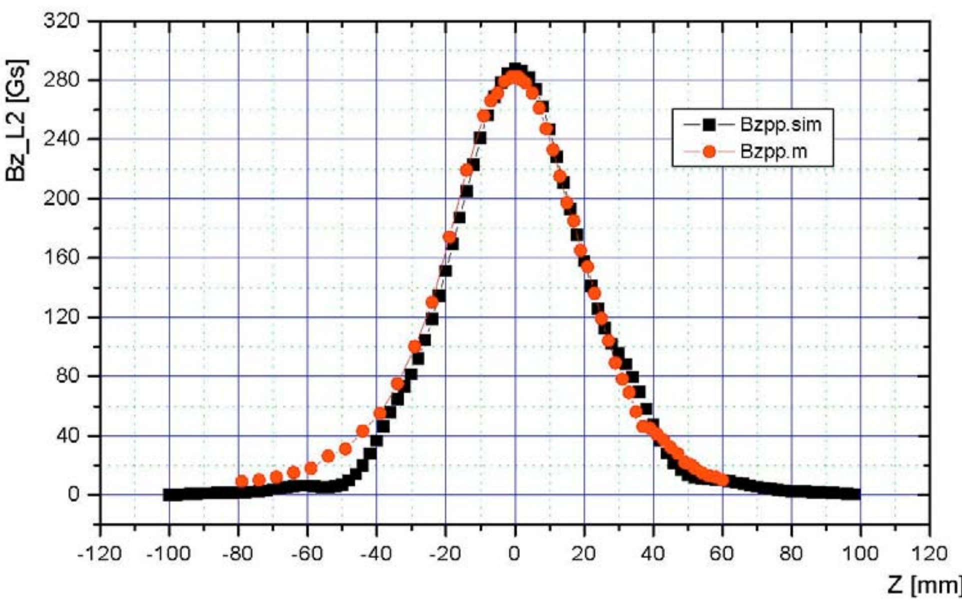


1. L2 sketch based on the geometry V2a; **2**. Photo after welding the spool, adding the polar pieces, facing, and boring; **3**. Final configuration, used as input for the numerical simulation.

L2 Check: Experiment vs. Simulation

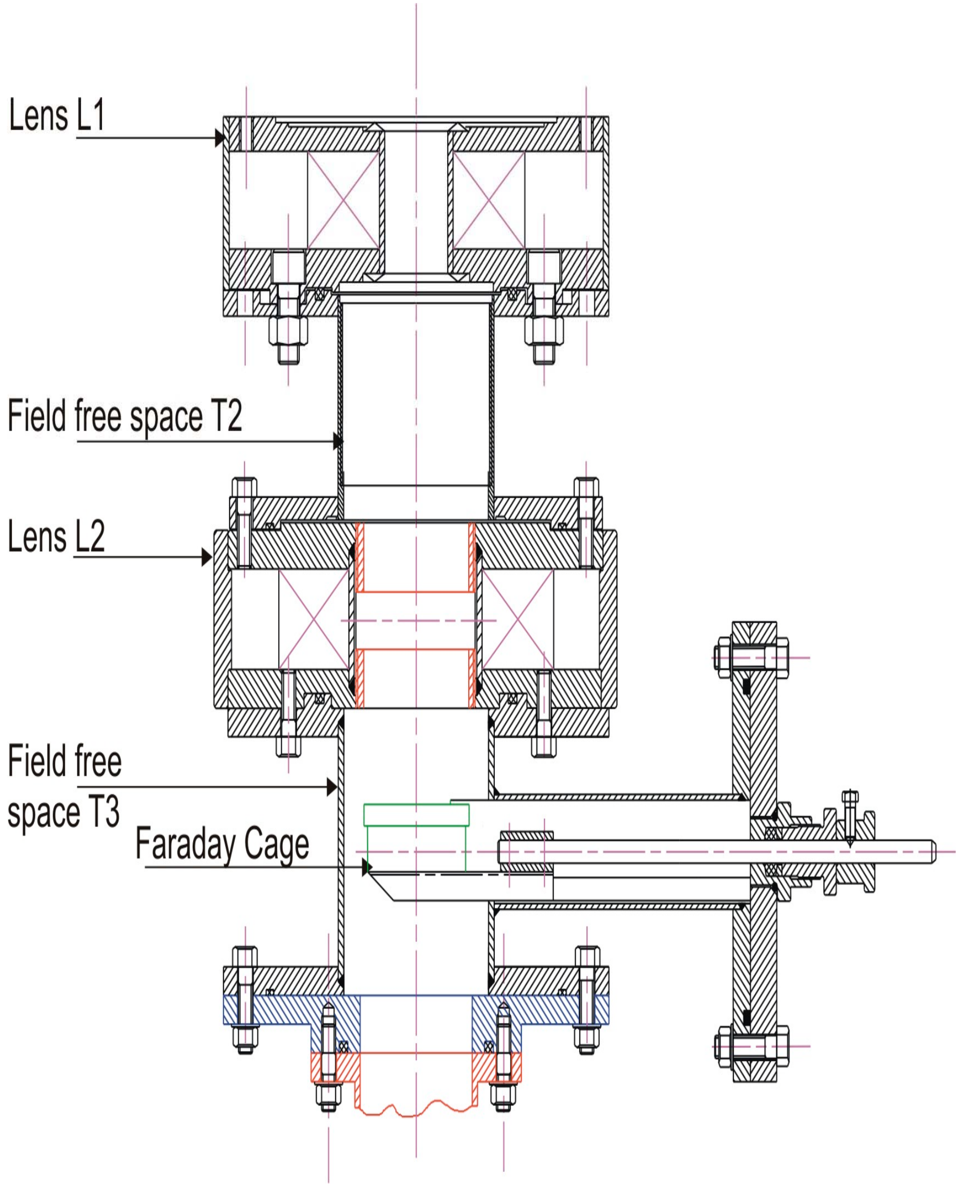


Experimental arrangement used to measure the magnetic field along the L2 axis. The red cover of the lens is a soft iron magnetic screen. Also visible are the power supply, an ampere-meter, and a gauss-meter with a Hall probe.



The agreement between the measured, Bzpp.m, and simulated, Bzpp.sim, values of the magnetic field is very good, except for small differences due mainly to errors in positioning the Hall probe.

G Modified Electron Beam Channel G



Realised upgrades of DIADYN. The electron beam channel has been improved by the new design of the lens L2. In the beam monitoring unit, the operation of the Faraday cage has been optimized by changing the measuring position and the movement system.

- Key changes in the design of the lens L2 are:
  - A larger spool internal diameter;
  - Edge flanges from soft iron instead of stainless steel;
  - Polar pieces inside the spool, which concentrate the magnetic field.
- The Faraday cage is mounted downstream L2 and moves perpendicular to the beam axis. The centering diaphragm between M1 and M2 has been removed, increasing the effective width of the beam channel.

H Summary and Prospects H

➢ The paper presents upgrade work on the low energy electron beam installation DIADYN. We focused on the hardware changes needed by the EBC and the beam monitoring unit.

➢ The main part of the EBC subject to modifications was the lens L2. The new design of L2 was successfully evaluated and checked by computer simulations.

➢ With its improved EBC and optimized beam monitoring unit, DIADYN is better suited to be used in the diagnosis and dynamics of low energy electron beams. The implemented hardware changes will enable a better matching between numerical and experimental results.

Acknowledgement The contribution of Emil Constantin to the execution of the experiments is thankfully acknowledged. The work was supported through the Project EGRETA, Contract 308 / 13.09.2006, Program RELANSIN.

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