Magnetic Lenses for Low Energy Beam Channels: Computer Simulations and Experimental Measurements

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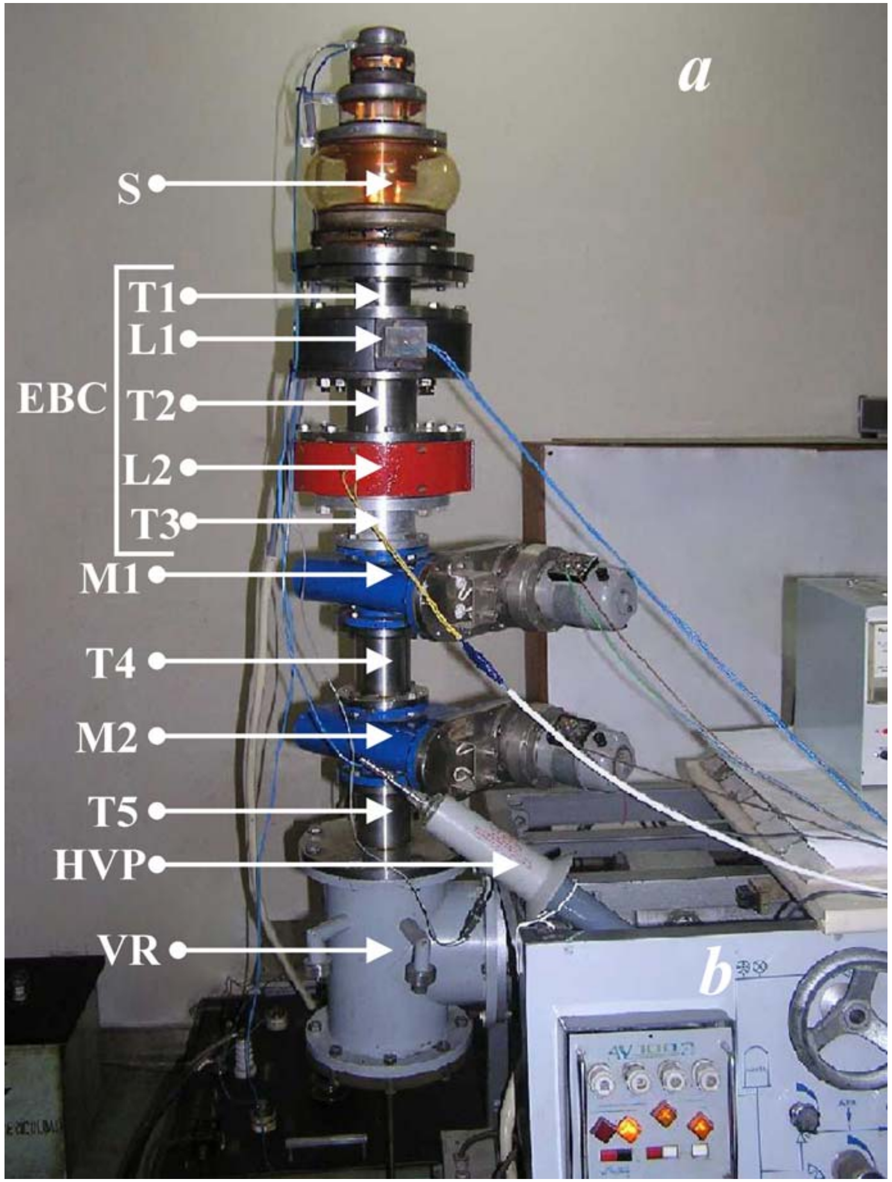
A Abstract A

Axial magnetic lenses are key elements of the beam channels in irradiation installations with low energy electrons. In order to achieve proper transport and focus of the electron beam in the target plane, careful computer design and execution of the lenses are needed. We present both the design and execution stages for an axial magnetic lens to be used with DIADYN, an effective laboratory installation for investigations of low energy electron beams. We also show experimental versus simulation results for one realized lens.

Introduction



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**.

Introduction

A successful application requires: (1) a good knowledge of the beam parameters, (2) a properly designed electron beam channel (EBC), and (3) a good understanding of the beam transport through the EBC. Here we concentrate on the condition (2), by describing the work done so far to improve the EBC for DIADYN. Details on the beam diagnosis and dynamics – conditions (1) and (3) – as performed with DIADYN are given in [1], [2], and [3].

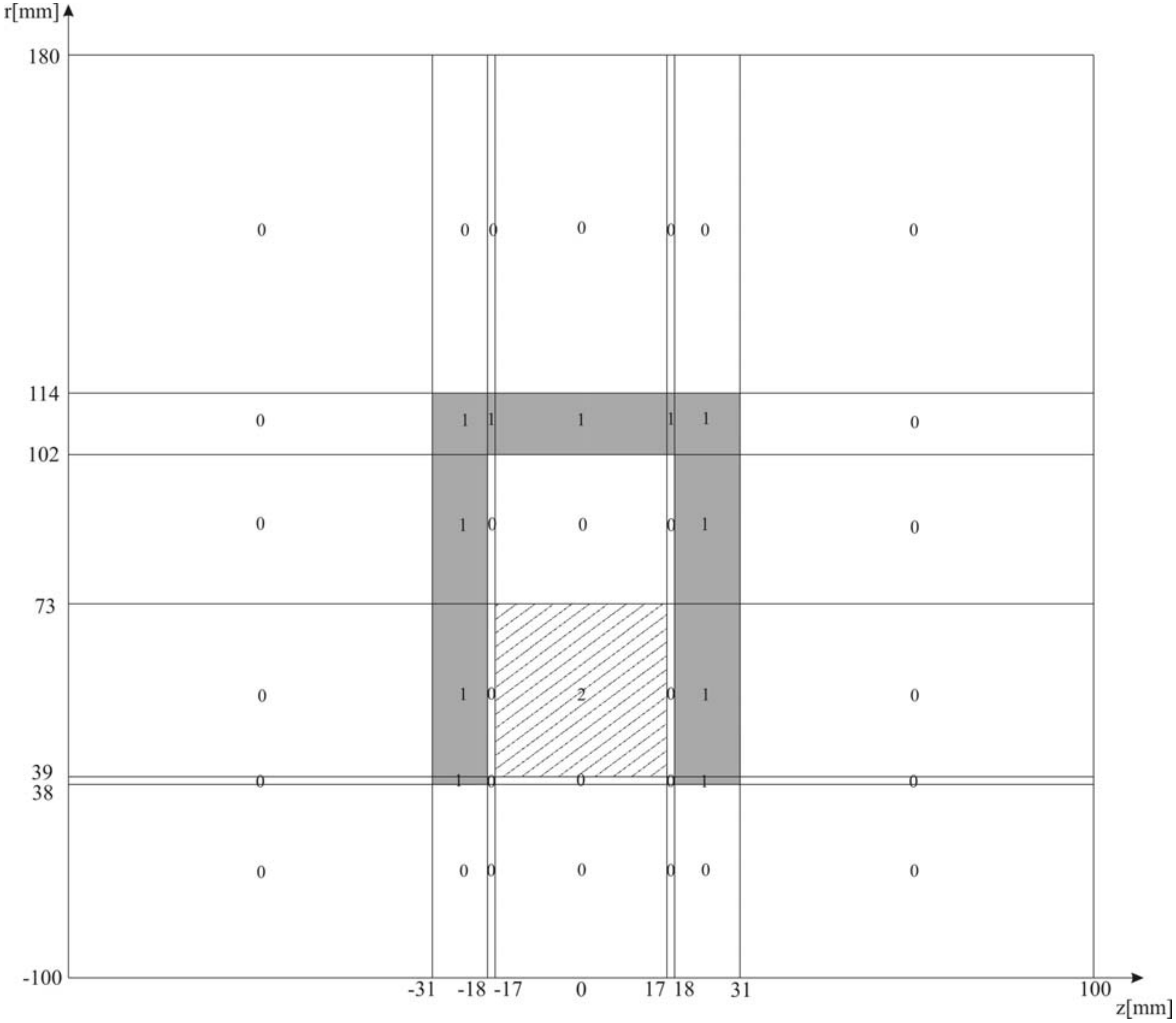
In a low energy beam channel with axial symmetry, consisting of magnetic lenses and free spaces, the root-mean-square (rms) beam radius, *R*, is governed by the equation [4, 5]:

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

where R = root-mean-square (rms) beam radius, 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. Equation (1) is valid only in paraxial approximation, which requires the beam to be ‘thin’ (empirically, the beam radius should be less than about 1/3 of each lens radius). Since previous experiments showed that the beam grows large particularly within L2, we started the optimization of the EBC with L2, to be presented in the following.

C L2 Design: Starting Point C

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 [6], 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.

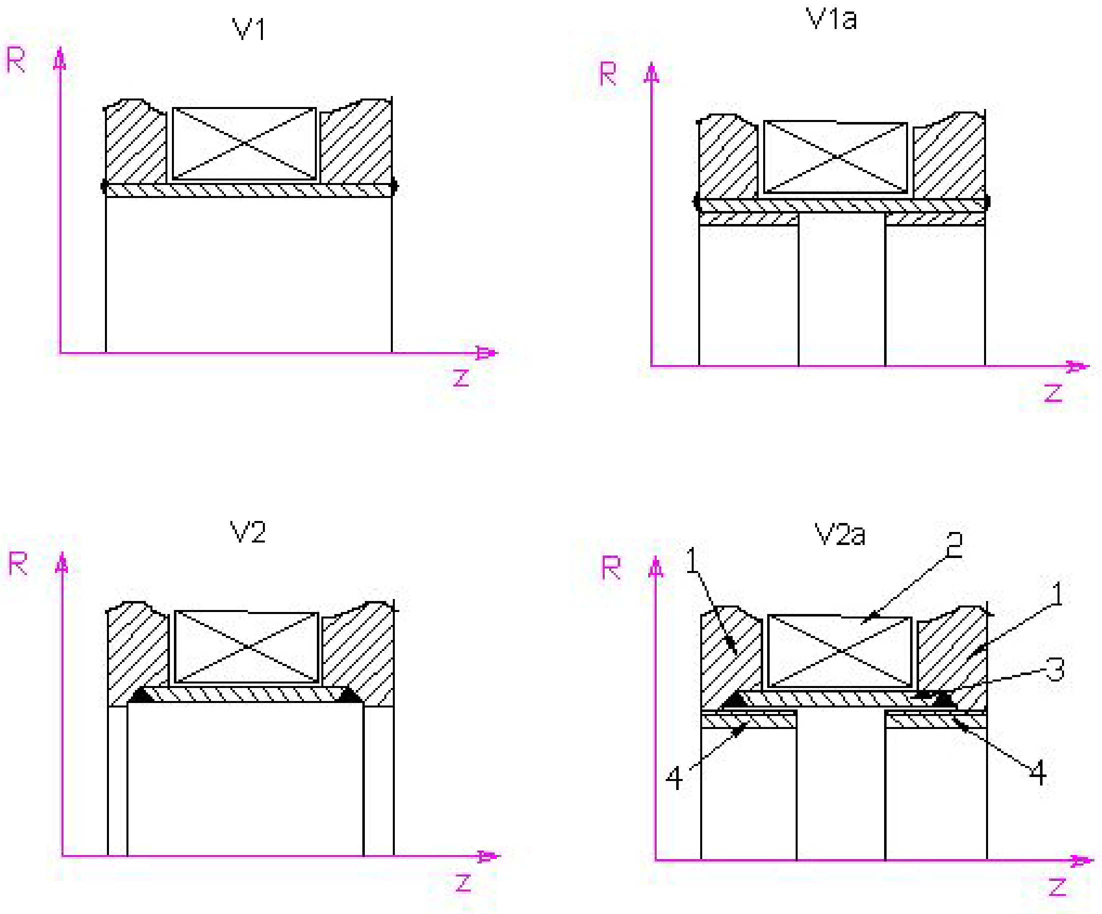


Geometry and magnetic properties for the initial, not optimized, lens configuration. The indices 0, 1, 2 indicate, respectively, air, soft iron, and winding.

C L2 Design: Possible Options C

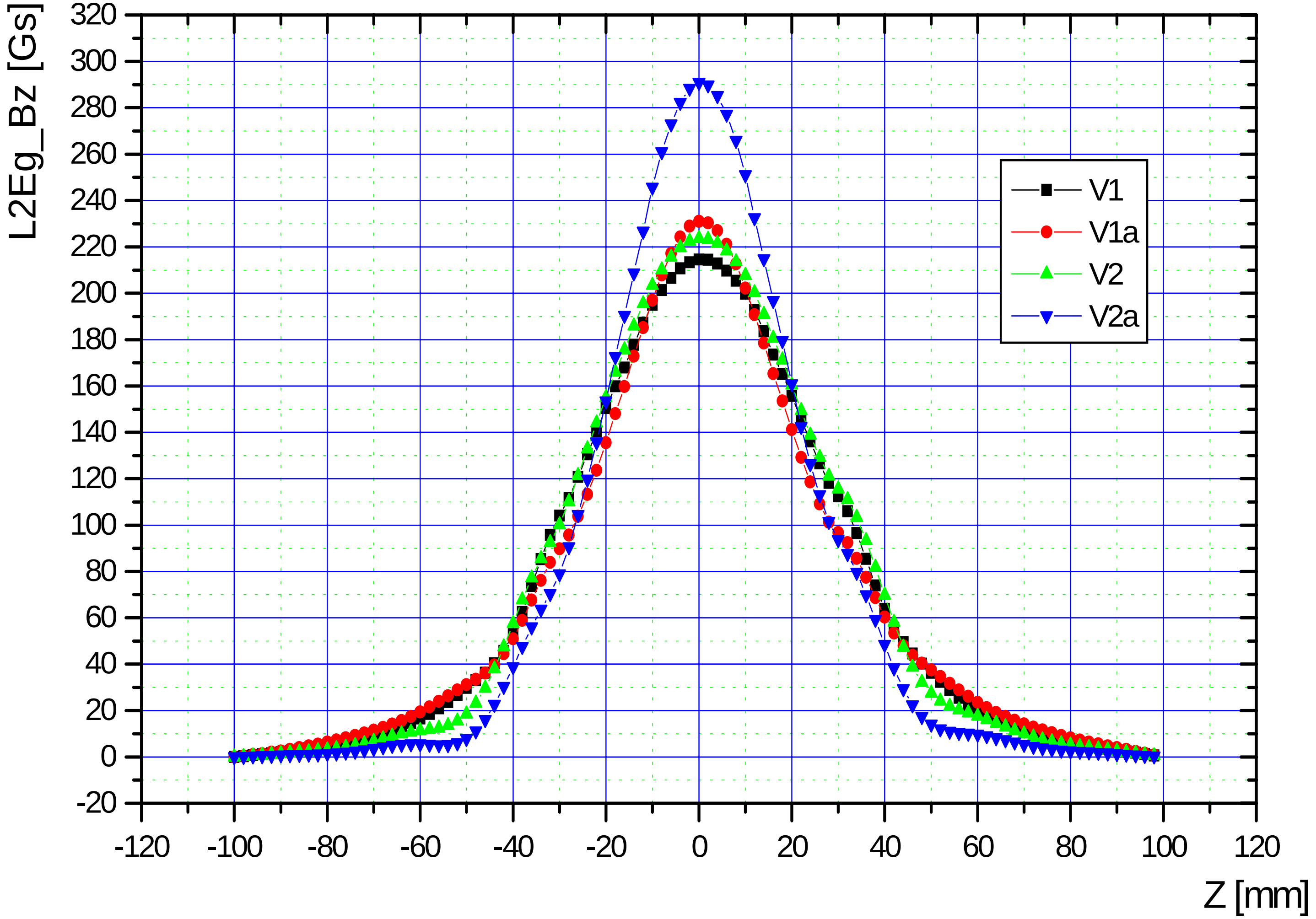
In order to find the best design solution, four alternative configurations have been modeled, as presented to the right:

- V1 has soft iron flanges at the edges. The spool welding belts are at the outer sides of the flanges.
- V1a is similar to V1, except for including soft iron polar pieces near the two interior faces of the spool. This adds a 20 x 4 mm air gap between the spool and the winding in the middle of the lens.
- V2 is similar to V1, but with the spool welding belts at the inner sides of the flanges.
- V2a is similar to V2, except for including soft iron polar pieces (same as V1a compared to V1).



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 Design: Axial Magnetic Field

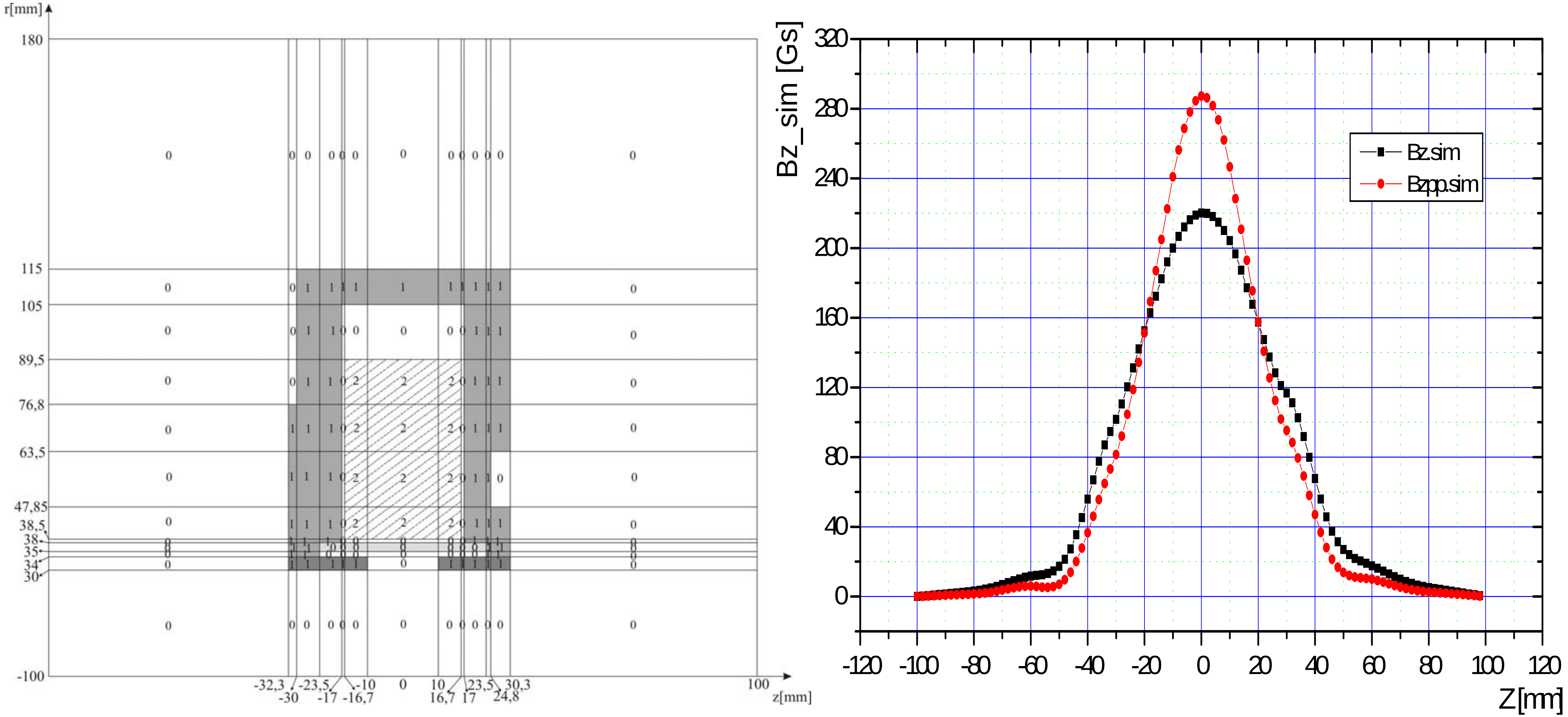


Axial magnetic field for the constructive options to the left. The configuration V2a provides the best field – maximum value in the central plane of the lens, as well as steepest decrease towards the edges of the lense. The simulations were performed with a coil current of 1150 A-t (1 A by 1150 turns) and a coil surface of 11.56 cm^2.

L2 Execution: Key Stages

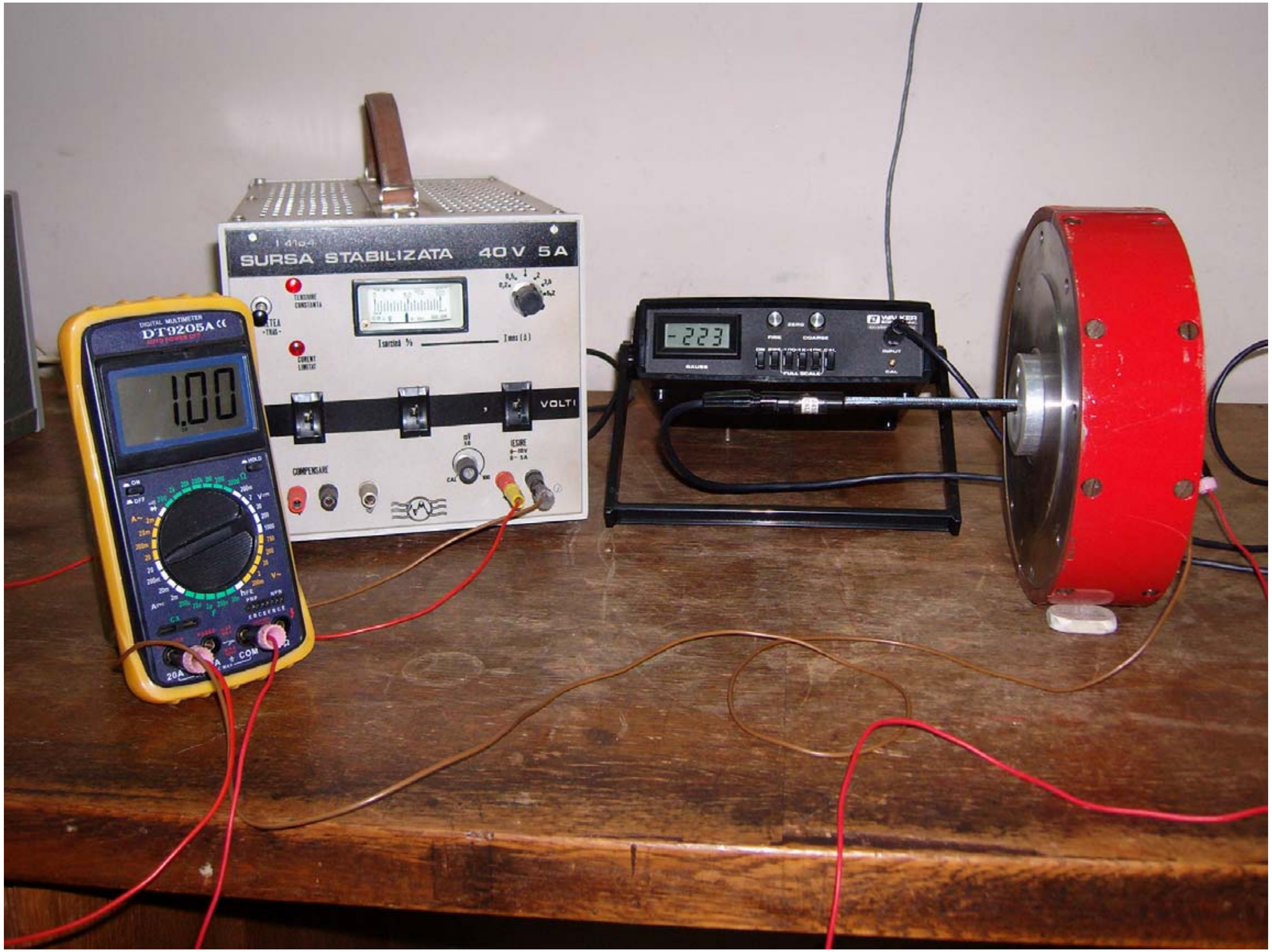
Left: the spool after welding, with the welding belts at the inner sides of the flanges. *Middle:* the flanges, with holes for fastening a soft iron cover. *Right:* the spool, after adding the polar pieces, facing, and boring.

L2 Execution: Final Configuration



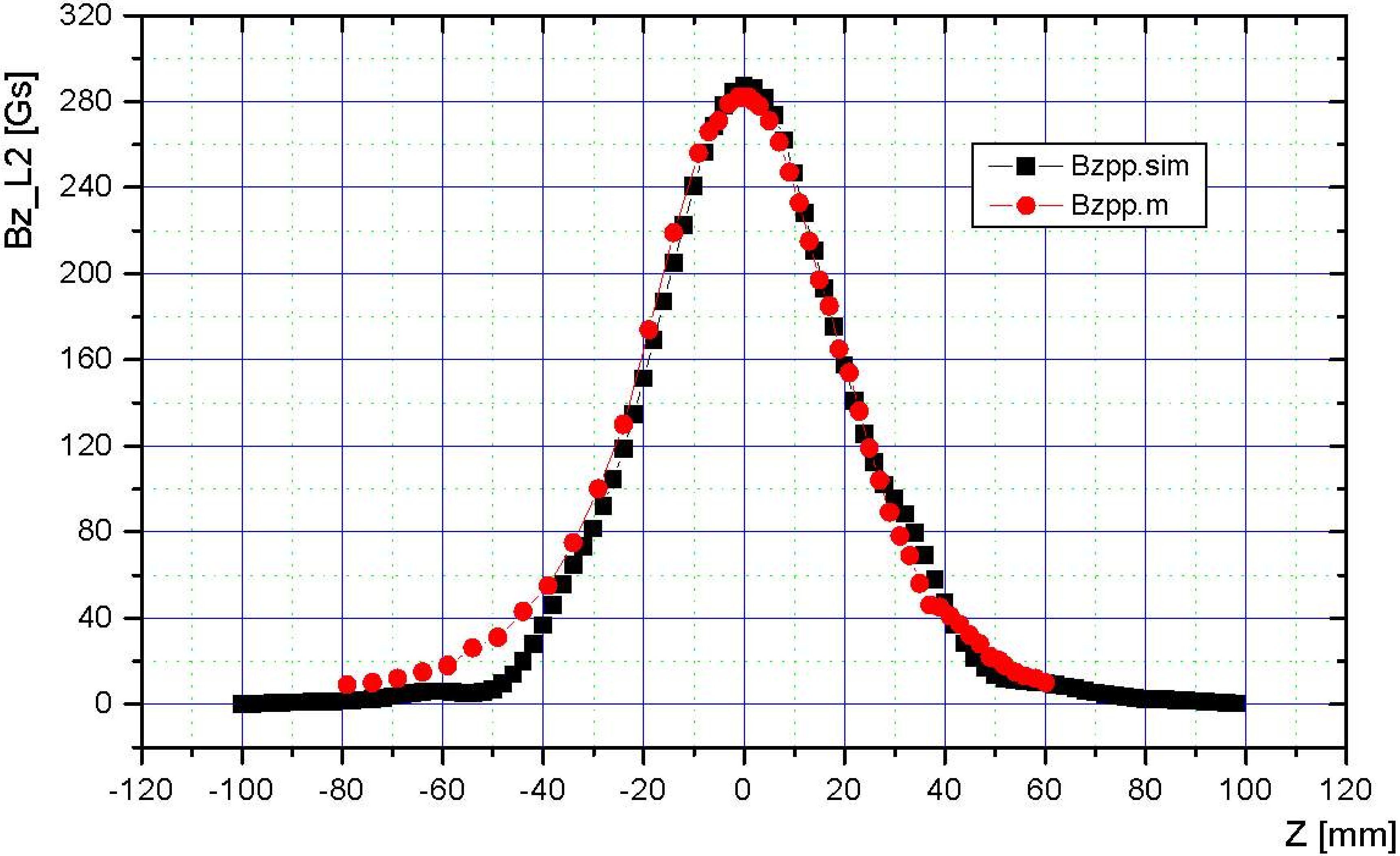
Left: Final L2 configuration, used as input for computer simulation. The wire used for the coil was thicker than assumed in the design simulations, which led to an increase of the winding surface from 11.56 cm^2 to 17.1 cm^2. *Right:* Axial magnetic field, Bzpp.sim, obtained for the executed lens. Bz.sim is the field that would be obtained without polar pieces.

L2 Execution: Magnetic Field Measurement



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.

Ɗ L2 Execution: Experiment vs. Simulation Ɗ



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.

E Summary and Prospects E

- ➢ Computer simulations were successfully used as a design tool, to optimize one axially symmetric lens in the electron beam channel of the DIADYN installation.
- ➢ The measured magnetic field of the executed lens was found to be in very good agreement with the simulation results, when all the constructive details were taken into account.
- ➢ By using the new lens, the transport of the beam will fit better the paraxial approximation, and the accuracy of the experiments run with DIADYN is expected to improve.
- ➢ This will be particularly helpful in extending the experience and results achieved so far to electron beams extracted from plasma sources.

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