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COMSOL Aided Design of an Extraction Pipe for the Electron Beam from a Plasma Focus device

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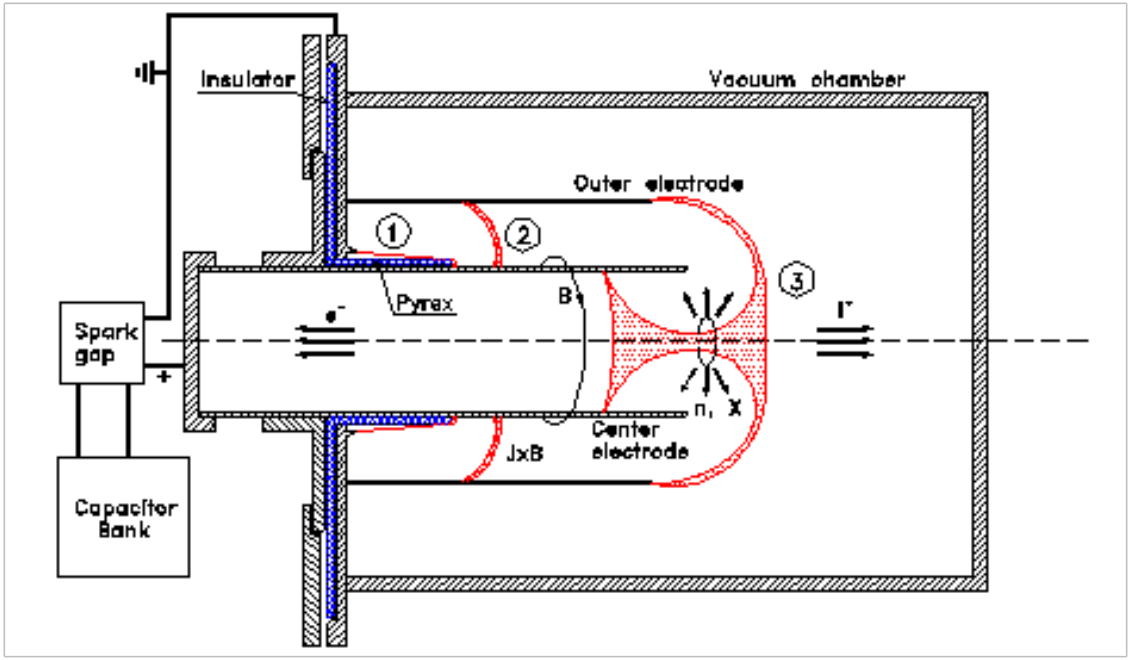
Introduction

- A prototype plasma focus named PFMA-3 has been designed and put into operation by the University of Bologna. The electron beam emitted can be used as an X-ray source in radiation therapy, particularly in IORT applications.
- To take the next step toward a medical use of the device it is necessary to optimize the materials composing the extraction tube for the electron beam.
- At the working frequencies of this device (10^5-10^6Hz), a steel extraction tube prevents the magnetic field produced by the device to modify the trajectory of the electrons; however, metallic materials are barred by electrical safety reasons.
- On the other hand, plastic materials proved completely permeable to the EM field, which deflects the electron beam and makes it impossible to generate X-rays.

Plasma Focus

A Plasma Focus device is basically composed of two coaxial cylindrical electrodes, closed at one end and open at the other. Between the two electrodes there is a cylinder made of insulating material. The inner electrode is connected to a capacitor bank by a fast switch, while the outer electrode is electrically grounded through the lower conducting plate. The electrodes and the insulator are contained in a vacuum chamber, later filled with a few Pascal of the working gas.

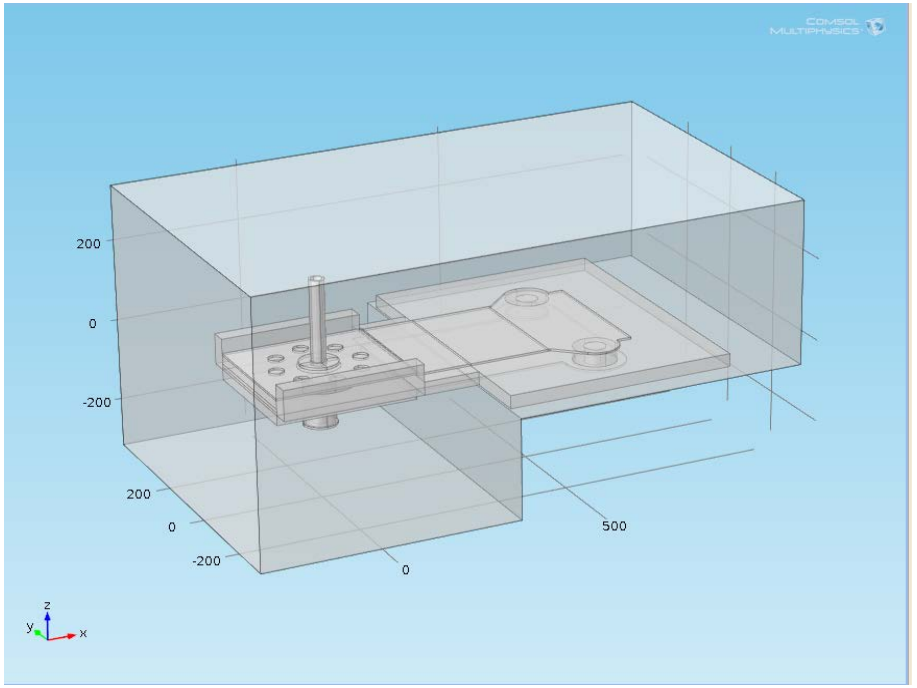


Use of COMSOL Multiphysics

- The AC/DC module in COMSOL Multiphysics (version 4.2a) has been used to simulate the electromagnetic field in the extraction tube at different frequencies and with different materials.
- The interface used is the “Magnetic and Electric Fields”, specifying a frequency domain study with frequencies ranging from 50Hz to 1MHz (50Hz, 1kHz, 100kHz and 1MHz).
- The tension input has been ensured by a “Terminal” boundary condition (with a 1V tension input) on the two copper pins connected to the upper plate
- On the lower plate a “Ground” condition has been added.
- The boundary conditions of “Magnetic Insulation” and “Ampere’s Law and Current Conservation” are added by default by the software.

PFMA-3 device

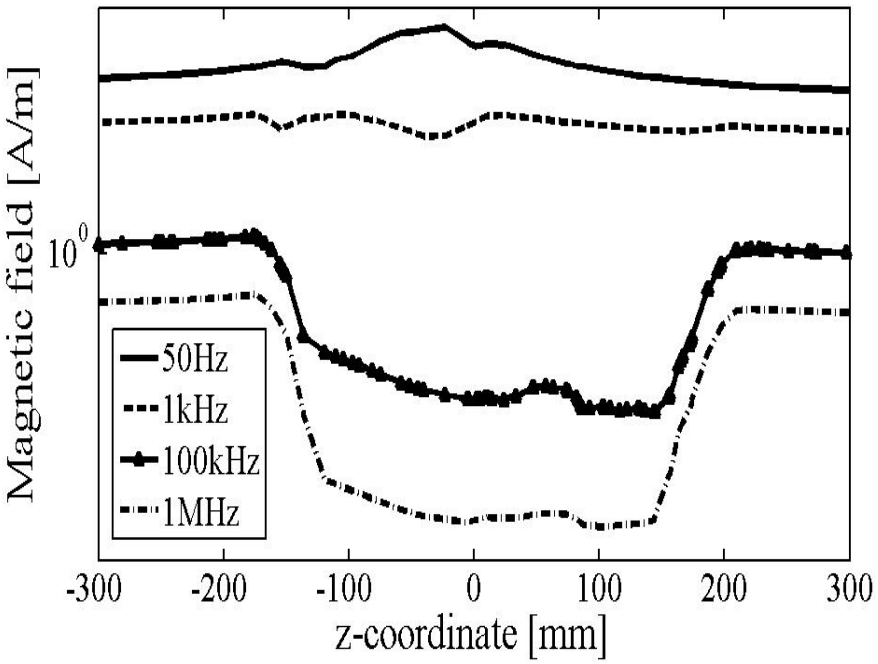
COMSOL model

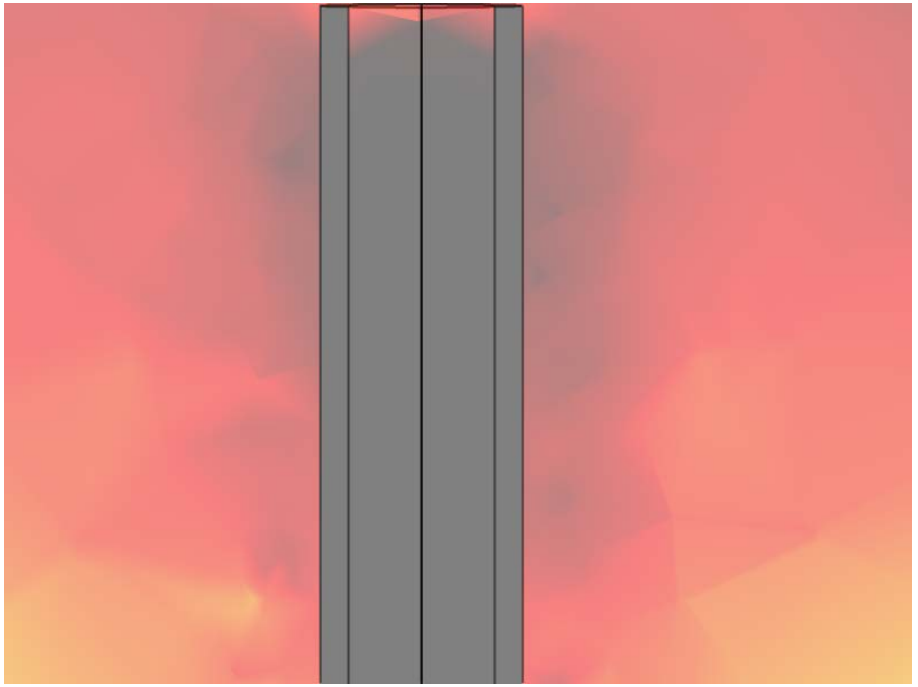


Results

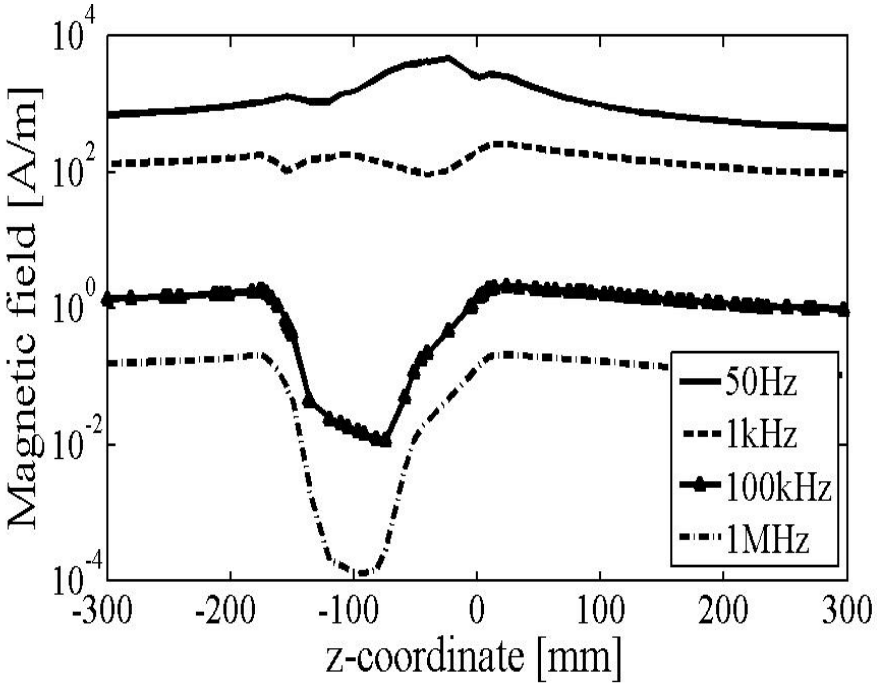
- Two materials have been chosen for the simulation of the extraction tube: stainless steel and Delrin
- Plots of the magnetic field vs the z-coordinate have been extracted using the cut line feature.
- The cut line has been chosen as the axis of the electrodes and of the extraction tube. This way, the plots show the trend of the magnetic field within the tube (0 to 150mm), thus making it possible to appreciate the possible effects of the EM field on the electron beam at different frequencies.
- Plots of the magnetic field energy trend in the extraction tube zone have been extracted too, using a cut plane feature (an xz-cut plane passing through the extraction tube axis is used).

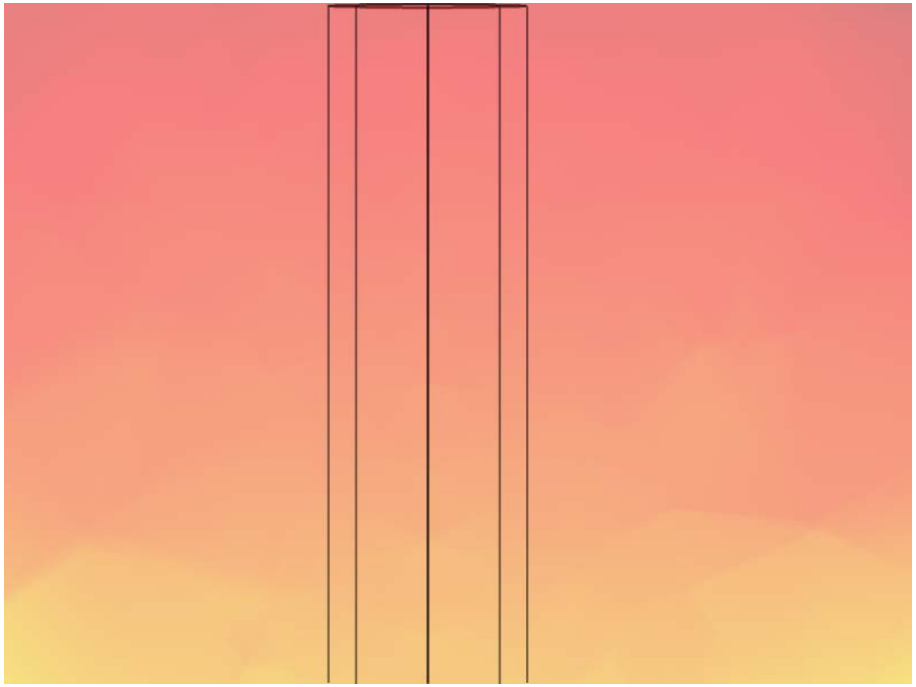
Results: Steel extraction tube



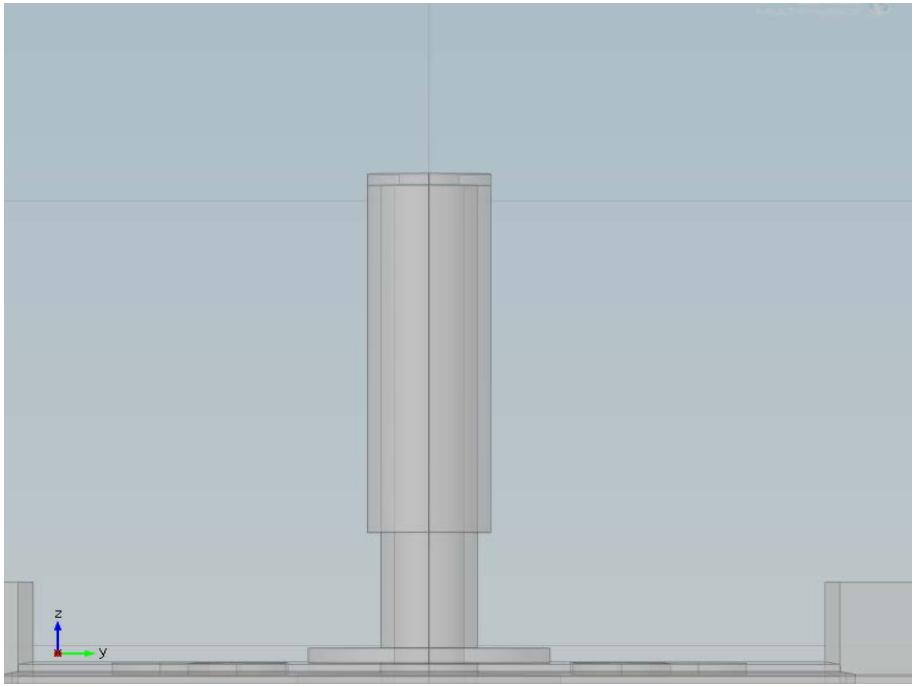


Results: Delrin extraction tube



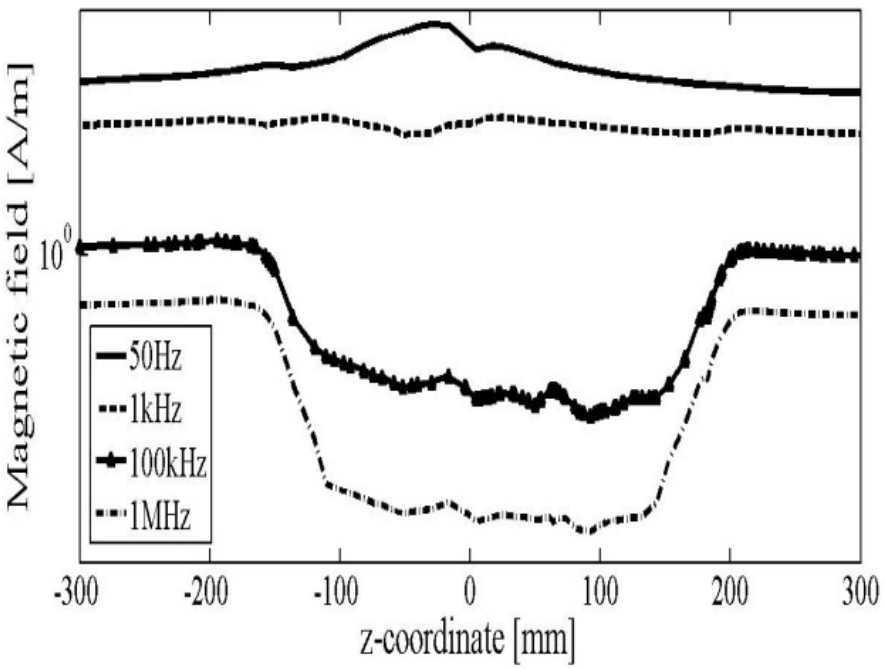


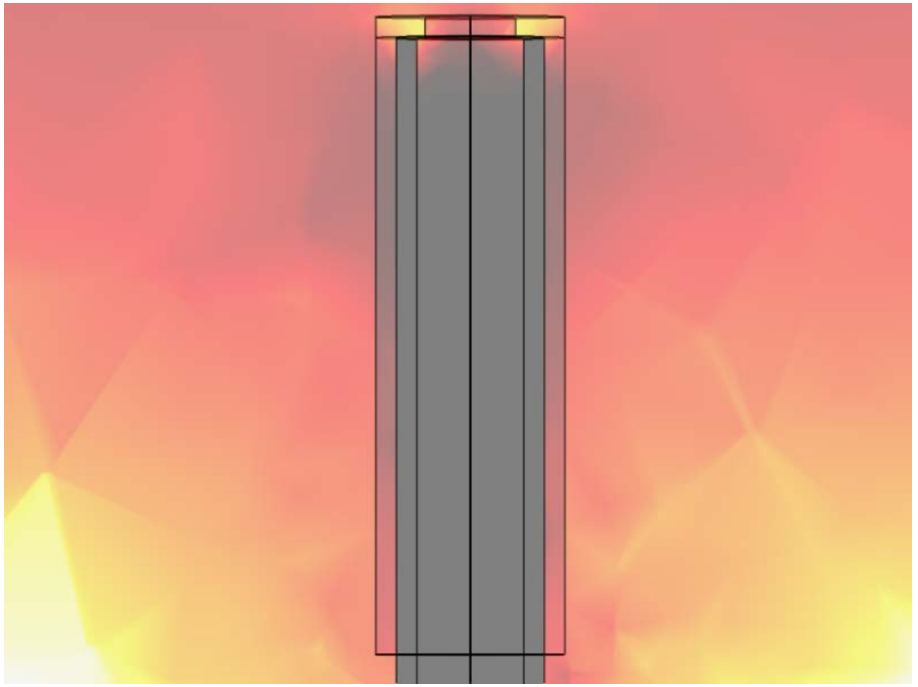
New configuration for the extraction tube



The extraction tube has been modified adding an external Delrin coating. This way, the tube should maintain the shielding capability against the EM field, and at the same time it should be safe from the electric point of view.

Results: new configuration





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Conclusions

The design of the extraction tube of the PFMA-3 device has two constraints: electrical
safety reasons ban the use of metallic materials, as the extraction tube is electrically connected to the upper plate; and, insulating materials seem to be completely permeable to the electromagnetic field produced by the device, resulting in undesired deflection of the electron beam.
Numerical simulations with COMSOL Multiphysics confirmed the initial hypothesis, and helped to find the optimum material configuration for the extraction tube: a steel tube with a Delrin coating.
This design solves the electrical safety problem and at the same time ensures negligible deflections of the electrons.

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Thank you for your attention