# *Optimization of the Radiation Resistant Quadrupole Magnets for the SIS-100 Accelerator of the FAIR Project*

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**Carsten MUEHLE(1), Alexander KALIMOV(2), Hanno LEIBROCK(1), Pavel NALIMOV(2) , Peter ROTTLÄNDER(1)**

(1) GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, GERMANY; (2) St. Petersburg State Polytechnic University, St. Petersburg, RUSSIA.



## *Abstract*

The SIS100 is a charge particle accelerator developed as a part of the challenging international project Facility for Anti-proton and Ion Research (FAIR) taking place in Darmstadt, Germany. The radiation resistant magnets are installed in the extraction section of the SIS100 accelerator and combine high quality of the field distribution, maximum field intensity at the pole tip of more than 1.3 T, and a wide range of the flux density variation. We used a specially developed optimization procedure to optimize 2D and 3D geometry of the magnets. Their application ensured the required field quality ant operational field gradient variation range.


## *Main parameters of the magnet*

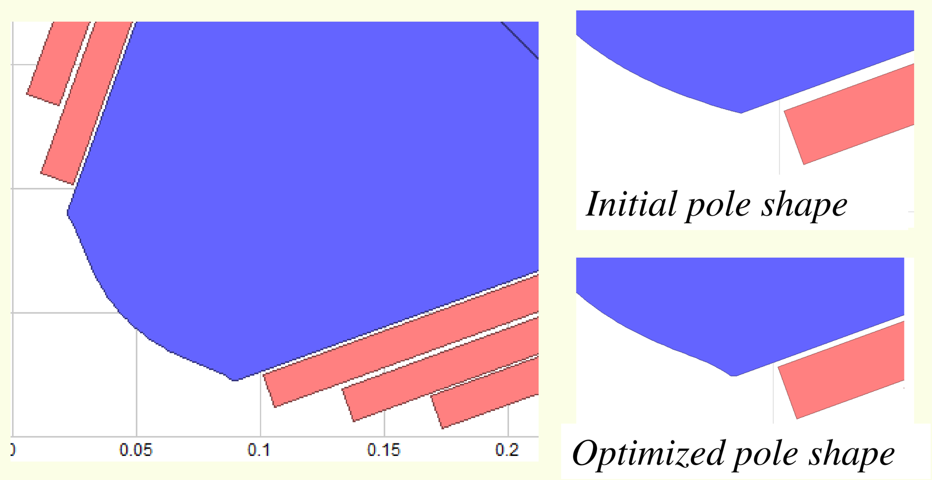
| Parameter | Unit | Value |
|---|---|---|
| Pole tip radius | mm | 66 |
| Magnet length | m | 1.76 |
| Maximum pole tip flux density | T | 1.35 |
| Maximum field gradient | T/m | 20 |
| Good field area radius | mm | 50 |
| Field quality | % | ±0.1 |

## *Main principles of the pole shape optimization*

*Basic steps of the used optimization strategy:*

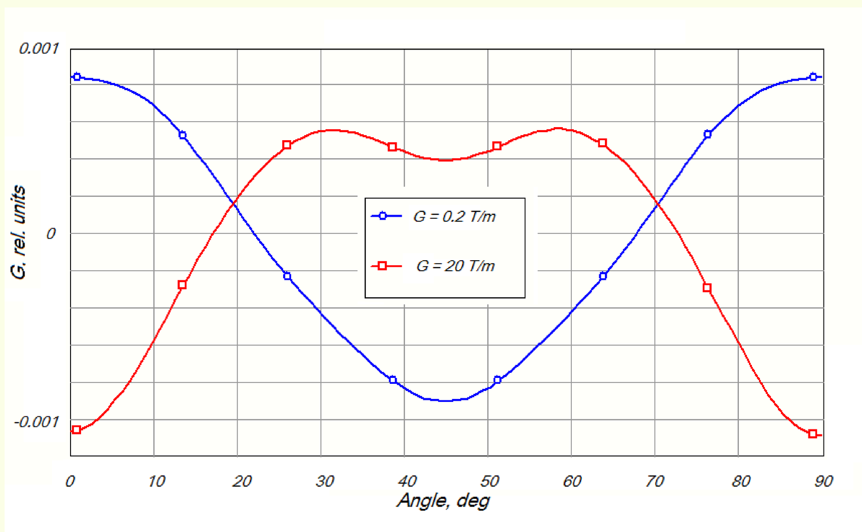
1. The scalar magnetic potential is expanded in the Fourier series inside the magnet aperture with circular border;
2. The pole tip border is described as a constant potential line corresponding to a certain superposition of Fourier harmonics;
3. The coefficients of two expansions are balanced;
4. After several iterations the pole shape expansion gives a field distribution in the aperture with desired set of the magnetic field (potential or flux density) harmonic amplitudes.

## *2D design of the magnet*



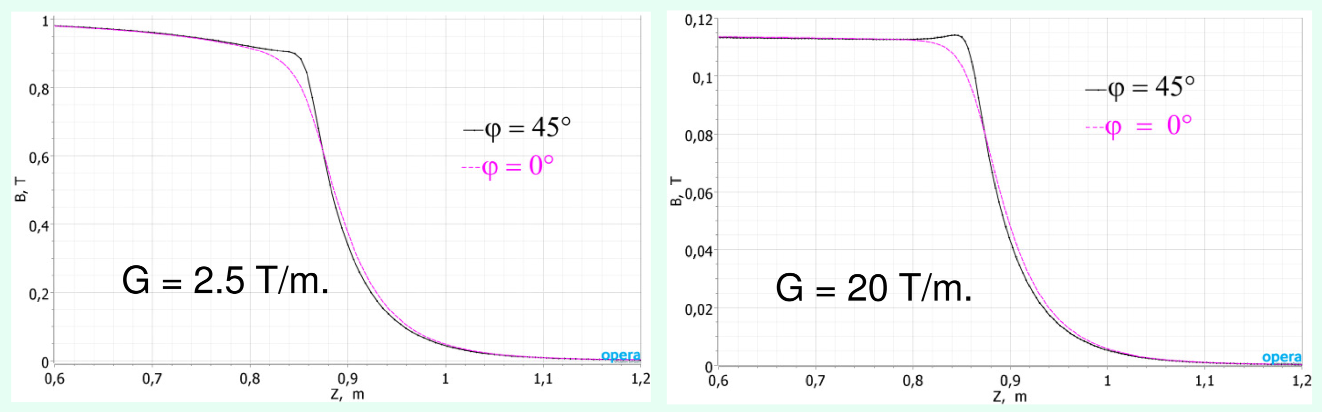

Optimization of the magnet cross section.

To provide required field quality in a wide range of excitation current variation we sacrificed high field quality in low field operation mode to ensure acceptable quality at high field gradients.

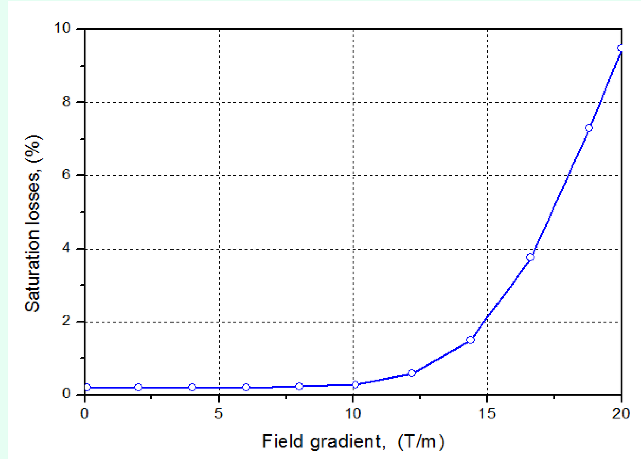



Flux density distribution at the border of the good field area for the low and high flux density in the aperture.

## *3D properties of the magnet*

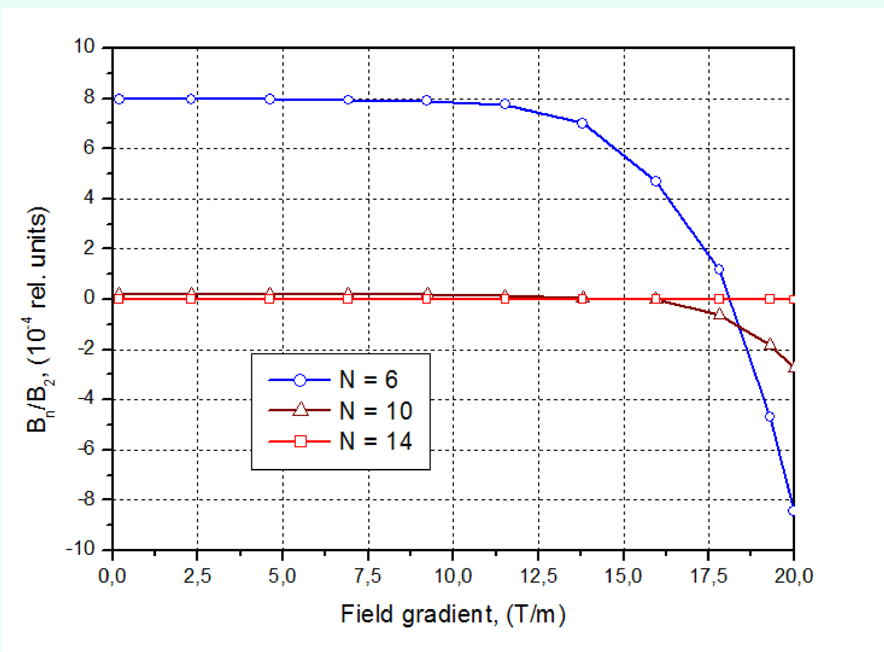



Flux density distribution along different longitudinal lines at the border of the good field area.

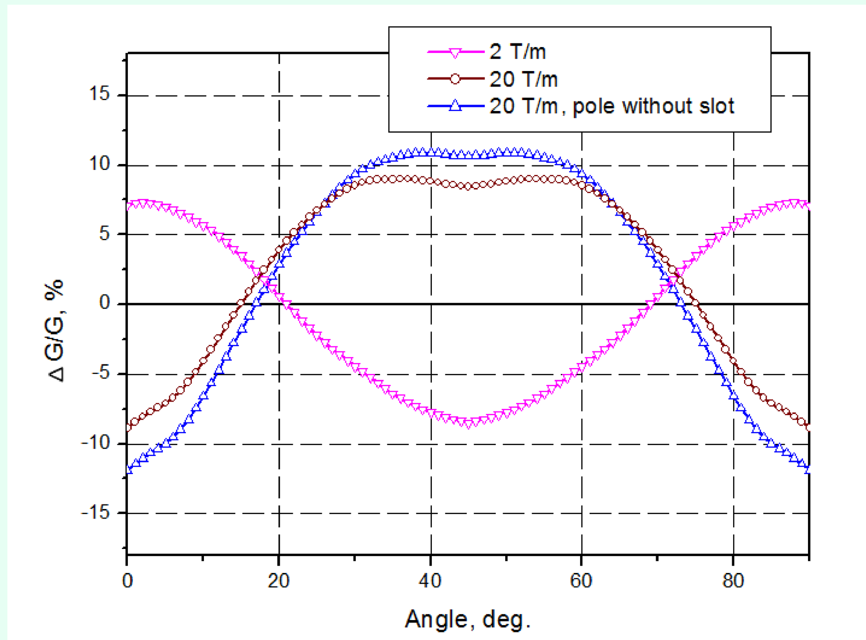



Saturation losses in the magnet.

The longitudinal flux density distributions for different field gradient levels and different positions of the test lines in the aperture are not identical. Nevertheless field integrals corresponding to these dependencies are very close.

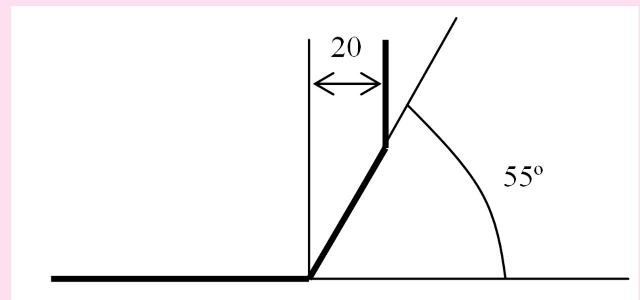



Field harmonics induced by different pole shape harmonics

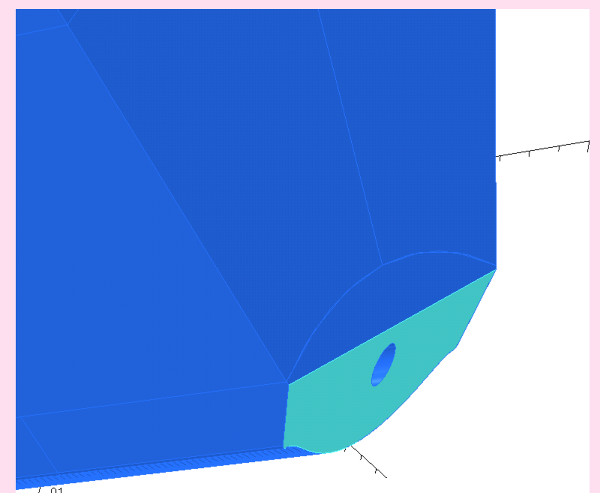



Integral flux density distributions along the border of the good field area.

## *End part of the pole*




End chamfer parameters.



Pole end view.

A round hole in the yoke produces effect of 'negative shimming' in the case of saturated pole and so corrects properly the field distributions at maximum excitation currents.

## *Main results*

- *The optimization procedure for the pole shape definition is modified and applied for the designing radiation resistant quadrupole magnets.*
- *A very wide range of the flux density variation was provided by artificial deterioration of the field quality in low magnetic fields.*
- *The maximum pole tip flux density of 1.35 T with acceptable field quality in the aperture is obtained for the maximum excitation current.*
- *Optimal shape of the end chamfer ensured similar magnetic field distributions in 2D cross section and for 3D design.*