# FIRST IDEAS TOWARDS THE SUPER-CONDUCTING MAGNET DESIGN FOR THE HESR AT FAIR

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*Abstract*

The Forschungszentrum Juelich has taken the leadership of a consortium being responsible for the design of the HESR going to be part of the FAIR project at GSI. The HESR is a 50 Tm storage ring for antiprotons, based on a super-conducting magnet technology. On basis of the RHIC Dipole D0 (3.6 T), the magnet design for the HESR has started recently. One key issue will be a very compact layout because of the rather short magnets (being 1.82 m for the dipoles and 0.5 m for the other magnets). This paper will present first ideas of the magnetic and cryogenic layout, give a status report on the achievements so far and discuss the need and possible solutions for a bent magnet with a radius of curvature of 13.2 m.

## INTRODUCTION

The High-Energy Storage Ring (HESR) is one component of the future international facility for antiproton and Ion research (FAIR) currently under design at GSI Darmstadt [1]. It is dedicated to strong interaction studies with antiprotons in the momentum range from 1.5 to 15 GeV/c. An overview of the HESR design work as a whole is given elsewhere [2] in this proceedings, this article will be dedicated to the superconducting magnet system.

## MAGNET SYSTEM

The magnet system of the HESR will be one of the major initial investments. The number of magnets required for the HESR is rather small (48 dipole magnets) compared to other machines, therefore the technical design process was governed by the search of adequate existing magnets and adopting major design features.

### *Dipole Magnets*

After a careful inspection of several designs, the most suitable magnet turned out to be the RHIC-D0 magnet[3]. It has a beam pipe aperture of 89 mm, a design field strength of 3.46 T and the original magnet has a length of 2.95 m. To use it for the HESR, this has to be reduced to 1.82 m being not a severe modification. The advantage of adopting this existing magnet layout is clear: The magnet design is highly developed, and as it was made build-to-print, blueprints of all components are available. The magnet has a proven history, all kind of performance data can be found and have been measured and excellent expertise is available.

During the design process, a 4 Tesla option was studied. As the RHIC dipoles were designed to have a field of 3.46 T this would require major changes in the magnet design. As the circumference of the whole machine would only change by 7 meters, which is roughly 1 % of the ring, the additional required R & D together with the risks seems not to justify these efforts. It was therefore decided to set the design field to amount 3.6 T, which is above the design field of RHIC, but below the reliable proven achievements.

Nevertheless there is still R & D required on the dipole magnets. The HESR lattice foresees a bending angle of 7.5 degrees in every dipole, leading to a radius of curvature of 13.9 m. Building and testing a magnet with such small radius of curvature (the RHIC dipoles have 220 m) has not been successful up to now. Therefore, one branch of R&D activity is devoted to the design of a bendable dipole magnet (see below).

Table 1: Parameters of the proposed HESR Dipole

| | |
|---|---|
| Number of Magnets | 48 |
| Magnetic length | 1.82 m |
| Beam pipe aperture | 89 mm |
| Coil aperture | 100 mm |
| Maximum field | 3.6 T |
| Minimum field | 0.3 T |
| Ramp rate | 25 mT/s |
| Current at max. field | 5000 A |
| Operating Temperature | 4.25 – 4.5 K |
| Cooling | Forced Flow |
| Cable | Rutherford 30 Strand RHIC Cable |
| Sagitta | 0 mm |

Currently it is planned to have a straight magnet with the beam passing on a curved path. This requires an increased field homogeneity and an improved mathematical representation of the end field. Table 1 summarizes the magnet parameters, fig. 1 shows the results of a ROXIE [4] calculation of a 2-D cross section.

Table 2: Multipole expansion of the HESR dipole magnet ($r_0$=35 mm)

| | |
|---|---|
| B1 | 10000 |
| b3 | 0.069 |
| b5 | 0.098 |
| b7 | -1.022 |
| b9 | -2.24 |
| b11 | -1.34 |

This single shell design contains 5 coil blocks with a total of 40 turns. The coil aperture is 100 mm and symmetric wedges have been used. At a current of 5000 A a magnetic field of 3.6 T is expected, giving a

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load line margin to quench of 24 % at 4.1 K operating temperature. Table 2 gives the relative multipoles calculated at a reference radius of 35 mm.

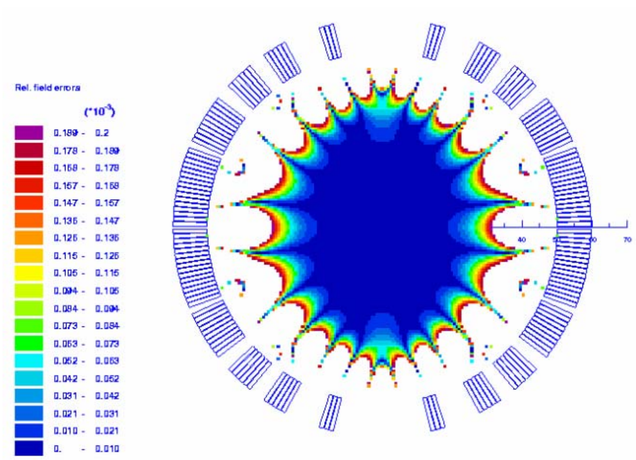


Figure 1: 2-D field quality computation of the HESR Dipole done with ROXIE[4]

### *Quadrupole Magnets*

The beam pipe aperture has been set by beam dynamics calculations, requiring a minimal aperture of 80 mm. Unfortunately there is no RHIC quadrupole or sextupole magnet satisfying this need. Therefore, a new magnetic design is required, but the main features (beside the coil arrangement) will be based on the dipole design.

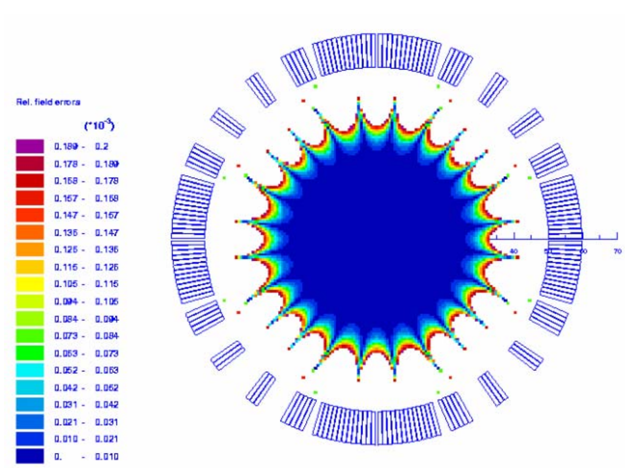


Figure 2: 2-D field quality computation of the HESR quadrupole.

As a first step towards the design, the 2-D coil arrangement has been calculated and optimised (see fig. 2 and tab. 3), aiming towards magnets with only small higher order components.

The design so far consists of 21 turns arranged in 3 blocks. Again, only symmetric wedges have been used. Operated at 5000 A a gradient of 60 T/m is expected, the load-line margin to quench is 32 % assuming a temperature of 4.1 K.

Table 3: Multipole expansion of the HESR quadrupole magnet ($r_0$=35 mm)

| | |
|---|---|
| b2 | 10000 |
| b6 | 0.00 |
| b10 | 0.00 |
| b14 | -4.69 |
| b18 | 1.18 |

## CRYOGENIC ASPECTS

Based on the RHIC magnet design [5], the cryogenic features of the HESR cryostats can be estimated quite accurately even in this early stage. The cooling of the magnet coils will be provided by forced flow cooling with supercritical helium. The temperature increase of the helium according to the heat transfer in the magnets should stay below 0.25 K. The maximum temperature reached in a magnet chain thus should be below 4.5 K.

In contrast to the RHIC cryogenic design, the HESR design tries to avoid the use of a cold compressor. This modified scheme was successfully applied at HERA and the TEVATRON.

Instead of heaving a large mass flow in the supercritical circuit and only few re-coolers, the magnets themselves act like re-coolers. Thus the cooling of the magnets is provided by a forced flow cooling of supercritical helium, while in the same time atmospheric 4 K helium is evaporated, guaranteeing the constant operating temperature.

The 2-phase helium is generated by simply expanding the super-critical helium via a JT-valve, making the layout rather simple. For stability reasons, a pre-cooler adjacent to the first magnet is introduced.

The required cooling of 750 W at 4.5 K is equivalent to approximately 38 g/s of evaporating Helium. Assuming 3 bar pressure for the super-critical helium flow and a temperature of 4.2 K, the liquefaction efficiency of the JT- valve is expected to be 75 %. Therefore, a 50 g/s mass flow of 3 bar, 4.2 K super-critical Helium is expected to be sufficient.

To save longitudinal space the HESR will consist of two cryostats only, each featuring a complete 180 degree arc. The cold mass will be segmented to allow easy assembly. The grade of segmentation is currently under investigation. The cryo-module is equipped with a shield cooling at an intermediate temperature of around 50-60 K. This heat shield provides also the cooling for the current leads.

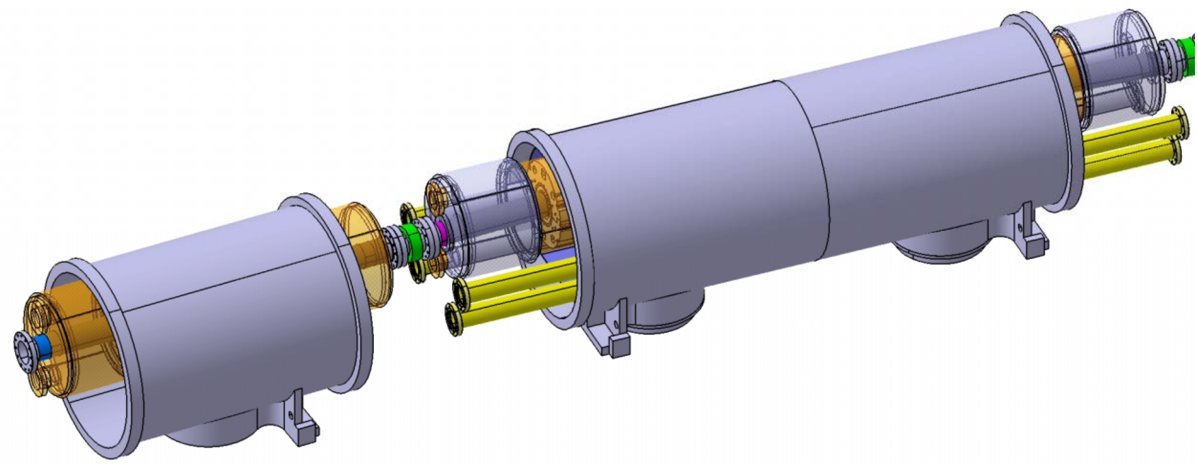

Figure 3: Three-dimensional view of a dipole and the adjacent quadrupole magnet of the HESR ring.

## INTER-MAGNET DISTANCE

Following suggestions by our collaborators at BNL and CERN, a magnet to magnet distance of 1 meter was assumed. As the magnets themselves are rather short, this assumed distance contributes significantly to the circumference of the HESR ring. Therefore, the three-dimensional magnet construction process has started recently to evaluate the possibility of shortening some inter-magnet distances (for example between a dipole and the adjacent quadrupole). This process started by transferring the 2 D drawings into a fully 3-dimensional model. A first impression of the geometric situation is given in fig 3.

## STATUS AND OUTLOOK

So far the two dimensional magnetic design has been finished. As a next step the end field region has to be designed and the iron saturation has to be modelled. First calculations have been started recently. The magnet design of the quadrupole and sextupole magnets has to go on including mechanical and cryogenic design aspects.

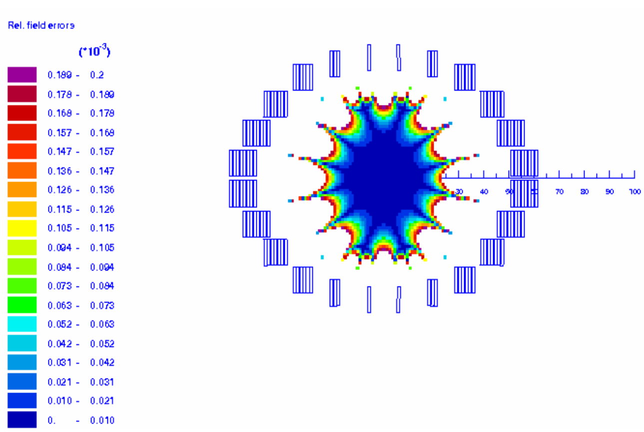


Figure 4: 2-D field quality computation of an alternative coil arrangement, investigated to design a curved dipole magnet

Beside this straight forward approach, some demanding R&D activities have been started:

- As the beam travels on a curved path inside the dipole (which in the current design is straight) leads to certain disadvantages: The effective beam pipe aperture is reduced and the impact of higher order field components is more severe. Curving the magnet according to the beam path curvature (13.9 m) would be advantageous. For this reason several ideas are investigated to estimate the possibility and the perspectives of a highly curved dipole magnet. One possible coil arrangement is shown in fig. 4.
- The beam dynamics in the HESR request strong sextupole magnets. Currently, a strength of 460 T/m$^2$ is required which could be reduced dramatically if one is able to place the sextupoles in places of high betatron amplitudes. This leads directly to a combined function magnet (quadrupole/ sextupole magnet). First magnetic field calculations have been performed- a carefull insight will follow.

## ACKNOWLEDGEMENT

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