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Dipole CR FAIR

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INTRODUCTION

The design of CR dipole magnets (24 + 2 pieces) for the FAIR (Fig. 1) project in Germany began in 2014 at BINP. CR is a special storage ring where the main emphasis is placed on efficient stochastic pre-cooling of intense beams of stable ions, rare isotopes or antiprotons.

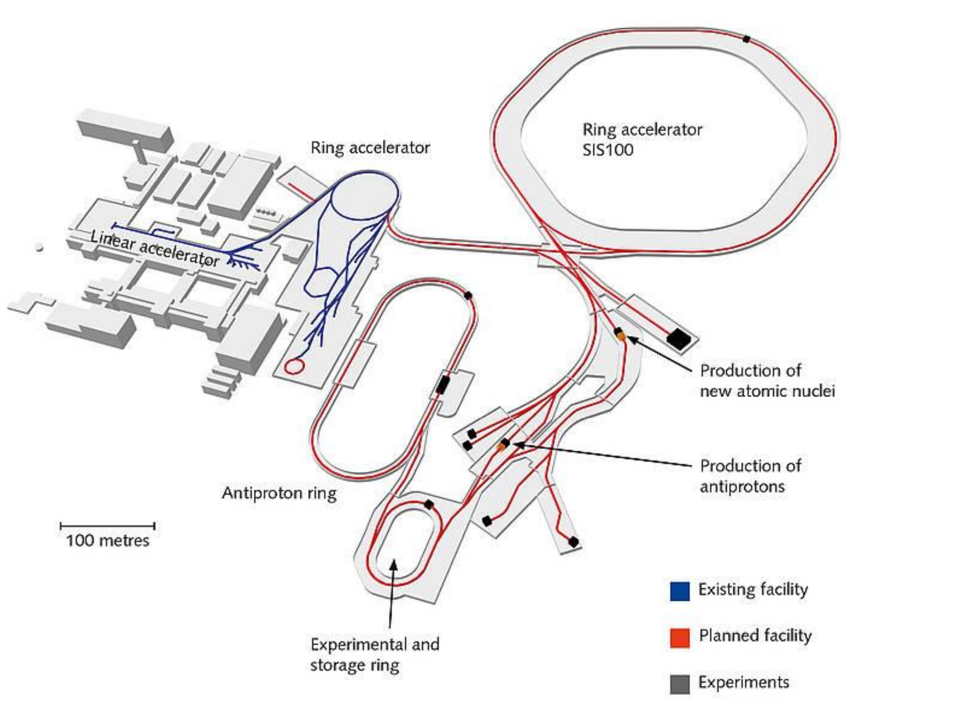


Fig. 1. Drawing of the current GSI complex (blue) and the future FAIR project (red).

This type of magnet is iron-based electromagnet with straight pole, sector form is realized by cutting ends. The maximum field value is 1.6 T. The integrated over the length of the magnet field quality as a function of radius is dB·l/B·l = $\pm 1\cdot 10^{-4}$ with 190 mm good field region as required from the beam dynamics simulations. This challenging field quality is necessary mainly for precise experiments with ion beam in ISO regime. Below 1.6 T the value dB·l/B·l can be higher with a linear approximation up to $\pm 2.5\cdot 10^{-4}$ at the field level of 0.8 T.

The first prototype has been manufactured at the end of 2020. Here we describe features of the dipole, 3D calculations and measurements of magnetic field.

MAIN PARAMETERS OF THE DIPOLE CR

Figure 2 shows the cross section of the CR dipole.

Fig. 2. Cross-section of a dipole CR magnet.

This magnet has a straight yoke .The shape of the sector is realized by the cut ends of the poles. The cross section of the coils is rectangular. Table 1 shows the main characteristic data of the CR FAIR dipole [1].

Table 1.
Characteristic data of the CR FAIR dipole

Rotation angle, α	15˚
Turning radius, R_0	8.125 m
Range of working fields, B_0	0.8÷1.6 T
Maximum integral of the magnetic field, I_0	3.403 T×m
Working area	380×140 mm^2
Air gap size	170 mm
Homogeneity of the integral of the magnetic field (in the working area) B=1.6 T	$\pm 1\cdot 10^{-4}$
Homogeneity of the integral of the magnetic field (in the working area) B=0.8 T	$\pm 2.5\cdot 10^{-4}$
Supply current	1421 A
Number of turns	176
Effective magnetic length	2.153 m
Yoke length	2.121 m
Magnet total length (with coils)	2.690 m
Iron weight	53.54 t
Coil weight	3.783 t
Total mass of the dipole (upper limit)	59.8 t
Loss	126 kW

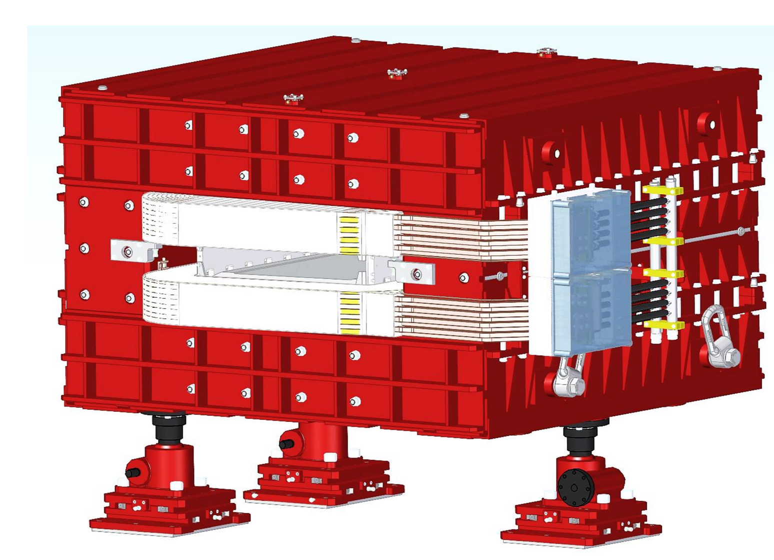
All 24 dipoles in the storage ring will be connected in series. The required uniformity of the integral of the magnetic field in a good field area should be:

$$\delta = \frac{\int (By_{measured} - By_{theory})dl}{By_{center}L_{eff}}$$

where $By_{measured}$ is measurement of the field along the trajectory of particles, By_{theory} is the theoretical field of a sector dipole with a turning radius of 8125 mm and a turning angle of 15 °, By_{center} is the measured field in the center. L_{eff} is the effective magnetic length of the dipole along the central path. Integration is carried out along the trajectories of particle motion. The length l varies depending on the radial position of the beam trajectory inside the sector magnet [2].

Figures 3 a and b show 3D models of a CR magnet.

a.



b.

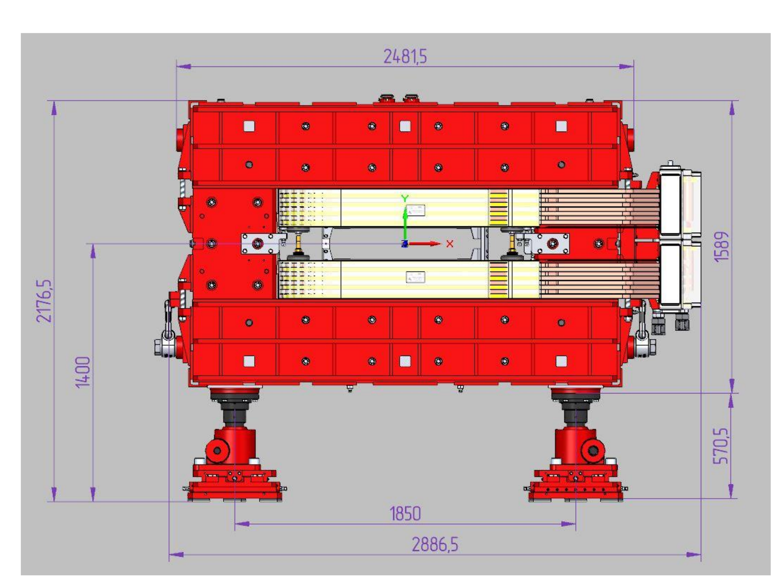


Fig. 3. a, b - 3D model of a dipole magnet CR

MEASUREMENTS OF THE CR FAIR DIPOLE MAGNET

The first CR dipole magnet was manufactured at the end of 2020. A number of measurements of the first ready-made dipole magnet CR was carried out at the stand of magnetic measurements of the BINP SB RAS (Fig. 4). The measurements were carried out at half current (I = 750 A), since the power supply available at the stand at the moment does not allow raising the value to I = 1497 A. Several variants of the pole profile were considered: without chamfer, with chamfers № 1 and № 3 (Fig. 5).

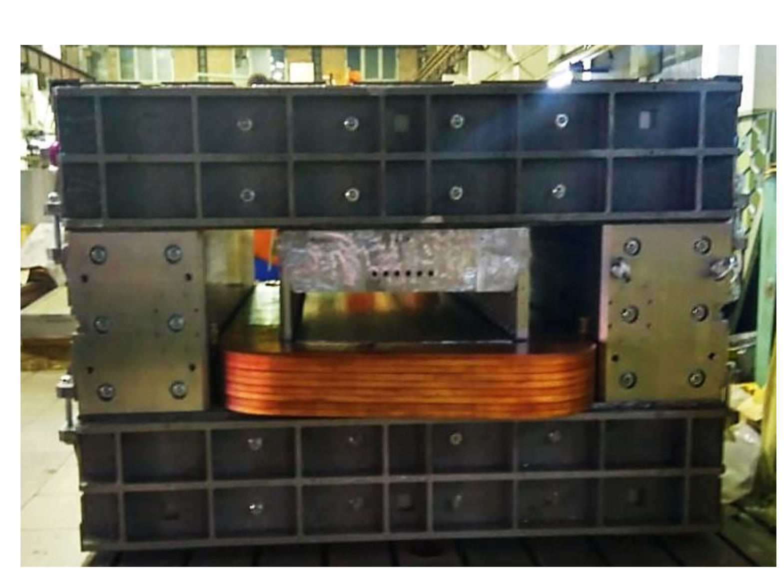


Fig. 4. Appearance of the assembled CR dipole magnet.

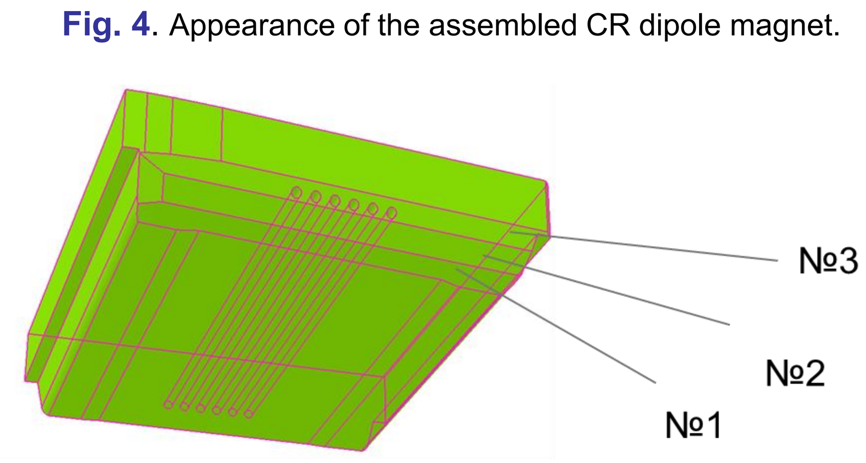


Fig. 5. Quarter pole chamfered dipole.

To obtain the data, we used a carriage with dimensions 164 × 240 mm^2, 14 mm high, with 17 Hall sensors spaced from each other with a step of 9.5 mm (Fig. 6). The carriage was placed on a plate, which was placed on rails specially prepared for this magnet and stretched along the length of the magnet (Fig. 7 a, b). The measurements were carried out in several planes: the carriage along the plate was shifted from the extreme left to the right positions; during processing, the obtained data were stitched together.

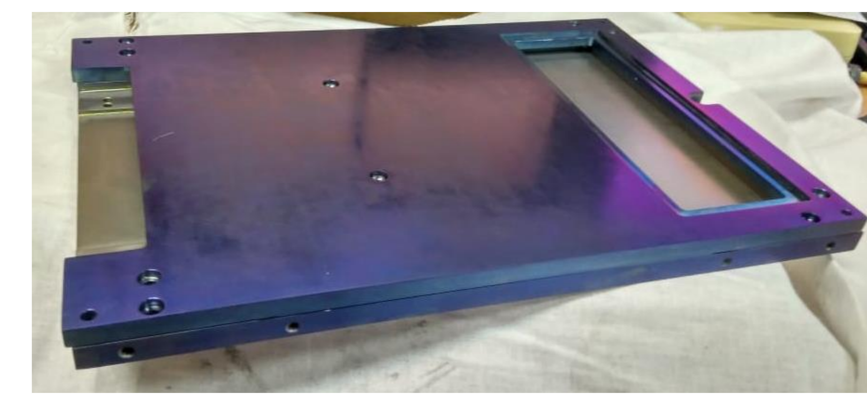


Fig. 6. Carriage with 17 Hall sensors

a.

b.

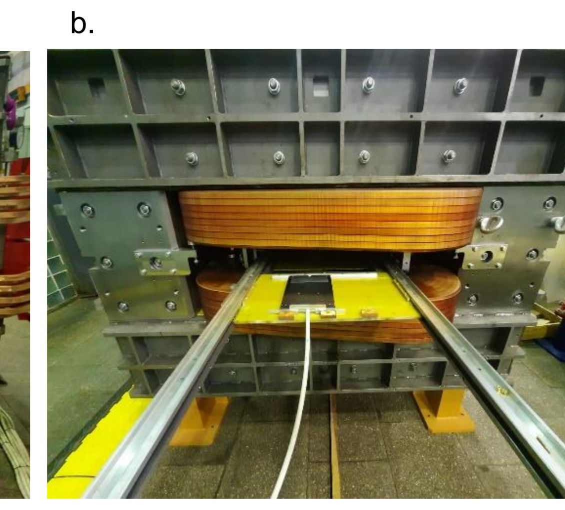


Fig. 7. a, b - CR dipole precision measurement system based on carriage with Hall sensors, plate and rail

Figures 8, 9 and table 2, show the obtained values of the field integral, integral homogeneity and field quality in comparison with the calculations made earlier in the program Opera at half current.

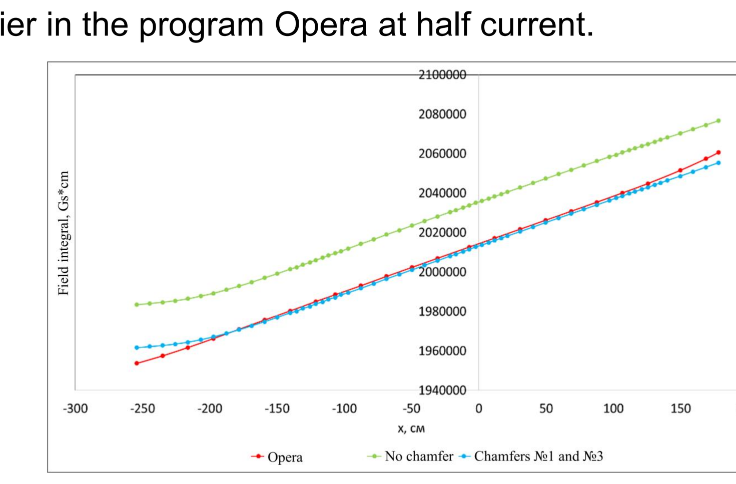
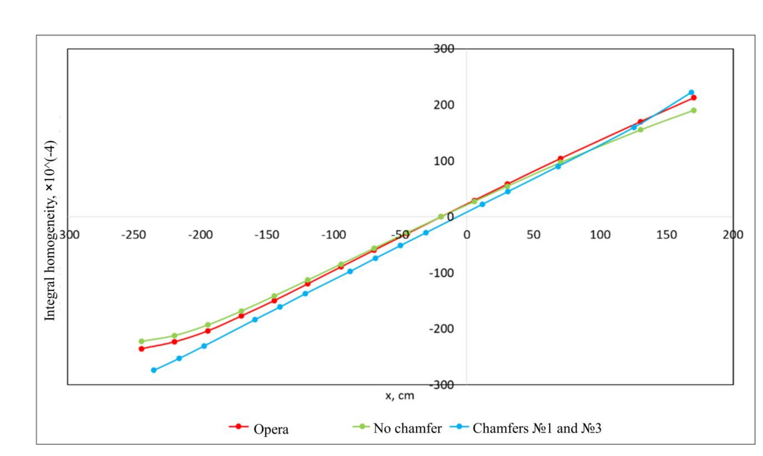
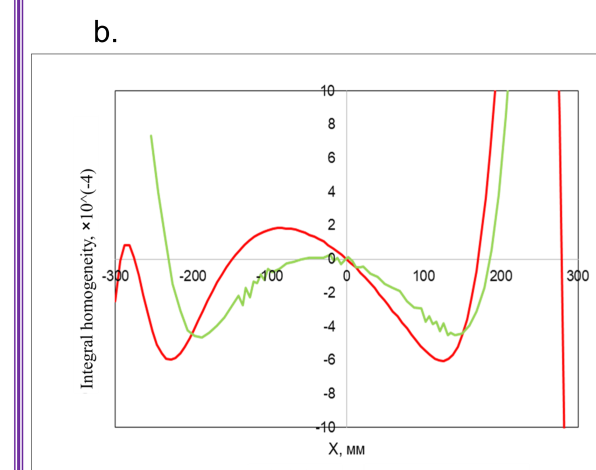


Fig. 8 Field integral plot at I = 750 A

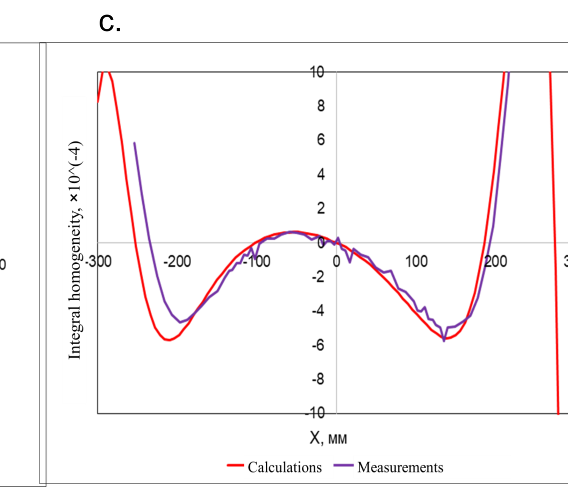
a.



b.



c.



d.

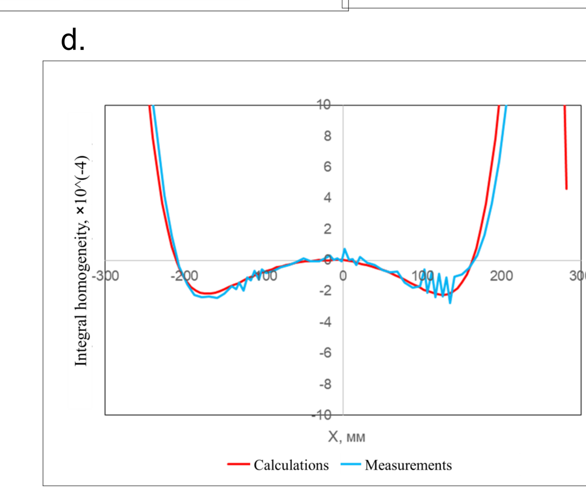


Fig. 9 A plot of the integral homogeneity at I = 750 A: a. no gradient deduction (calculations, no chamfer and final); b. with the deduction of the gradient (calculation and version without chamfer); c. calculation and variant with chamfer № 1; d. calculation and variant with chamfers № 1 and № 3

Table 2.
The obtained values of the CR FAIR dipole in comparison with the calculated ones at I = 750 A

	B in the center, G	Field integral,G*cm	δmax, ×10^(-4)	δmin, ×10^(-4)
Opera				
Without chamfer	9316.568	2084510	1.863071721	-6.043616834
Chamfer №1	9316.74	2043918	0.637129927	-5.606226406
Chamfers №1 and №3	9316.98	2022179	0.785455103	-2.21800595
Measurements				
Without chamfer	9276.901	2076194	0.247310774	-4.536204065
Chamfer №1	9280.429	1997787	0.626216124	-5.735716598
Chamfers №1 and №3	9280.118	2012802	0.746499898	-2.766242263

REFERENCES

[1] A.Starostenko, et al., Parameter table for the laminated straight CR-Dipole. Novosibirsk (2016)
[2] H. Leibrock, et al., Detailed Specifications of pbar and CR Dipoles. GSI, Darmstadt (2014)