GEOMETRY OF QUADRUPOLE MAGNET FOR THE U-3.5 ACCELERATOR IN THE OMEGA PROJECT

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Abstract

Accelerating complex of intensive beams of charged particles (project Omega) is being developed at IHEP. The main part of this complex is 3.5 GeV ring accelerator. The basic parameters of the quadrupole magnet for this ring are: 5.564 T/m central gradient in the 102.9 mm radius of the "good field"; the injection gradient is 1.222 T/m; the gradient ramp rate is 334 T/m/s. Different profiles of the poles were considered for the purpose of selecting the most optimal 2D and 3D geometries of the magnet. The basic parameters of the optimal geometries are presented.

INTRODUCTION

IHEP (Protvino, Russia) is developing an accelerating complex of charged particles of high intensity (project OMEGA [1]). This complex is designed to create megawatt power beams. The OMEGA project consists of a new cascade of high-intensity accelerators, which includes a linear accelerator of H^- ions and protons with energy of 400 MeV, followed by a rapid cycling synchrotron with energy of 3.5 GeV. Basic parameters and preliminary optimization of the geometry of the main dipole were presented in [2]. Further the 2D and 3D geometry optimization for the main quadrupole in the 3.5 GeV ring is considered.

THE OMEGA PROJECT

The OMEGA project involves the construction of Accelerator Complex for Intense Hadron Beams. This multipurpose mega-project is being discussed at IHEP [1, 3] and is shown in Fig. 1. The proposal outlines a long-term plan to develop the accelerator and experimental facilities on the IHEP grounds for fixed-target research within and beyond the scopes of elementary particle physics. The base-line design foresees construction of a pulsed facility that will exceed 1 MW of proton beam average power, will have a pulse rate of 25 Hz, pulse width ≤ 1.5 µs, clear staging, site-specific integration and upgraded plans, and reduced technical risk (through use of proven technologies). The facility comprises of a non-superconducting 400 MeV linear accelerator LU-400 followed by a 3.5 GeV rapid cycled proton synchrotron (RC PS) U-3.5. At a later stage, the U-3.5 is engaged as a new injector to the existing U-70 PS, or its updated successor. A particular stage of the project addresses either applied or fundamental science (Fig. 1). Stage-1 assumes construction of a short-pulse accelerator-driven 1 MW neutron source for applied research (material and life sciences).

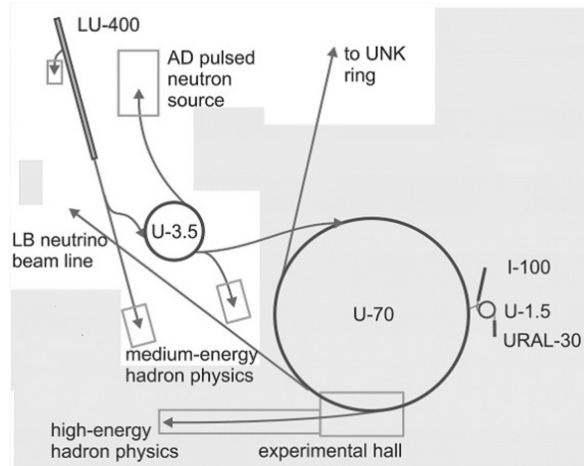

Figure 1: Tentative layout of the OMEGA facility.

Table 1: Specifications of U-3.5 (Project).

Specification	Value
Energy (kinetic), E, GeV:	0.4–3.5
Orbit length, L, m:	445.11
Magnetic rigidity, $B\rho$, T·m:	3.18–14.47
Compaction factor, α:	0.0173
Transition gamma, γ_t:	7.60
Intensity, N, ppp:	$7.5\cdot10^{13}$
Ramping time, t_R, s:	0.020
Cycle period, T, s:	0.040
Average beam current, µA:	300
Beam power, P, MW:	>1
RF harmonic, h:	9
Radio frequency, f_{RF}, MHz:	4.322–5.925
Net RF voltage, V_{RF}, kV/turn:	720
Lattice period:	FODO (90°)
No. of periods:	36
No. of super periods:	6
Betatron tune (H/V):	9.15/7.20

The goal for the next stage-2 is to develop the second direction of fast extraction from the U-3.5 to feed a new experimental zone dedicated to intense-beam medium-energy hadron physics. At a later stage the U-3.5 is engaged as a new injector to the existing U-70 PS, or its updated successor. To this end, the orbit length and RF harmonic number of the U-3.5 amount to 3/10 of those in the U-70. It facilitates, at most, a 3-train bunch-to-bucket transfer from U-3.5 to the U-70 ring thus yielding a beam pattern 3 × (9 filled + 1 empty) bunches there. Apart from the lower-energy mode of a 3.5 GeV proton beam stretcher delivering slow spills, the U-70 will accelerate

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intense beam to higher energies. The core of the OMEGA Project constitutes a new 3.5 GeV rapid cycled proton synchrotron U-3.5, ramped at 25 Hz (sinusoidal) and yielding $7.5 \cdot 10^{13}$ ppp. Other specifications of the machine are listed in Table 1.

REQUIREMENTS TO QUADRUPOLE

The RCS quadrupole of U-3.5 is characterized:

- The central gradient is 5.564 T/m;
- The injection gradient is 1.222 T/m;
- The gradient ramp rate is 334 T/m/s;
- The repetition field frequency f is 25 Hz;
- The radius of the good field region is 102.8 mm;
- Integral field multipole b_6^{int} must be less than $|2| \times 10^{-4}$.

MATERIALS

Current-carrying elements should be developed so that reduction of the large dynamic losses in the cable is taken into account, as well as possibility of manufacturing the cable or its acquisition. For further calculations we selected the cable, which was designed for the J-PARC and SCNS projects [4, 5]. It was made of 33 aluminum wires of 3.2 mm diameter, which were wound on a 10 mm diameter tube for water cooling. Then the bare winding is formed into a square with a 20 mm side. The coils in all types of magnets consist of $N = 16$ turns. The total current $I_T = NI_{op}$ (I_{op} is the operating current) is equal to 36.38 kA. M250-50 steel [6] is selected for an iron yoke. It is characterized: the maximal magnetic permeability is >7500; the coercive force is 33 A/m; the saturation magnetization is 2.05 T; the sheets are 0.5 mm thick.

2D GEOMETRY OPTIMIZATION

The magnet cross section is shown in Fig. 2. The main task of optimization is to minimize the overall dimensions of the cross section keeping the low order multipoles within the required limits. In the magnet design the computer code MULTIC [7] was used. The field quality in the aperture is formed by poles of the magnet, the profile of which can be made either by a hyperbola, or a circular arc. Two parameters can be used for goptimization: the pole width, which is defined by horizontal coordinate of the bottom pole corner x_p, and a thickness of the iron yoke ΔFe. Note that the x_p influences both on the multipole b_6 and the normalized gradient b_2, while ΔFe mainly affects only on b_2. The normalization is performed on a central gradient at infinite permeability in the iron yoke. Fig. 3 and Fig. 4 present dependences of normalized gradient and multipole b_6 on coordinate x_p for two profiles of the pole and two radii of aperture r_{ap}. For each curve in Fig. 4 there is an optimal $x_p = X_{opt}$, at which $b_6 = 0$ and it has a linear dependence on r_{ap} within [105 mm, 130 mm]:

$$X_{opt} = 0.31413 + 1.52543\, r_{ap} \text{ (hyperbola)};$$
$$X_{opt} = -0.01305 + 1.52377\, r_{ap} \text{ (arc)}.$$

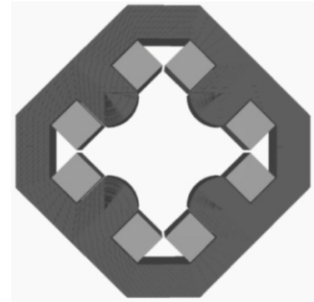

Figure 2: General view of the quadrupole magnet.

Results, presented in Fig. 3 and Fig. 4, were calculated at $\Delta Fe = 200$ mm. Dependence of normalized gradient b_2 on ΔFe is shown in Fig. 5. Taking into account that the yoke should have holes and cutouts for mounting, it is necessary to choose the thickness not less than 140 mm.

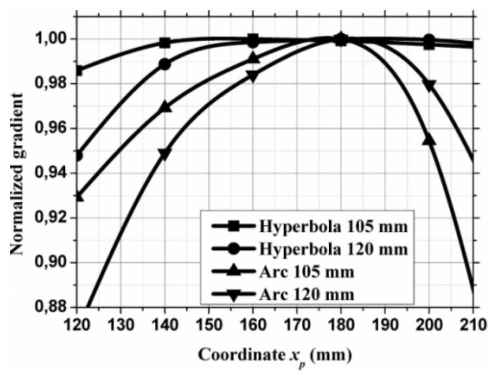

Figure 3: Normalized gradient versus coordinate x_p.

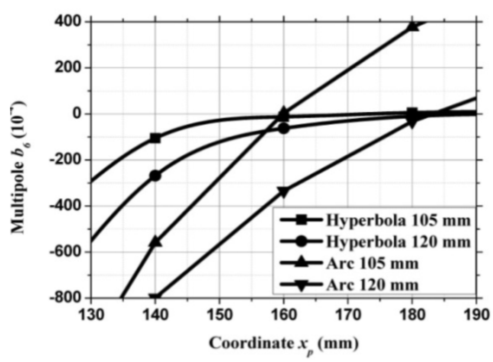

Figure 4: Multipole b_6 gradient versus coordinate x_p.

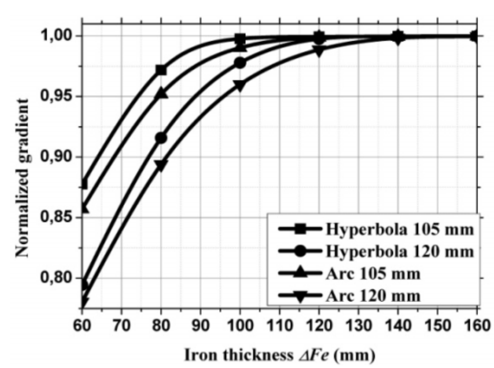

Figure 5: Normalized gradient versus iron thickness.

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3D GEOMETRY OPTIMIZATION

The general view of the magnet is shown in Fig. 6.

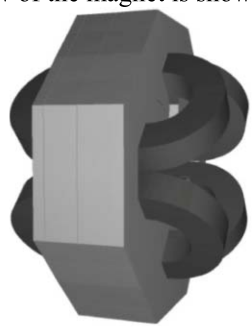

Figure 6: General view of the magnet.

Further we will consider only the 120 mm aperture. The final its diameter will be made after the determination process sizes, in particular, a vacuum chamber. Since the magnet is too short, then the integral multipole b_6^{int} will be suppressed by an appropriate choice of the central multipole b_6 using parameter $x_p = X_{opt}$, at which $b_6^{int} = 0$. Fig. 7 – Fig. 10 present dependences of X_{opt}, the normalized gradient, lower central multipoles and the normalized effective length $L_{eff}^{(n)}$ on a geometric length L_g of the magnet. Here $L_{eff}^{(n)} = L_{eff}/L_g$, L_{eff} is a real effective length of the magnet. The integral multipole b_{10}^{int} is lesser 2×10^{-4} for the hyperbola and changes from -18×10^{-4} to -30×10^{-4} for the arc versus the magnet length. Fig. 8 shows that the pole in the arc form has significantly smaller geometric length, which can chose in 700 mm, as well as overall dimensions, while a minimum length with a hyperbolic pole is at least 1800 mm.

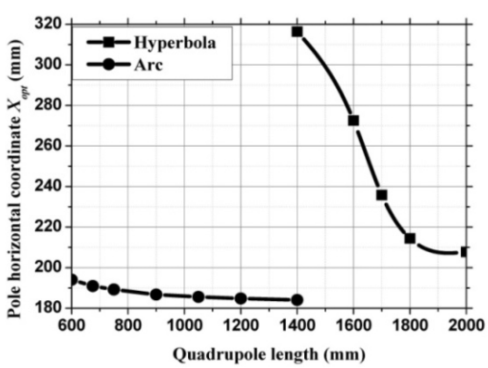

Fig. 7: Dependences of X_{opt} on a geometric length.

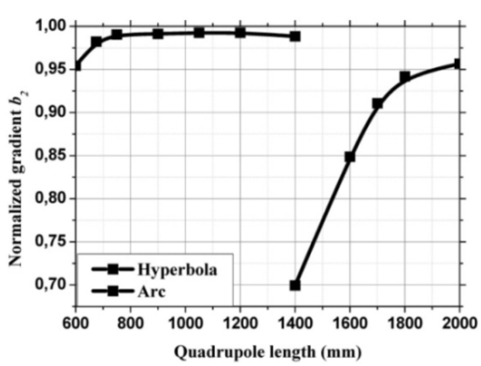

Figure 8: Dependences of the central normalized gradient on a geometric length.

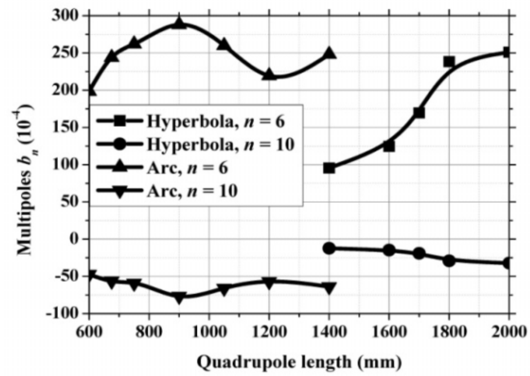

Figure 9: Dependences of the central lower multipoles on a geometric length of the magnet.

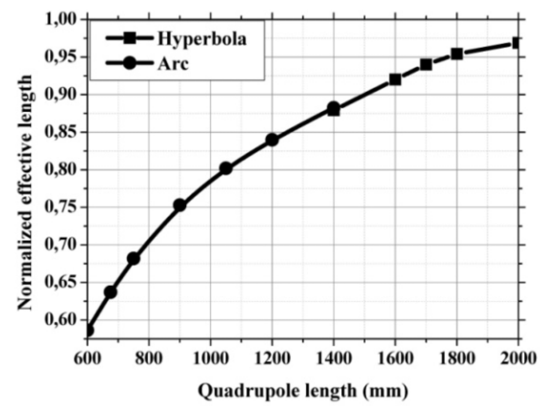

Figure 10: Dependences of the normalized effective length on a geometric length of the magnet.

CONCLUSION

Comparative characteristics of two types of the poles have been considered. Based on these calculations the final 2D and 3D geometries will be performed after formulation of the requirements on the field and integral field values as well as other technological and geometric parameters such as a beam tube, vacuum chamber etc.

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