DIPOLE MAGNET OF SYNCHROTRON SOURCE FOR NATIONAL SYNCHROTRON CENTRE OF UKRAINE

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The paper contains the revised design of a dipole magnet for a synchrotron radiation source. Usage of such a magnet allows to reach the energy of electrons in a ring up to 1.2 GeV. In paper the result of simulation of a magnet for all modes of operations of a source are shown. The proposed variant of the dipole magnet considerably raises parameters of the synchrotron radiation source.
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1 INTRODUCTION

In 1994 in NSC KIPT the design of a 800 MeV synchrotron radiation source for Ukrainian Synchrotron Center was developed. To realize this design in 6 years, it is expedient to revise some physical properties of the facility. With this purpose the upgrading of the design of a dipole magnet is conducted. ***The basic purpose of this upgrading is the raise of a maximum energy of a synchrotron ring***.

2 MAIN SPECIFICATIONS OF A DIPOLE MAGNET

The main specifications of a dipole magnet are listed in Table 1. In this table the parameters of a former dipole magnet are given too.

Table 1. Comparison of demanded parameters of former and updated dipole magnets

Parameter	ISI-800M	ISI-800
Bending radius, m	2.3	2.005
Eff. Angular Dim.,deg.	30°	30°
Field nom.(***B***), T.	1.45	1.34
Max dev., $\Delta B/B$	$1\cdot10^{-4}$	$1\cdot10^{-4}$
Gradient, T/m	0.0208	0.03
Field index	3.3	3
Work area mm×mm	40×20	30×20
Gap, mm	36	36
Sexst. strength (no more), T/м	3	
Oct. strength (no more), T/m^2	30	
Gradient dev. in work area, %	±1	±1
Number of magnet in proj.	12	12

As it is seen from presented data that updating of a magnet is reduced to expansion of an area of a good field, modification of the field index and increasing the bending radius of the magnet. As a matter of fact, it is the new design. Let's consider the basic calculated parameters for a dipole magnet.

3 FIELD OF A DIPOLE MAGNET IN A REGULAR PART

Concerning a high bending radius allows to use a flat 2-D model for calculation of the pole shape of magnet. For calculation both numerical methods [1, 2], and analytical ones were used [3]. The basic geometrical parameters of the magnet were selected so to minimize a field in a yoke. Fig. 1 illustrates the cross- section of the magnet.

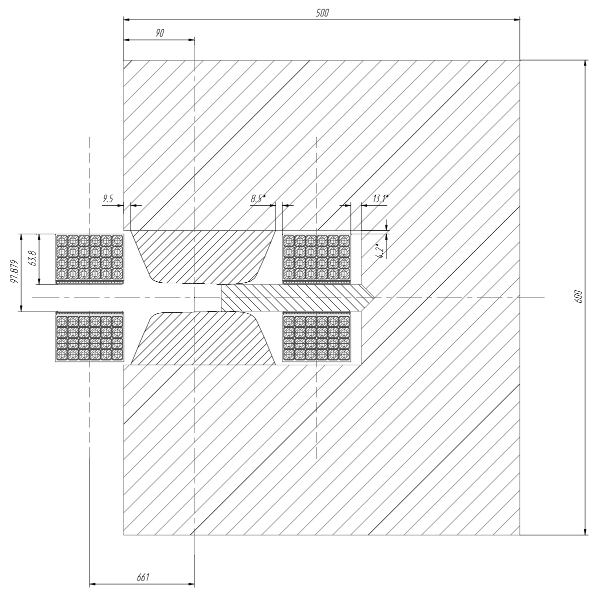

Fig. 1. Cross section of dipole magnet.

The pole shape was determined, considering the requirements:

- ·at a rated energy of nonlinearity fields should be minimum;
- ·the field on a pole should not exceed a field on an equilibrium orbit more than by 10 %.

The cross-section of a pole shape is illustrated in Fig. 2.

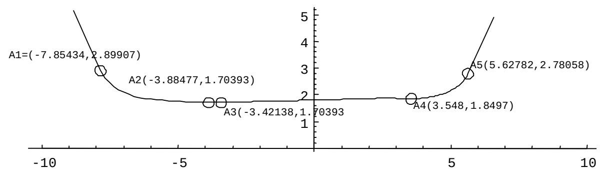

Fig. 2. Pole shape in a regular part of the magnet.

For calculation of the pole shape, 6 areas were selected. Areas]-∞, A1], [A5, ∞[are the bevels of a pole. Their inclination angle (of ±66°) was selected so that the field decreases from a surface of a pole inward a yoke. The shape of shims (areas [A1, A2], [A4, A5]) was selected so that the field on them did not exceed a certain magnitude (see Fig. 3). The total field on a pole depends on the product of the contributions of fields of different areas (see Fig. 4).

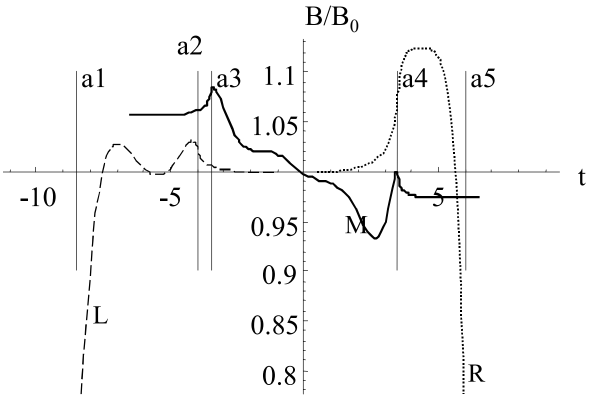

Fig. 3. Contributions of different areas of a pole in the field.

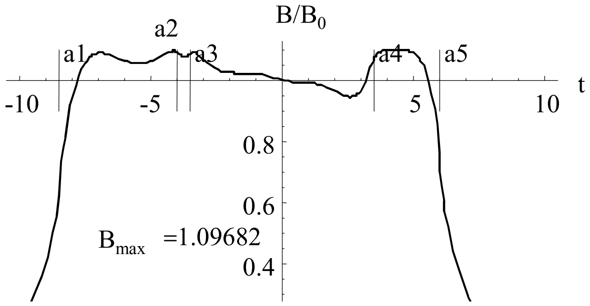

Fig. 4. Total field on the pole.

So, for the left shim [A1, A2] (curve L in Fig. 3) the field should be less, than for the right one [A4, A5] (curve R in a Fig. 3), because the resultant field is shaped with considering a field of a medial part [A3, A4] (curve of M in a Fig. 3). The shapes of the corresponding pieces are selected so that on the left-hand and right-hand shims the field was equal and did not exceed a field at centre of a magnet more than on 10%.

On a pole the horizontal segment [A2, A3] was provided intended for a stay of poles on the spacer of a gauged thickness. It is necessary for preventing a modification of a gap under an operating radiation-pressure forces.

The shape of the segment [A3, A4] was determined so that with allowing for the shape of all above mentioned segments, the field in a working area satisfies the requirements illustrated in Table 1. In Fig. 5 the distribution of the gradient, normalized on the field for different values of the field is illustrated. In Fig. 5 it is seen, that the minimum of nonlinearities is reached in fields, corresponding to the energy 1.1-1.16 GeV. The characteristics of a field of such anideal magnet are shown in Table 2 and are illustrated by Fig. 6-Fig. 9.

However the real magnet is produced from a material, the permeability of which can differ from a permeability, which one was taken into consideration in our calculations. Assembly and manufacture of poles also are yielded with a certain exactitude. Therefore the influence at any rate of enumerated factors should be estimated.

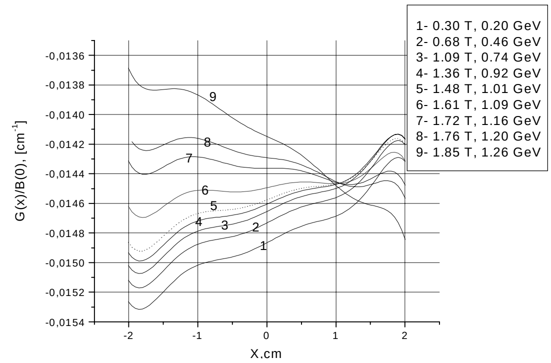

Fig. 5. Radial distribution of the normalized gradient at different field values.

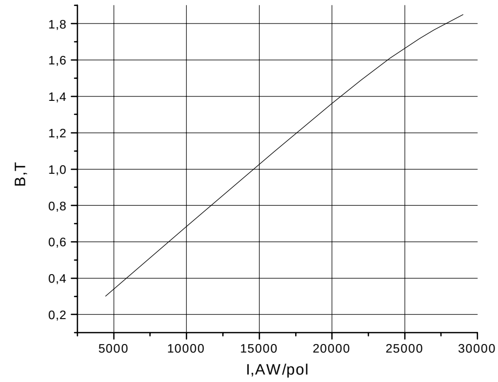

Fig. 6. A magnetization curve of a magnet.

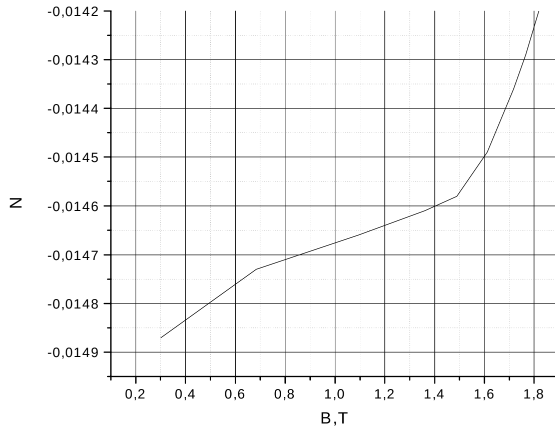

Fig. 7. Dependence of the field index on a stable orbit.

Table 2. Physical properties of a calculated magnet

E, GeV	I, кAW/pol	B, T	G_0/B_0, cm^{-1}	S_0/B_0, cm^{-2}	S_0/B_0, cm^{-3}	N	N/N_0-1
0.20	4.4	0.3	-0.01487	$2.4\cdot10^{-4}$	$8.7\cdot10^{-5}$	-3.42	-0.04
0.46	10.	0.7	-0.01473	$2.4\cdot10^{-4}$	$8.5\cdot10^{-5}$	-3.39	-0.03
0.74	16.	1.1	-0.01466	$2.2\cdot10^{-4}$	$8.1\cdot10^{-5}$	-3.37	-0.02
0.92	20.	1.4	-0.01461	$2.0\cdot10^{-4}$	$7.6\cdot10^{-5}$	-3.36	-0.02
1.01	22.	1.5	-0.01458	$1.8\cdot10^{-4}$	$7.2\cdot10^{-5}$	-3.35	-0.02
1.09	24.	1.6	-0.01449	$1.1\cdot10^{-4}$	$6.7\cdot10^{-5}$	-3.33	-0.01
1.16	26.	1.7	-0.01436	$5.3\cdot10^{-6}$	$4.0\cdot10^{-5}$	-3.30	$-8.48\cdot10^{-4}$
1.20	27.	1.76	-0.01429	$-5.4\cdot10^{-5}$	$2.7\cdot10^{-5}$	-3.29	0.004
1.25	29.	1.85	-0.01415	$-2.1\cdot10^{-4}$	$6.9\cdot10^{-6}$	-3.25	0.01

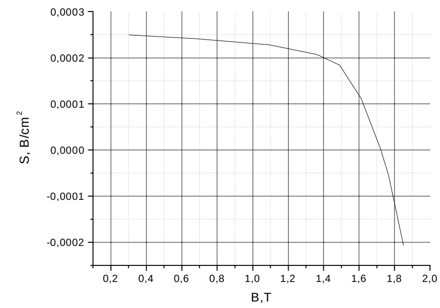

Fig. 8. Dependence of the sextupole component from the field on a stable orbit.

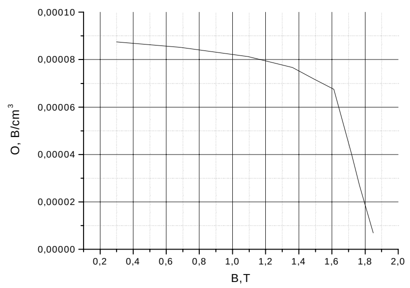

Fig. 9. Dependence of the octupole component from the field on a stable orbit.

4 INFLUENCE OF PERMEABILITY

The above-mentioned results were obtained in the supposition that both the pole and the yoke are manufactured from the steel 10, the magnetic permeability of which is characterized by a curve labeled as st10 in Fig. 10.

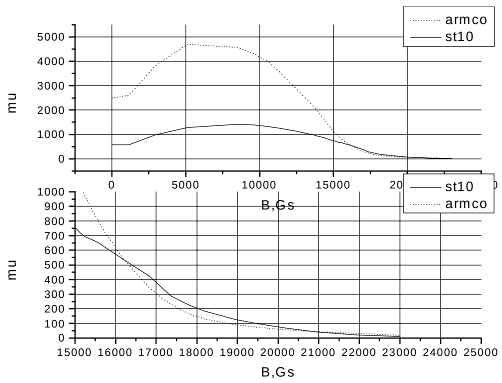

Fig. 10. Comparison of permeabilities for Armco and steel 10.

To estimate influence of permeability, the poles were calculated in the supposition that they are made of different materials and have the same shape. The results are shown in Fig. 11.

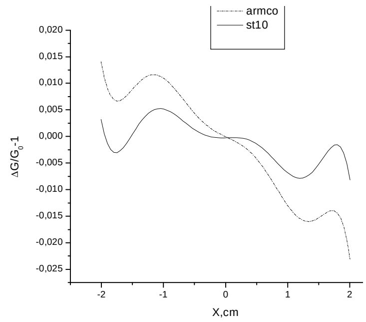

Fig. 11. Comparison of a gradient for poles of equal shape but manufactured from different materials. The optimization was done for a pole of steel st10.

The Fig. 11 testifies that the magnetic permeability essentially influences on the magnitude of nonlinearities. Therefore should be correct of a pole shape on data of measuring of the permeability. On the other hand the permeability deviations at a homogeneous material will have an effect only on the field magnitude, at which one the minimum of nonlinearities is reached. For a magnet under consideration the optimum energy is decreased from 1.15 GeV at poles from steel 10, up to 1.0 GeV at poles from Armco.

Thus a basic criterion of the material quality is homogeneity of a material, even to the detriment of magnitude of the permeability.

5 INFLUENCE OF AN EXACTITUDE OF MANUFACTURING

When estimating the manufacturing tolerances for the magnet pole surface the perturbations of the pole shape showed in Fig. 12-15 were considered. Here in this figures shown are the perturbations in a gradient following from the errors of pole manufacturing.

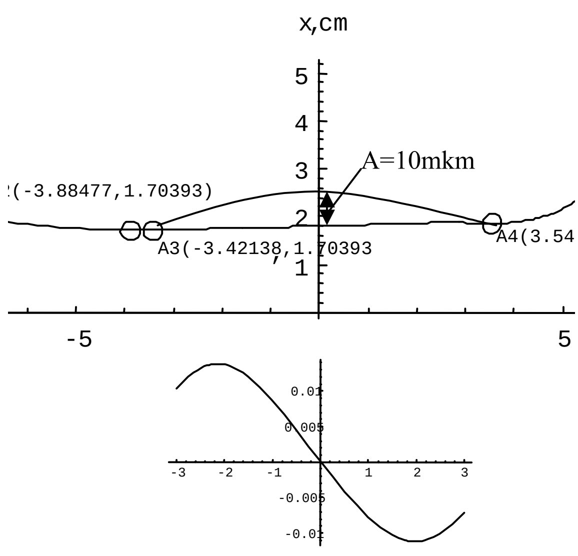

Fig. 12. The cavity of the central part of the pole (upper part of the figure) results to uprising of the sextupole component of the field (bottom part of the figure).

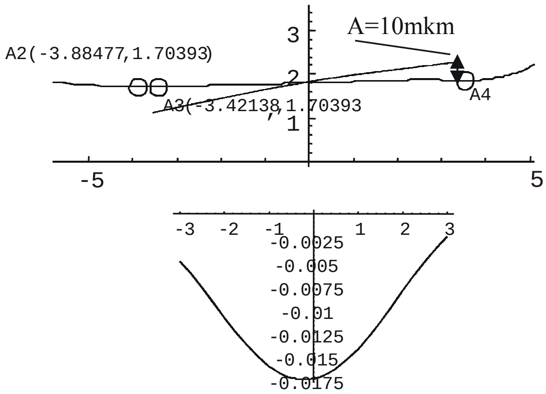

Fig. 13. The skewness of the central part of the pole (upper part of the figure) results in uprising of the octupole component of the field (bottom part of the figure) let alone quadrupole.

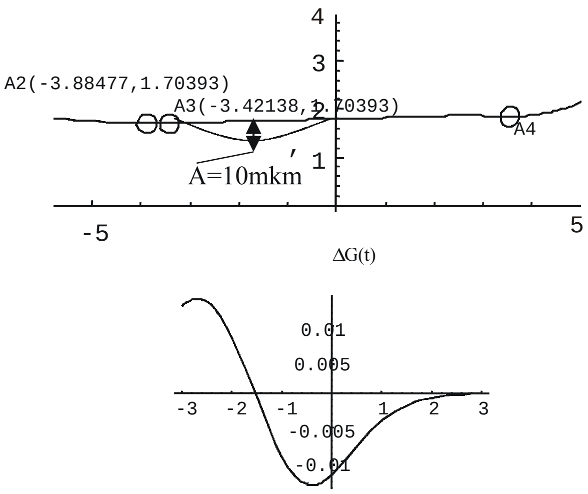

Fig. 14. The nonsymmetrical cavity of central part of the pole (upper part of the figure results in uprising of the sextupole, octupole components of the field and of the quadrupole error (bottom part of the figure).

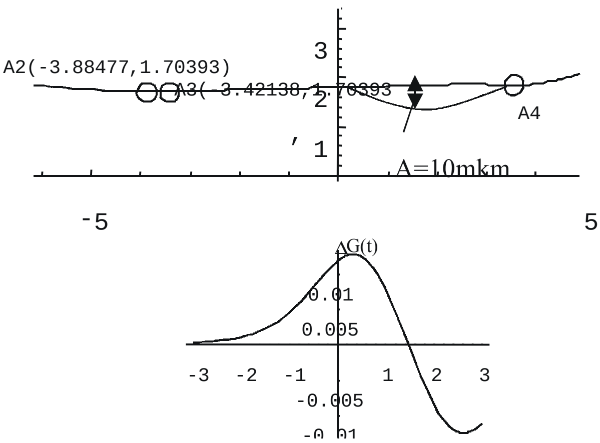

Fig. 15. See the caption of Fig. 14.

The tolerance on a gap follows from the expression:

$$G_0 = -\frac{B_0^2 \alpha_0}{H};$$

where α_0- inclination of the pole profile at center; H-half-gap; B_0-field at center of the gap.

This means, that an error surveyed before in manufacturing the pole are much more dangerous and their amplitude should not exceed 5 μm.

6 THE EDGE SHAPE OF A MAGNET

The edge shape of the magnet is determined by following reasons:

- on the edge there should not be a supersaturation;
- the magnet should have a boundary focusing.

The first requirement is ensured with the shape of the magnet edge along a bending radius (Fig. 16). The smoothly varying passage to a yoke ensures a weak dependence of the effective length of the magnet on the field. The difference of the effective length of the magnet at a maximum and minimum fields is 150 μm.

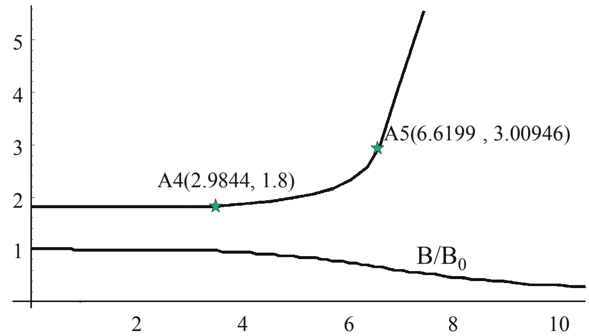

Fig. 16. Edge of the magnet and field distribution on the magnet edge azimuth.

The boundary focusing is ensured that since an azimuth 13.58° concerning centre of a magnet the edge of a pole will be formed by means of translation of cut conducted in this place, under this angle to radius to a vector with a scaling ratio, equal the ration of a gap (Fig. 16) to a gap of a regular part.

The edge shape of the magnet should be correct before manufacturing.

7 CONCLUSION

The calculations conducted for upgrading the design of the magnet system ISI-800M shows that a magnet manufactured with calculated tolerances under the calculated shapes completely meets the requirements, which are following from a beam dynamics in a synchrotron. The magnet with such requirements/specifications can be manufactured in Ukraine already in the next year under condition of sufficient financing.

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