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Magnet design for the storage ring of TURKAY

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Abstract: In synchrotron light sources the radiation is emitted from bending magnets and insertion devices (undulators, wigglers) placed on the storage ring by accelerating charged particles radially. The frequencies of produced radiation can range over the entire electromagnetic spectrum and have polarization characteristics. In synchrotron machines, the electron beam is forced to travel on a circular trajectory by the use of bending magnets. Quadrupole magnets are used to focus the beam. In this paper, we present the design studies for bending, quadrupole, and sextupole magnets for the storage ring of the Turkish synchrotron radiation source (TURKAY), which is in the design phase, as one of the subprojects of the Turkish Accelerator Center Project.

Key words: TURKAY, bending magnet, quadrupole magnet, sextupole magnet, storage ring

1. Introduction

At the beginning of the 1990s work started on building third generation light sources. In these sources, the main radiation sources are insertion devices (undulators and wigglers). Since the radiation generated in synchrotrons can cover the range from infrared to hard X-ray region, they have a wide range of applications with a large user community; thus a strong trend to build many synchrotrons exists around the world. The brilliance of these X-ray sources is high and this makes data collection faster. The light is used for fundamental research in areas as diverse as condensed matter physics, medical and pharmaceutical research, and cultural heritage. According to lightsource.org, in the American continent 9 (7 in USA), in Asia 15 (7 in Japan), and in Europe 18 synchrotron radiation sources are in operation or under construction. In addition, the Australian Light Source is in operation in Australia. The MAX-IV in Sweden, SIRIUS in Brazil, NSLS II in USA, and SESAME in Jordan are examples of SR facilities under construction. CANDLE in Armenia, ILSF in Iran, and TURKAY in Turkey are SR light source projects at the planning stage.

The Turkish Accelerator Center (TAC) Project, of which TURKAY is a subproject, consists of several accelerator-based light sources started in 2006 in Turkey, under the coordination of Ankara University [1]. An IR FEL facility (TARLA) based on a superconducting linac with 15–40 MeV energy under construction at the Institute of Accelerator Technologies of Ankara University is the first facility of TAC [2,3]. One of the possible steps after TARLA is a synchrotron radiation facility, TURKAY, which is at the conceptual design report stage currently. The design concept of TURKAY is composed of three parts: injector, full energy booster ring, and storage ring. The electrons generated by an electron gun are firstly accelerated to 100 MeV in a linac and they are injected into a booster synchrotron, which raises the electron energy up to 3 GeV, the nominal energy of

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operation. Then they are transferred into the storage ring of 477 m length, where they are maintained as long as possible [4]. The synchrotron radiation will be produced from the undulators placed in the straight sections and bending magnets on the storage ring. The ring consists of 20 main cells and the main cells consist of 4 identical bending magnets and 4 families of quadrupole magnets. The main cells are multibend lattice and have finite dispersion in straight sections.

One of the important parameters of a light source is brilliance. The brilliance is the photons flux per area and opening angle. To achieve a high brilliance value the emittance of the electron beam should be as low as possible. Emittance value depends on the optical design of the storage ring. The main parameters of the storage ring can be seen in Table 1 [5]. The target emittance of TURKAY is ambitious and shows the design is comparable with other facilities in the world community. Some important parameters of different light sources are shown in Table 2. In TURKAY, the energy of radiation produced can be in the range of 0.01–60 keV by using bending magnets and special undulators. Radiation with a brilliance value of 1.25×10^{21} photons/s/mm^2/mrad^2/0.1%BW can be produced from undulators [6].

Table 1. Storage ring parameters.

Parameters	Value
Energy (GeV)	3
Circumference (m)	477
Current (mA)	500
H. emittance (nm rad)	0.51
V. emittance (nm rad)	0.0051
RF frequency (MHz)	500
Number of str. sections	20
Length of str. sections (m)	5

Table 2. Parameters of some light sources in operation or construction (all sources are designed for 3 GeV electron beam energy).

Light source	Circumference (m)	Emittance (nm rad)	N. of SS × length (m)
TURKAY	477	0.51	20 × 5
MAX-IV	528	0.32/0.26	20 × 5
NSLS-II	792	0.93	15 × 6, 15 × 9.3
TPS	518	1.7	18 × 7, 6 × 12
ALBA	268	4.3	4 × 8, 12 × 4.2, 8 × 2.6

2. Magnet design

In a synchrotron, the electron beam is guided in a circular trajectory by the use of bending magnets and focused by the use of quadrupole magnets. Sextupole magnets are used to correct chromaticity. The curvature of a bending magnet is given in practical units as

$$\frac{1}{\rho}\left[m^{-1}\right] = 0.2998\frac{|B\,[Tesla]|}{\beta\,E\,[GeV]}, \tag{1}$$

where g is bending radius, B is peak magnetic field in the bending magnet, and E is total particle energy [7]. β is the ratio of the velocity of the particle to the speed of light and $\beta \approx 1$ for relativistic particles. Similar to the definition of bending curvature of the bending magnet the focusing strength of a quadrupole magnet with practical units is defined by

$$k\left[m^{-2}\right] = 0.2998\frac{g[Tesla/m]}{\beta\, E[GeV]}, \tag{2}$$

where g is the field gradient [7]. The strength parameter of the sextupole magnet can be written as

$$m\left[m^{-3}\right] = 0.2998\frac{1}{\beta\, E[GeV]}\frac{\partial^2 B_y[Tesla]}{\partial x^2[m^2]}. \tag{3}$$

The main cell of storage ring consists of 4 bending, 16 quadrupole, and 23 sextupole magnets with different lengths and strengths. The layout of the half main cell is shown in Figure 1. The designed magnet parameters are given in Table 3.

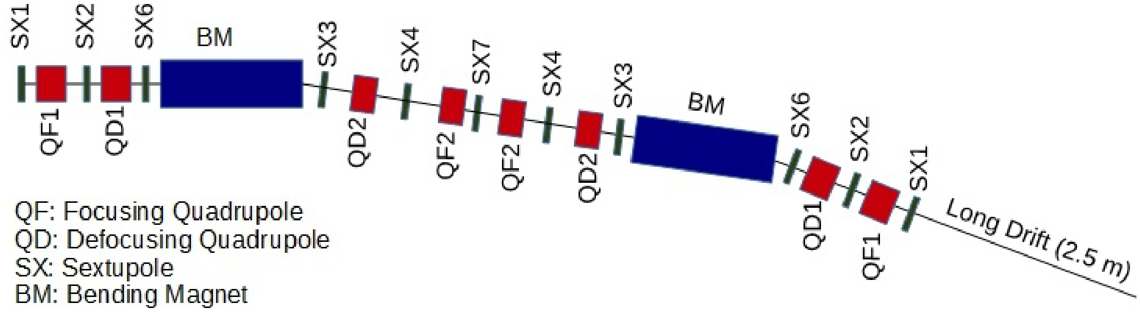


Figure 1. Schematic layout of the half main cell of storage ring.

Table 3. Main parameters of the designed magnets.

Parameters	Bending	Quadrupole (QF1)	Sextupole (SX1)
Bending angle (deg)	4.5	-	-
Magnetic length (m)	1.5	0.30	0.10
Total length (m)	1.58	0.40	0.14
Dipole field (T)	0.52	-	-
Gradient field (T/m)	-	23.8	-
Quad. strength	-	2.38	-
Sext. component (T/m^2)	-	-	1030
Bending radius (m)	19.1	-	-
Gap (mm)	20	-	-
Aperture radius (mm)		25	30
Current (A)	156	204	650
Numb. of turns per coil	27	30	10
Pole width (m)	0.20	-	-
Magnet type	C-type	-	-

2.1. Bending magnet

The storage ring is equipped with 80 bending magnets of 1.5 m length and each magnet produces a field of 0.52 T in the central gap of 20 mm. All the magnets are identical due to keeping the dynamic aperture larger. The bending radius of the magnet is 19 m and it deflects the electron beam by 4.5° at electron energy of 3.0 GeV. The bending magnets are chosen as C-type with rectangular pole face. Although the rectangular magnets need a larger good field region, manufacturing is simpler and to achieve the tolerances is easier. A C-type magnet also needs a strong yoke to avoid deformation due to magnetic force and heavy mass. The magnet is designed by two-dimensional design code POISSON SUPERFISH [8] and three-dimensional design code RADIA [9]. A model of the designed magnet is shown in Figure 2. The magnetic field for 1.55 A/mm^2 current density (total excitation current in a coil is 4200 A) and 20 mm gap is shown in Figure 3. Assuming the conductor area is 100 mm^2, the number of turns is 27 and the conductor current is 156 A. The peak magnetic field versus conductor current is shown in Figure 4. From the figure, the saturation starts around 0.6 T. The magnetic field in the magnet along the beam direction and perpendicular axes to the beam direction can be seen in Figures 5 and 6, respectively.

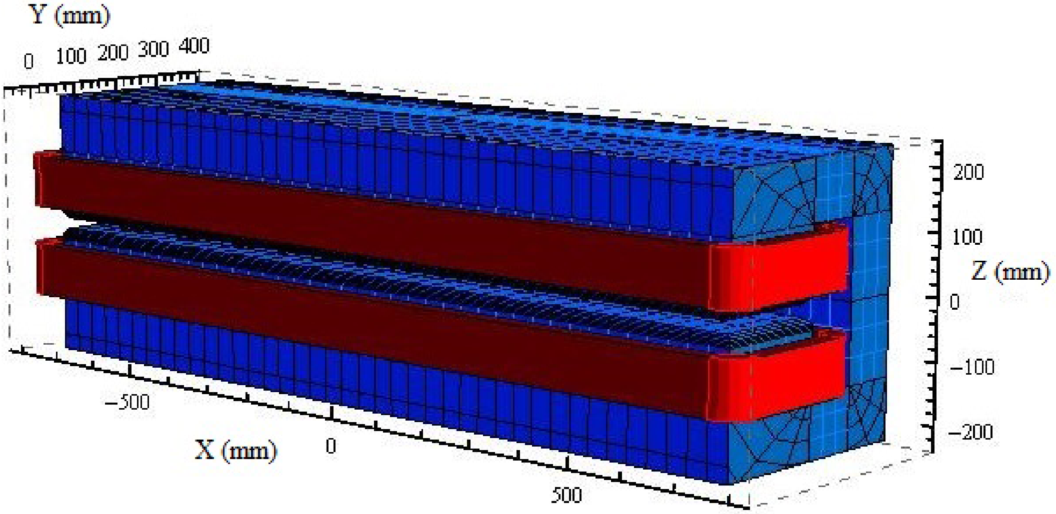
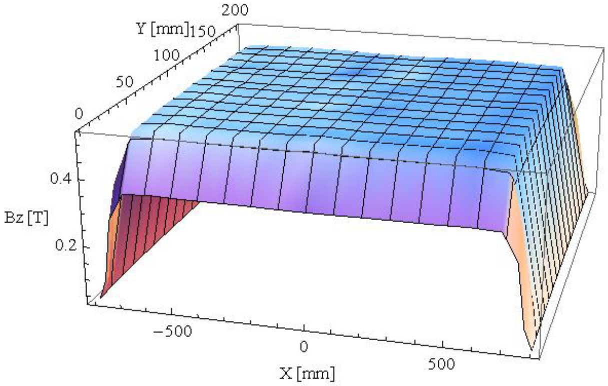


Figure 2. C-type magnet modeled using RADIA (the coils are red and the magnetic core is blue).



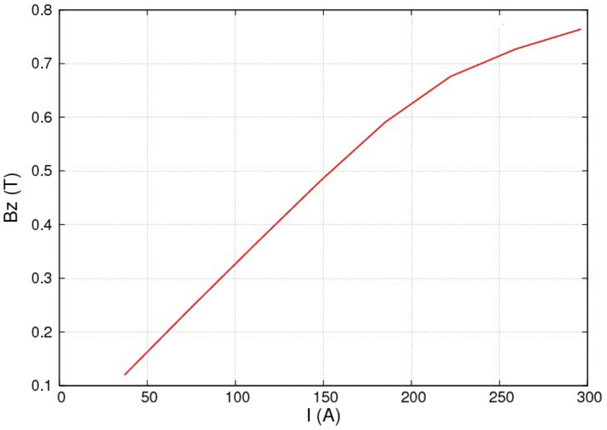


Figure 3. Magnetic field map in the dipole magnet.

Figure 4. Peak magnetic field vs. wire current of coils.

A bending magnet will also be used to generate radiation for users. The critical photon energy of the radiation is 3.1 keV and the generated photon energy range is 0.01 to 20 keV. The spectrum can be extended to the hard X-ray region using high-field magnet insertion [6].

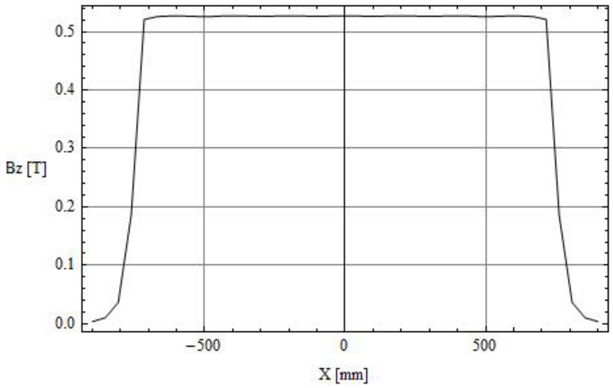


Figure 5. Magnetic field of the bending magnet along the beam path.

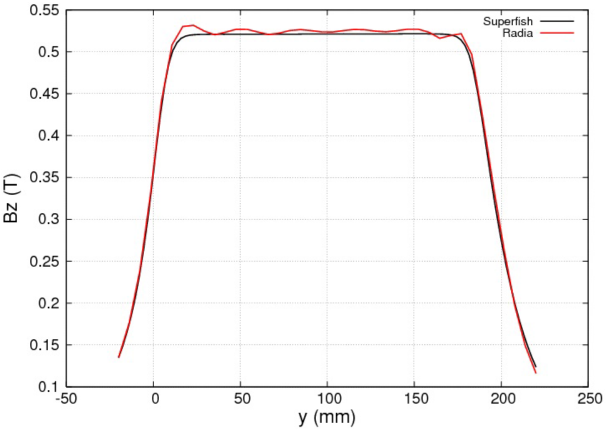


Figure 6. Magnetic field of bending magnet in perpendicular axes of beam path (POISSON SUPERFISH result is black and RADIA result is red).

2.2. Quadrupole magnet

In the storage ring 160 horizontal and 160 vertical focusing magnets will be installed. The strongest quadrupole (QF1) in the ring is 0.30 m long and has a gradient 23.8 T/m. The quadrupole magnets are modeled by RADIA and POISSON SUPERFISH. The model of the magnet is shown in Figure 7. To produce the required magnetic gradient for the given design, one needs 6144 A.Turn coil current. The magnetic field and gradient in the magnet can be seen in Figures 8 and 9, respectively. The good field region is approximately 2 cm and magnetic field tolerance in this region is 1×10^{-3}.

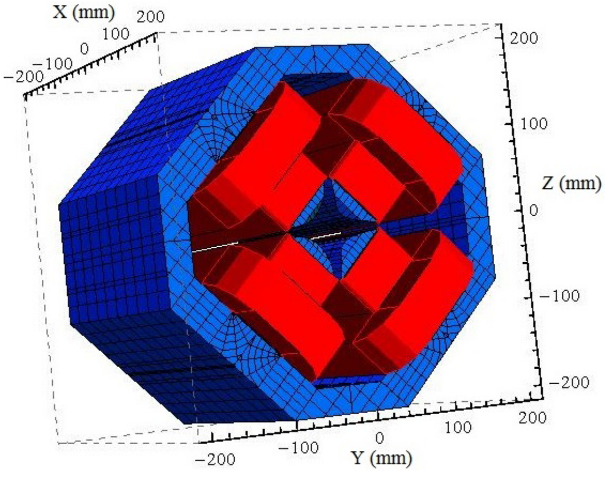


Figure 7. Quadrupole magnet modeled using RADIA (the coils are red and the magnetic core is blue).

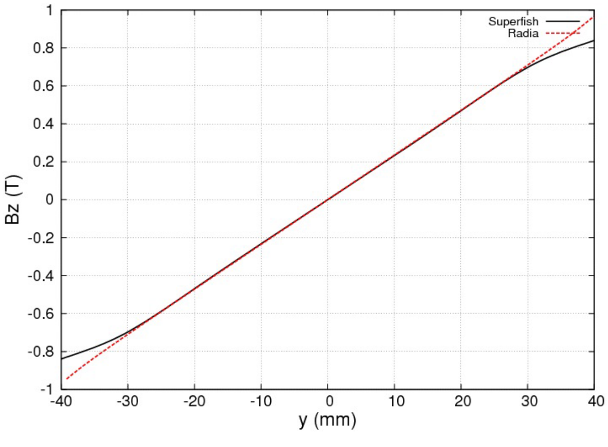


Figure 8. Magnetic field variation along the aperture of the quadrupole magnet (POISSON SUPERFISH result is black and RADIA result is red).

2.3. Sextupole magnet

In a main cell of the ring, 7 families of sextupole magnet are used and the lengths of all sextupole magnets are 10 cm. The preliminary simulation was done for the strongest sextupole magnet (SX1) with sextupole component of 1030 T/m^2. The cross section of the magnet designed by POISSON SUPERFISH is shown in Figure 10. Magnetic field and field gradient in aperture diameter are shown in Figures 11 and 12, respectively.

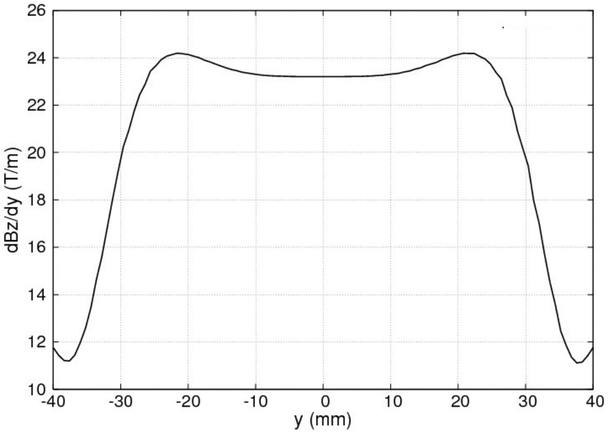


Figure 9. Magnetic field gradient of quadrupole magnet.

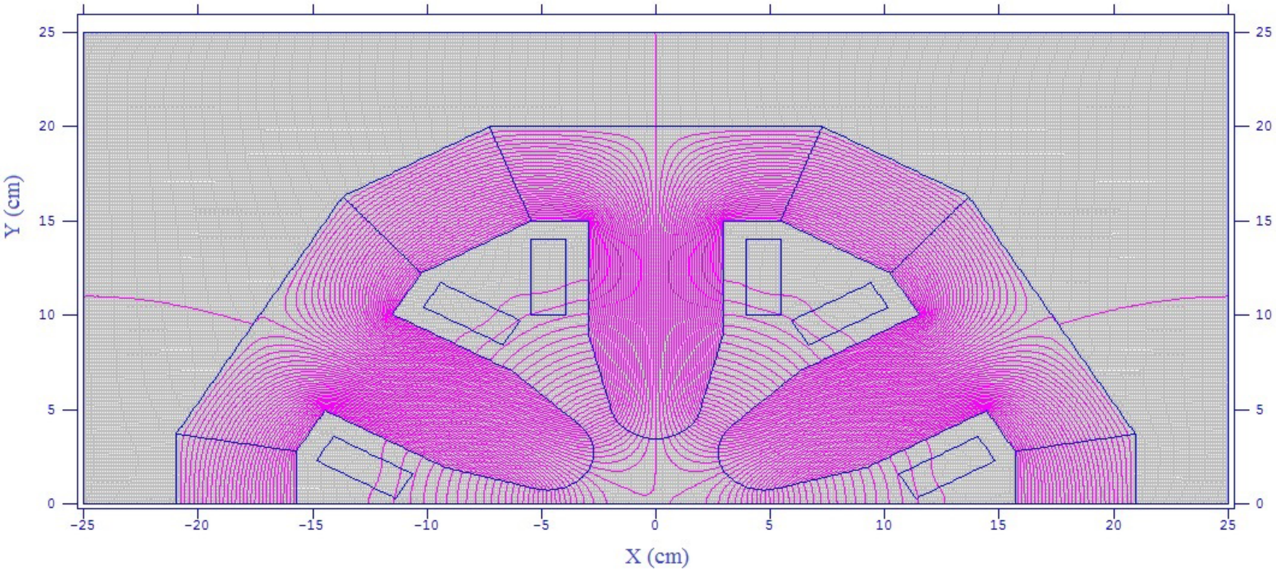


Figure 10. Cross section and magnetic field lines of half of the SX1.

3. Conclusion

Bending, quadrupole, and sextupole magnets are designed according to the requirements for the TURKAY storage ring. The bending magnet generates the magnetic field of 0.52 T and required current is 4200 A.Turn. The tolerance of the magnetic field (ΔB/B) in the good field region is 2×10^{-3}. The strongest quadrupole in the ring needs a magnetic field gradient of 23.8 T/m. This value is achieved with the current of 6144 A.Turn. The preliminary simulation was done for the strongest sextupole magnet (SX1). The required sextupole component of 1030 T/m^2 is achieved with the total coil current of 6500 A.Turn. Engineering studies for the magnets will be detailed in technical design report stage. These engineering studies should contain the design studies about power requirements, material specifications, heat load, and cooling channels, and detailed drawings.

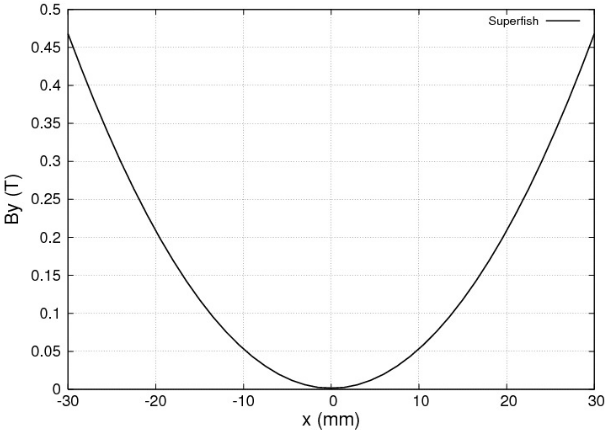


Figure 11. Magnetic field in the SX1 along the aperture.

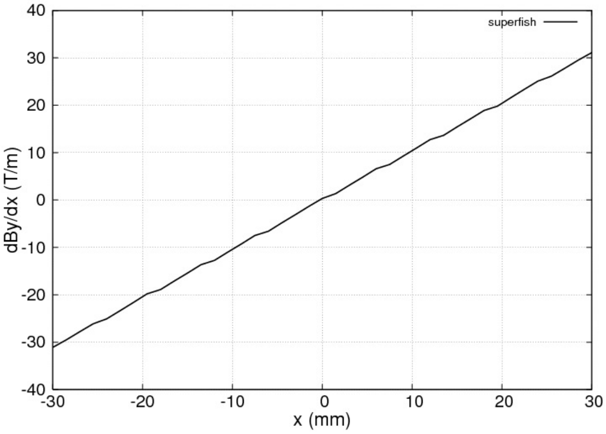


Figure 12. Magnetic field gradient in the SX1 along the aperture.

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