COCKCROFT INSTITUTE

Conventional Magnets for Accelerators
(Alex Bainbridge)

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Answer **ALL** questions
The completed assessment should be returned to Alex Bainbridge either by email (alex.bainbridge@stfc.ac.uk) or in person (to office A15 if possible, otherwise to ASTeC administration office). The due date is **24TH FEBRUARY 2023**.

Whilst this assessment may be completed using only notes from CI-MAG-106, you may find notes from CI-ACC-101 & 102 and CI-BEAM-104 & 105 useful

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Postgraduates may use electronic calculators, computers
and other aids (e.g. Internet) to assist in their completion of this assessment.

The numbers are given as a guide to the
relative marking weights of the different parts of each question.

1. Before simulating any magnet, it is always wise to do some basic pen and paper calculations to estimate certain parameters. A new accelerator is being designed and the accelerator physicists have determined that the lattice requires a curved parallel-ended H dipole with a bend angle of 25 degrees (436.332 mrad) and an effective length of 0.25 metres. The maximum electron energy will be 50 MeV. The beam pipe has an outer radius of 38 mm and so the minimum allowable magnet full gap height is set at 40 mm. The "good field region" must extend to ± 18 mm on each side of the centreline to encompass the whole beam pipe.

Determine the following:
A) The integrated B field required and nominal central B field required to achieve the desired bend angle

[2 marks]

B) The bend radius and distance between the parallel ends of the magnet

[2 marks]

C) Estimate the total width of the pole needed (assume no shims) to achieve a field uniformity of $\Delta B/B_0 \leq 10^{-4}$ across the whole good field region.

[2 marks]

D) An estimate of the needed ampere-turns per coil to achieve the nominal central B field.

[2 marks]

E) An estimate of the stored energy in the magnet.

[1 marks]

F) An estimate of the magnetic force between the poles of the magnet.

[1 marks]

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2. A coil for a magnet requires 10000-Ampere turns and must fit inside a 75x75mm cross-section. The average loop length is 1 metre. We must determine a suitable water-cooled coil design. First, we choose square wire with a side length 7.5 mm, a circular cooling channel with a diameter of 3.4 mm. We assume infinitely thin insulation.

Determine the following:
A) The current density in the wire.

[2 marks]

B) The total resistance of the coil assuming copper has a resistivity of $1.68 \times 10^{-8}.\Omega m$

[2 marks]

C) The power dissipation in the coil and voltage required.

[2 marks]

D) We calculate that if our cooling water is backed by 6 bar pressure, the Reynolds number will be 2812 and the water temperature rise at the coil exit will be 10.14 degrees. Comment on why this design is risky and why the temperature rise prediction may be inaccurate.

[2 marks]

E) A change to the design requires a stronger magnet. The news comes too late and the magnet yoke is already under manufacture, so the total coil size may not be increased, this must be achieved through increased current. Briefly suggest two changes that could be made to the coil design to allow it to maintain thermal performance at the higher current.

[2 marks]

3. The current through an iron dominated dipole electromagnet is doubled so in theory the central field should also double. Instead, measurements show the field increasing by much less than would be expected. State the most likely reason for this discrepancy and at least two different changes to the design of the magnet which would ensure the field doubles as desired.

[5 marks]

4. Plot using your software of choice (please do not attempt to hand-draw) the theoretically perfect pole contour for a combined function dipole-quadrupole magnet with a central flux density of 1 Tesla and a field gradient of 6 T/m. The vacuum chamber through the magnet is a 25 mm wide, 10 mm high rectangle and must be accommodated.

[10 marks]

5. A dipole is needed that can rapidly switch on and off in milliseconds to separate sequential electron bunches. Discuss in detail the reasons why designing a yoke for such a magnet is a particular challenge and the mitigations that may be used for each reason.

[10 marks]

6. A hall probe is calibrated against a standard water NMR probe. With the NMR locked to 13 Mhz the Hall probe records 32 mV. The Hall probe is then inserted into a dipole magnet where it records 71 mV. Assuming the calibration is completely linear, what is the flux density in the dipole?

[5 marks]

END OF EXAMINATION PAPER