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 **FRI 13TH FEBRUARY 2026**.

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.

I would prefer you to submit your typed answers by email in **either Microsoft Office or PDF format**, or in person as printouts of these files. I will also happily accept hand written answers (except Q4) as long as they are legible, but if you choose to hand write your answers **please hand in the physical written paper rather than emailing a photograph of the page**, as photographs tend to be far less legible.

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 physics group have determined that the lattice requires a curved parallel-ended H dipole with a bend angle of 5 degrees (87.2665 mrad) and a length of 0.7 metres. The maximum electron energy will be 1.8 GeV. The beam pipe has an outer diameter of 28 mm and so the minimum allowable magnet full gap height is set at 32 mm.

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 of the dipole

[1 marks]

Hint: It is possible to either calculate part A first and use the result to calculate part B, or part B first and use the result to calculate part A

C) An estimate of the needed ampere-turns **per coil** to achieve the nominal central B field calculated in part A.

[2 marks]

2. A coil for a magnet requires 6000-Ampere turns and must fit inside a 100x100 mm cross-section. The average loop length is 1.5 metres. We must determine a suitable water-cooled coil design. First, we choose square wire with a side length 7 mm, a circular cooling channel with a diameter of 3 mm. We assume infinitely thin insulation.

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

[1 marks]

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

[1 marks]

C) The power dissipation in the coil and voltage required to drive the needed current.

[2 marks]

D) We calculate that if our cooling water is backed by 6 bar pressure, the Reynolds number will be around 1170 and the water temperature rise at the coil exit will be around 8.5 degrees. Explain on why this 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, the extra strength must instead be achieved through increased current. Manufacture of the coils has not yet started, so changes that fit within the same cross sectino are acceptable. Conceive **two** changes that could be made to the coil design to allow it to maintain thermal performance at the new higher current, and outline the merits and drawbacks of these changes.

[4 marks]

3. A dipole electromagnet with an isotropic steel yoke is operated at a current of 50 A and produces a field of 0.5 T. When operated at 100 A the same magnet produces a field of 1 T. When operated at 150 A the magnet produces 1.38 T. Explain in detail the most probable reason for this relationship and suggest at least **two** different changes that could have been made to the magnet during the design phase which would have resulted in more desirable magnet behaviour.

[5 marks]

4. Plot using your software of choice the theoretically perfect contour of the steel pole tip for a combined function dipole-quadrupole magnet with a central flux density of 0.8 Tesla and a field gradient of 10 T/m. The vacuum chamber through the magnet is a 38 mm wide, 18 mm high rectangle and must be accommodated. Show on the plot that this condition is met.

[10 marks]

Regarding Q4, ***Please do not hand in a hand-drawn plot, it will not be accurate and you will lose marks.*** *As an alternative to copying the graph into your answer document I can accept Mathematica notebooks, Excel files, or Python scripts as long as I can run them locally with no troubleshooting.*

5. A free electron laser features two beam-lines fed from a single accelerator. This may be achieved by an RF cavity or by a dipole that can rapidly switched on, deflect an electron bunch into the first line, then rapidly switch off in a similar time to allow the next bunch to pass into the second line undisturbed, before switching on again to deflect the third bunch into the first line (and so on...)

Discuss **in detail** the following:

A) Why the choice of yoke material is particularly important for this magnet. What impacts will the yoke material have on the magnet, and what effects may be mitigated or worsened by particular material choices?

[4 marks]

B) Why the choice of beam pipe may be important in this magnet. What effects will beam pipe shape, size and material have on the magnet performance.

[4 marks]

C) The particular challenges related to supplying power to this magnet.

[2 marks]

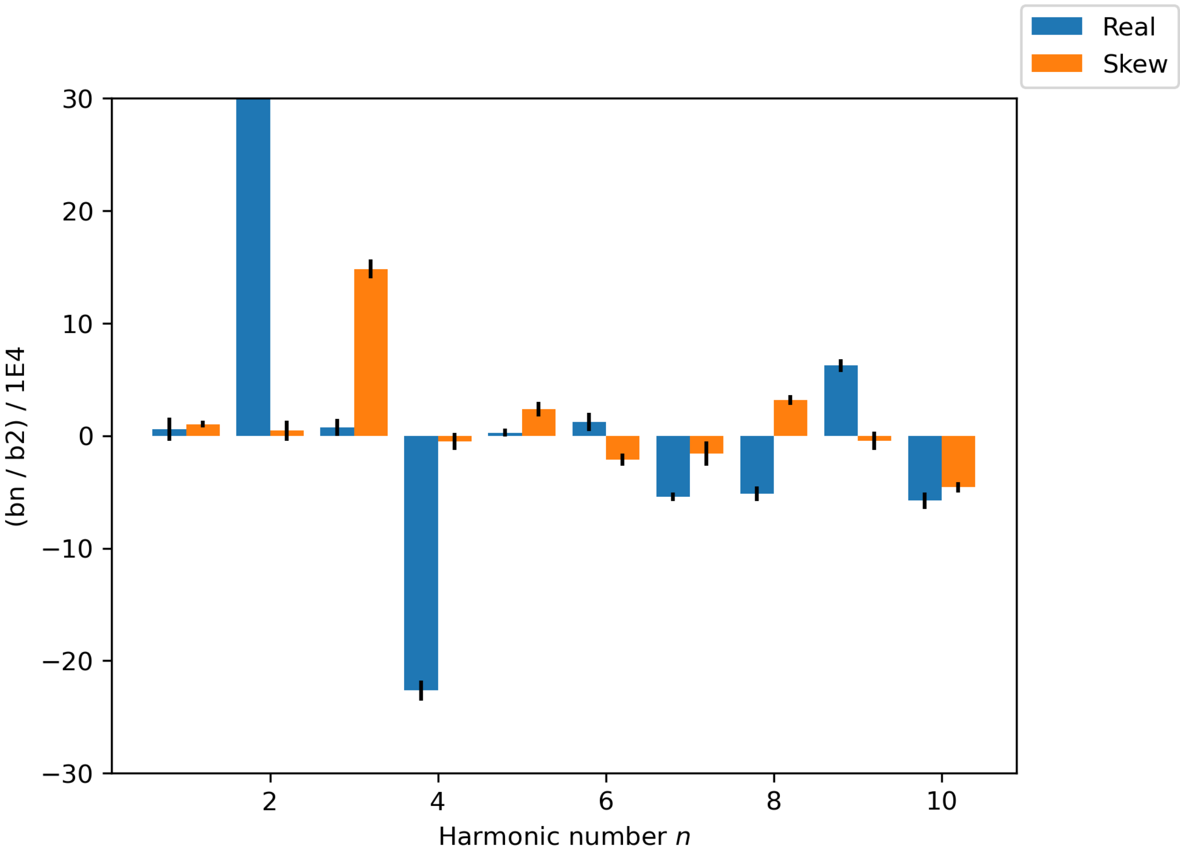
Regarding Q5: There is a lot you can write about here, and full marks will require going into quite deep detail! Treat the answer as a 1-2 page essay. The mark scheme for this question is looser than the other questions, and will be based on how well your answer makes me think that you have understood and grasped the difficulties of AC magnets.

6. A hall probe is calibrated against a standard NMR probe which uses a water vial as the sample. With the NMR locked to 16 Mhz the Hall probe records 42 mV. The Hall probe is then inserted into a dipole magnet where it records a voltage of 61 mV. Assuming that the Hall coefficient and Geometric factor are constant, what is the flux density in the dipole?

[5 marks]

7. The chart below shows the (real!) measurement results of a permanent magnet quadrupole where the yoke and poles are assembled from a complex series of parts, making it susceptible to mechanical assembly errors. The results show the measured integrated cylindrical harmonics, taken by sweeping a stretched wire in a circular pattern and calculating the Fourier coefficients of the resulting signal. They are normalised such that the real n=2 coefficient is 10000. Examine this chart and give a detailed overview of what asymmetries you can deduce exist in the magnet pole tips.

[5 marks]



END OF EXAMINATION PAPER