Conceptual design of extremity MRI magnet using commercial MgB_2 conductor

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Abstract –This paper presents a conceptual design study of commercial low field extremity MRI magnet using MgB_2 (Magnesium Diboride) In this study, we aim to explore the feasi bility and performance of MgB_2 magnets in 0.5 T, low field condition. We have used critical temperature value of 20 K and critical current margin as 30%. The study involves conside rations of critical parameters including field homogeneity and 5-gauss line for safety issues. The geometry of the magnets will then be optimized using such parameters by the most basic *"fmincon"* operation in Matlab. Furthermore, we look forward to achieve economic conclusions about extremity MRI systems with low field strength to be achieved.

1. Introduction

1. Development of superconducting magnet using MgB_2

- The most currently developed superconducting magnet using MgB_2 boasts 30 K higher critical temperature than post-conventional magnet using NbTi.
- This mitigates the impact of rising liquid helium demand and its associated cost escalation
- This poster aims to explore the extremity magnet structure utilizing the MgB2 material.

2. Low field extremity MRI

- The utilization of low field MRI systems is accompanied by certain limitations, primarily centered around their reduced sensitivity, specificity and accuracy.
- However, as low field extremity MRI (0.2 T Esaote Artoscan) was used to detect *Synovitis*, the mean value of its sensitivity, specificity, and accuracy was 92.3% matching to that of high field MRI (1.0 T Siemens Impact)[1].
- This poster aims to build a conceptual design of a considerably low field extremity MRI with magnetic flux density 0.5 T inside the center of its Diameter Spherical Volume (DSV)

2. Main Design Considerations: (1) Field Homogeneity; (2) 5-Gauss Line; (3) Critical Current Margin

1. Magnetic flux density requirement and homogeneity (ppm)
   - We aim for magnetic flux density 0.5 T measured inside our 8 cm DSV.
   - Field homogeneity is an important consideration to ensure safe and efficient operation
   - We aim to minimize homogeneity below 100 ppm
   - ➢ Magnetic flux density was designed to be 0.5 T
   - ➢ Under 0.5 T field condition, basic optimization operator, *"fmincon"* in MATLAB was used to find coil parameters where non-homogeneity is minimized.

$$\text{Homogeneity} = \frac{B_{max} - B_{min}}{B_{max} + B_{min}} \times 10^6$$

B_{max}: Maximum flux density within DSV
B_{min}: Minimum flux density within DSV

2. 5-Gauss line
   - Safety area determined around the magnet of the MRI, specifying the distance at which the stray magnetic field is 5 gauss (0.5 mT)

3. Critical current margin and current density
   - Superconductor can only operate under its critical current (I_c).
   - We aim to optimize critical current margin for the magnet to maintain its superconducting state through out.
   - ➢ We considered the packing factor of orthocyclic winding (λ=0.907)

3. Design Results

Conductor selection:

- To achieve 0.5 T magnetic density, commercial MgB2 conductors manufactured by Sam Dong Inc. was considered as an option.
- We assumed 20 K operation by conduction cooling; thus 20 K critical current data of Sam Dong's conductor[2] was considered.

Table I. Conductor selection and operating conditions

Parameters	Unit	Value
Manufacturer	[-]	Sam Dong Inc.
Filament no.	[-]	18+'1' Cu
Wire diameter without insulation	[mm]	0.83
Operating temperature	[K]	20
Operating current	[A]	88
Engineering current density	[A/mm^2]	126
Diameter Spherical Volume	[cm]	16

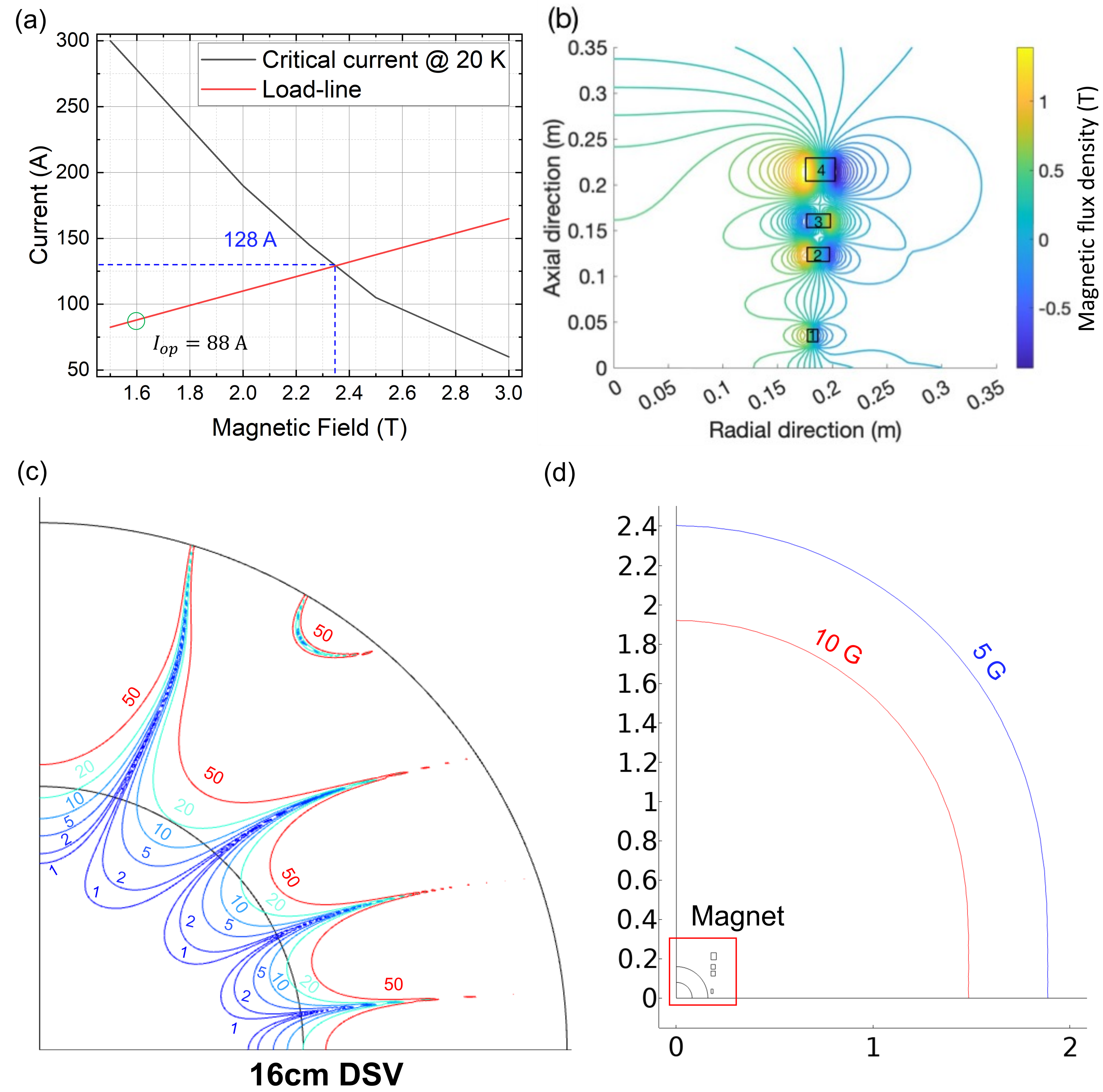

Fig 1. (a) Magnetic flux density, B to Critical current, I_c as Temperature changes[2] (b) Magnetic flux density distribution on and around the bundles (c) Homogeneity near 0.08m DSV in ppm (d) The 5 Gauss footprint

Table II. Key parameters of designed MRI magnet

	Coil 1	Coil 2	Coil3	Coil4
a1 (mm)	176.0			
a2 (mm)	186.5	197.7	198.1	202.7
b1 (mm)	24.1	112.3	147.4	194.8
b2 (mm)	46.1	137.3	170.4	230.8
J_e (A/mm^2)	126	126	-126 (Shield)	126
Homogeneity (ppm)	52			
5G line (m)	1.9 (R) X 2.4 (Z)			
Current margin	31 % (load-line)			

4. Discussion: Shield coil (Coil 3)

Current direction:

As it can be seen in **Fig 1.** (b), Coil 3 is producing negative field lines that reduces electromagnetic impact on external environment. However, in the employed design the shielding coil is aligned with the normal Coils. Inducing a negative current only on Coil 3 may result in some structural issues.

5. Conclusion

We have successfully created a low-field extremity MRI system within specific design parameters. Whilst low-field MRI may possess accuracy constraints, as mentioned the limitations are relatively modest. Furthermore, by integrating current noise reduction techniques in image processing, strict criteria for MRI machines will enhance and consequently increase accessibility to MRI usage.

Reference

[1]Ejbjerg, B J. "Optimised, Low Cost, Low Field Dedicated Extremity MRI Is Highly Specific and Sensitive for Synovitis and Bone Erosions in Rheumatoid Arthritis Wrist and Finger Joints: Comparison with Conventional High Field MRI and Radiography."pg. 5, Table.4, 2004

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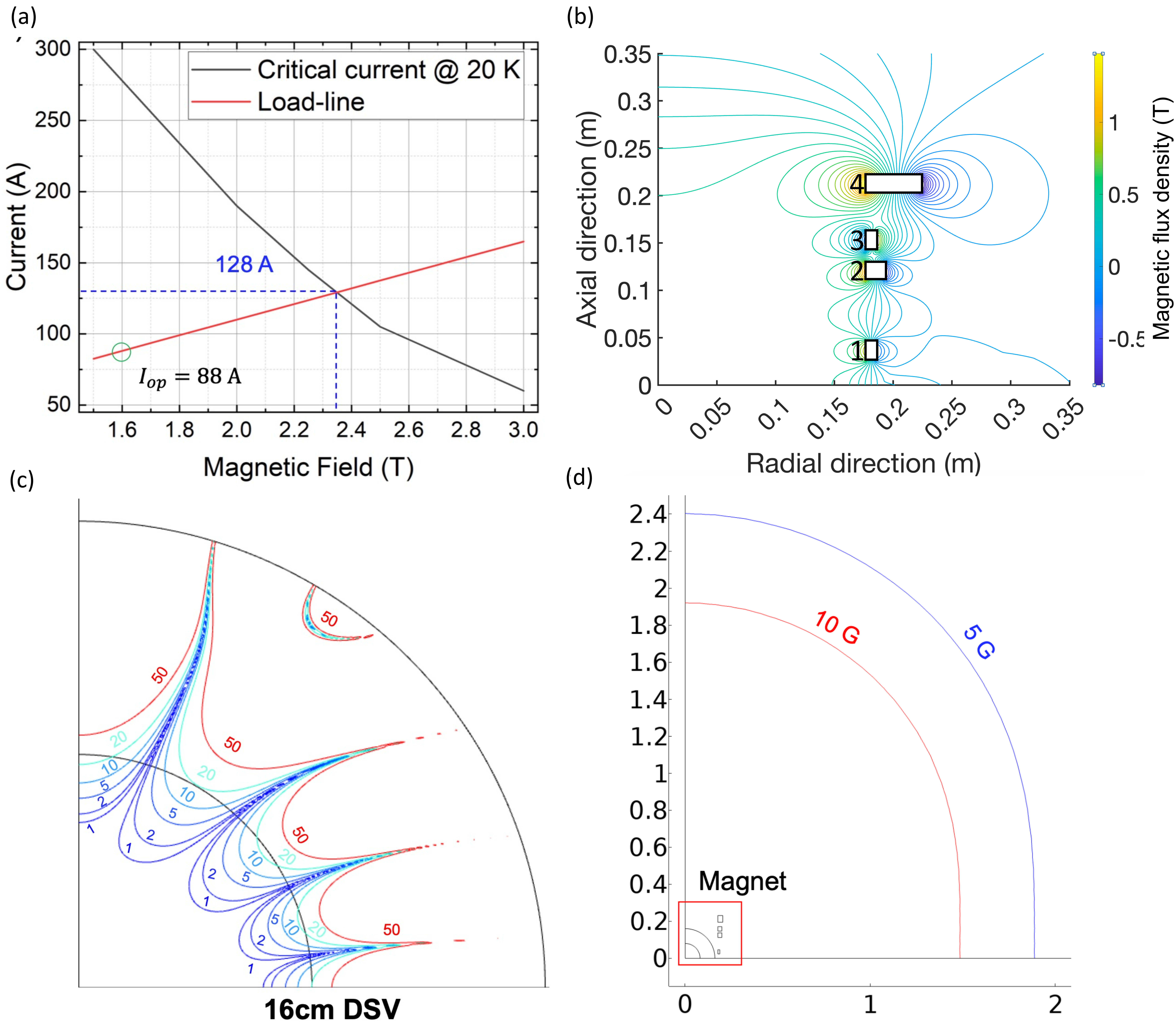
(a)
Critical current @ 20 K
Load-line
128 A
$I_{op} = 88$ A
Current (A)
Magnetic Field (T)
(b)
Axial direction (m)
Radial direction (m)
Magnetic flux density (T)
(c)
16cm DSV
(d)
10 G
5 G
Magnet