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IFAST WP11.3

Permanent Magnet Quadrupoles & Combined Function Magnets for Ultra Low-Emittance Rings

IFAST kick-off meeting

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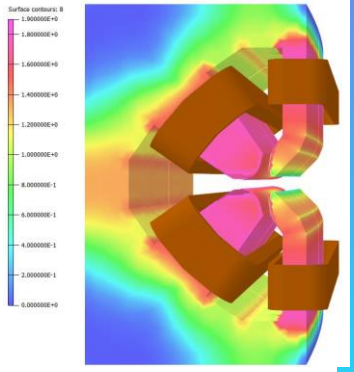
IFAST

Task description

- ***Task 11.3: Permanent Magnet Quadrupoles & Combined Function Magnets for Ultra Low-Emittance Rings***
  - Partners: UKRI – Diamond Light Source – Kyma
- This task addresses the need for reducing the electricity consumption and carbon footprint in future storage rings
- Two prototypes to be designed, assembled and tested: (**D11.3**)
  - PM-based strong focusing quadrupole magnet
  - PM-based combined function dipole-quadrupole (DQ) magnet
- Parameters similar to Diamond-II and other facilities
- Second-stage prototypes
  - Basic concept already tested
  - Examine requirements for cost-effective series production
- Adjustment using either coils or motors

UKRI's ZEPTO tunable PM quadrupole

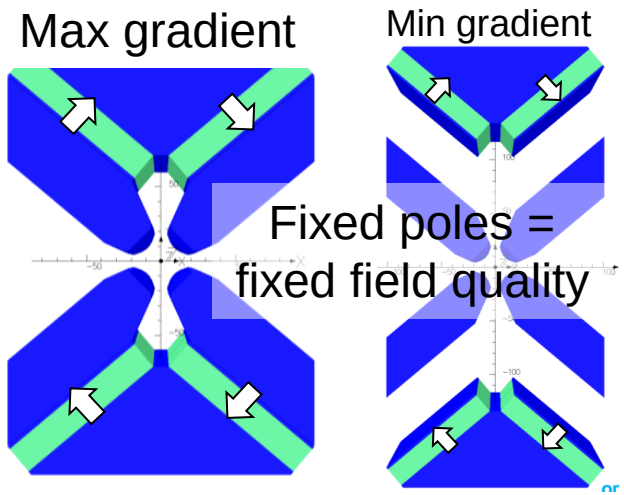


Diamond combined function DQ magnet

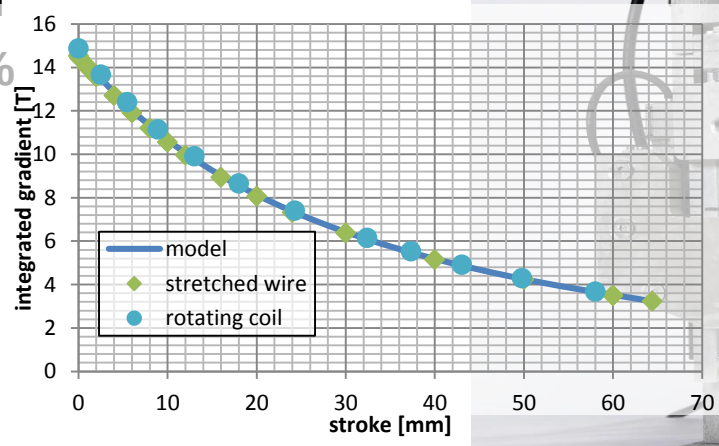
Shepherd *et al*, IEEE Trans Appl SC, vol. 22, no. 3, p4004204 (2012)
Shepherd *et al*, IPAC2013 THPME043

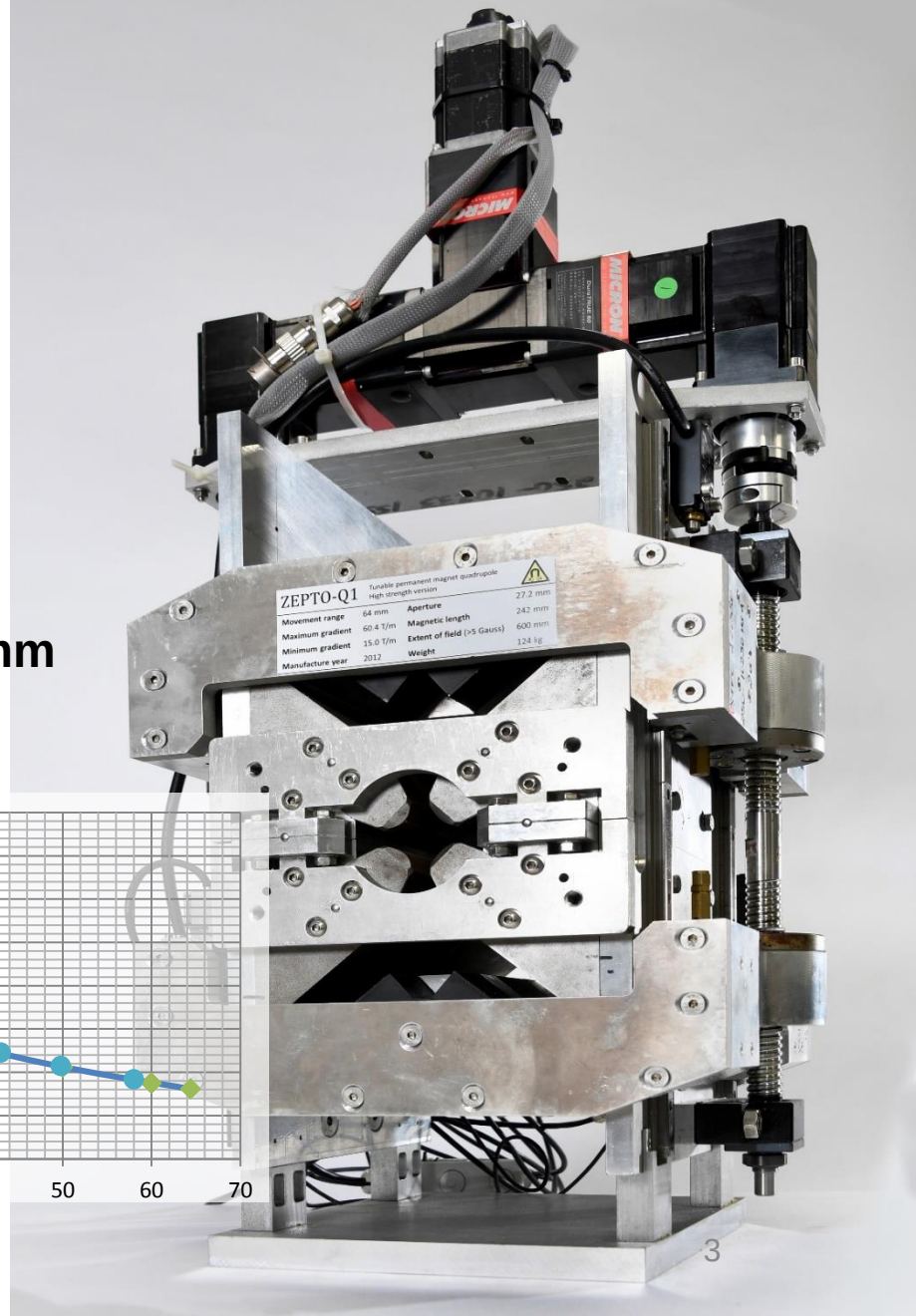
ZEPTO Q1: High Strength

- ZEPTO “Zero-Power Tunable Optics”
- High gradient: **60 T/m**
  - Can reduce to **15 T/m** by moving PMs up to 64 mm
  - Tuning using variable gap in magnetic circuit
- Magnetic force: **16.4 kN** per side
  - Pulling PMs parallel to magnetic axis → large forces
- Some unwanted magnetic centre movement (100 µm) due to ferromagnetic rails



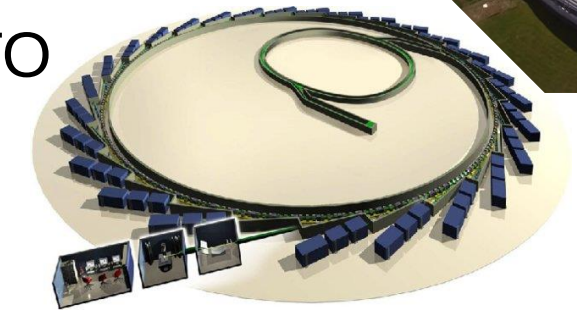
- 4 **NdFeB** blocks, each **18 x 100 x 230 mm**
- Gradient **15-60 T/m**
- Pole gap **27.2 mm**
- Field quality **±0.1%** over **23 mm**
- Length **230 mm**

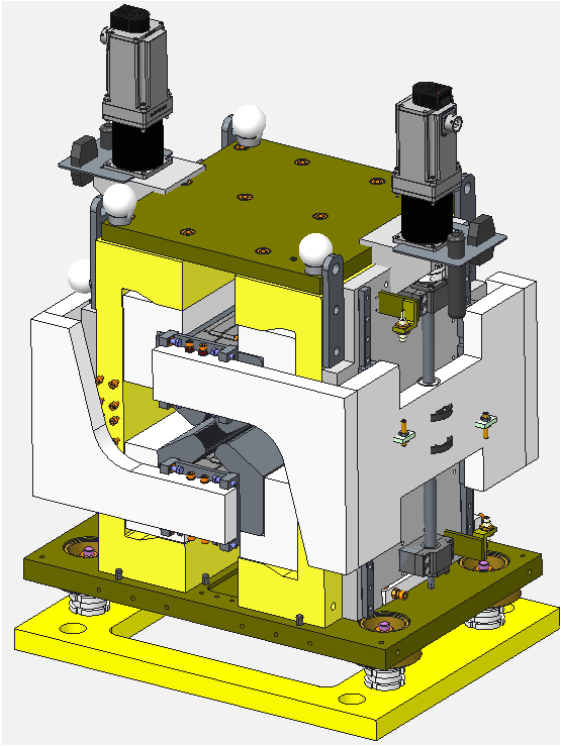




ZEPTO Diamond Quadrupole

- Aim: demonstrate operation of a ZEPTO quadrupole on a working accelerator
- Install a tunable PM quad as a drop-in replacement for an EM quadrupole
- To be installed at Diamond Light Source, on the BTS transfer line
- Enabled by STFC's Proof of Concept Fund
  - Step towards commercialisation of ZEPTO technology
- Design complete
  - Assembly and testing at Daresbury in early 2021
  - Installation at Diamond in May-June 2021 shutdown

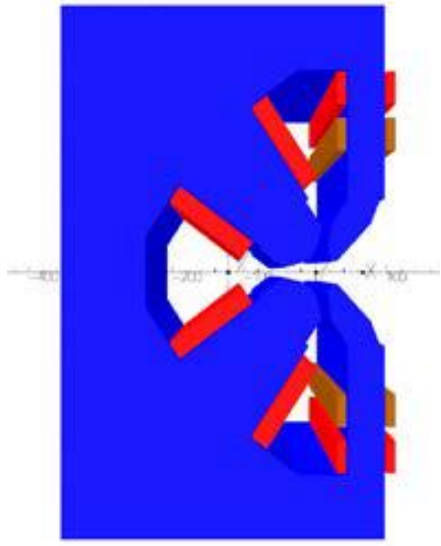




- Similar design to ZEPTO-Q2
  - Outer shell for large tuning range
- SmCo blocks
  - improved temperature stability
  - radiation resistance
- Max gradient **19 T/m**
- Min gradient **0.5 T/m**
- Movement range **90 mm**
- Aperture diameter **32 mm**
- **Splittable** to allow installation around vacuum chamber
- **Two independent motors** for magnetic centre correction

“Diamond-II” prototype

- DQ magnet
- Permanent magnet version
- Tunable over a small range – maybe use coils



Parameter	Value	Unit	Parameter	Value	Unit
Field	0.7	T	Curvature Radius	16421	mm
Gradient	-33	T/m	Yoke Material	Low carbon steel	-
Half Gap at 0.7 T	~14.2	mm	Total Yoke Mass	~1150	kg
Int. B	0.607	T m	Good Field Region (GFR)	±10	mm
Int. G	28.6	T	ΔB/B within GFR	5E-04	-
Iron Length	867	mm	ΔG/G within GFR	1E-03	-

iFAST

“PETRA-IV” prototype

- PETRA IV in TDR phase
- What to do with quadrupoles, DQs, sextupoles: EM or PM?
  - Quads: 90 T/m, 12.5mm radius
  - Sextupoles: 4000 T/m², 200mm length
  - DQs:

Name	L_{eff}	L_{tot} [m]	Ø [mm]	Gradient max	ΔB/B (at radius 7.9 mm)
DQ1	1.02	1.108	>25	0.28 T and 38.4 T/m	$5 \cdot 10^{-4}$
DQ2	0.795	0.895	>25	0.19 T and 27.0 T/m	$5 \cdot 10^{-4}$

- Need to look at adjustment requirements

Outline plan

- MaRS staff to develop magnet design for Diamond-II PM-based prototype
- DLS staff to validate compatibility of design with Diamond systems
- Kyma to develop mechanical design, assemble and test magnet

Magnet Projects	numbers are level of effort	21											22								
Project	**Task**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
IFAST grant agreement					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diamond-II TDR phase		0	0	0	0	0	0	0	0	0	0	0									
Diamond-II booster magnets	Magnet design			0.5	0.5	0.5	0.5	0.5													
Diamond-II DQ magnet	Magnet design				0.8	0.8	0.5	0.4													
	Magnet design				0.4	0.4	0.2														
	Mechanical design					1	1	1	1	1	1										
	Procurement of materials									0.2	0	0	0								
	Assembly													2							
	QA & measurement														1						
PETRA-IV TDR phase		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PETRA-IV quadrupole	Magnet design									1	1	1	1								
	Mechanical design											2	2	2	2	2	2				
	Procurement of materials															0.2	0	0	0		
	Assembly																			2	
	QA & measurement																				1