CLIC Permanent Magnet Studies

CLIC-STFC Work Package Update

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Work Package Content

- Previous STFC-CLIC work package on permanent magnets was reviewed in 2016
  - "*excellent example of potential cost and power reduction*"
  - High cost of PM-based magnets due to complex design
  - Concerns about radiation damage of PMs

- Investigate possibility of reducing magnet costs
- Literature survey of radiation damage in PMs
- PM-based designs for magnet families in CLIC-380
- Construction and measurement of a tunable PM-based dipole

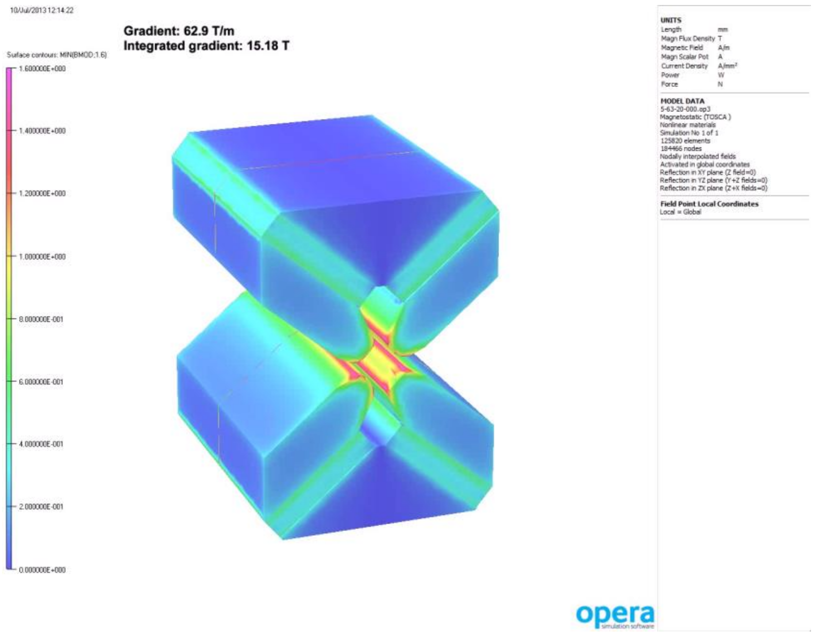
Tunable PM Quadrupole Prototypes

Designed for CLIC Drive Beam Decelerator specifications

Fixed poles; movable PMs; 27 mm aperture; 230 mm length; 1.2-14.6 T integrated gradient range

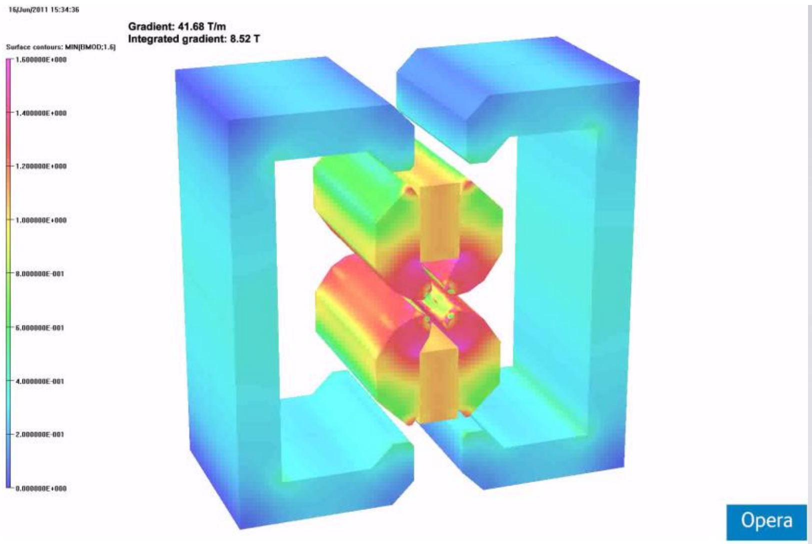
High strength

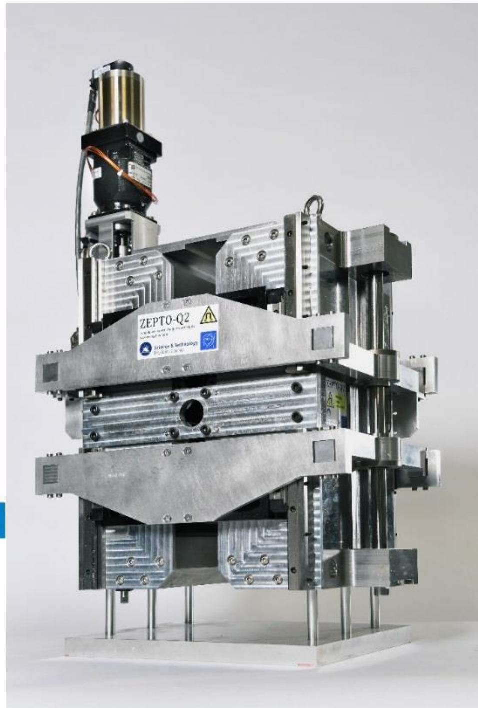
- 15-60 T/m range



Low strength

- 3.5-43 T/m range



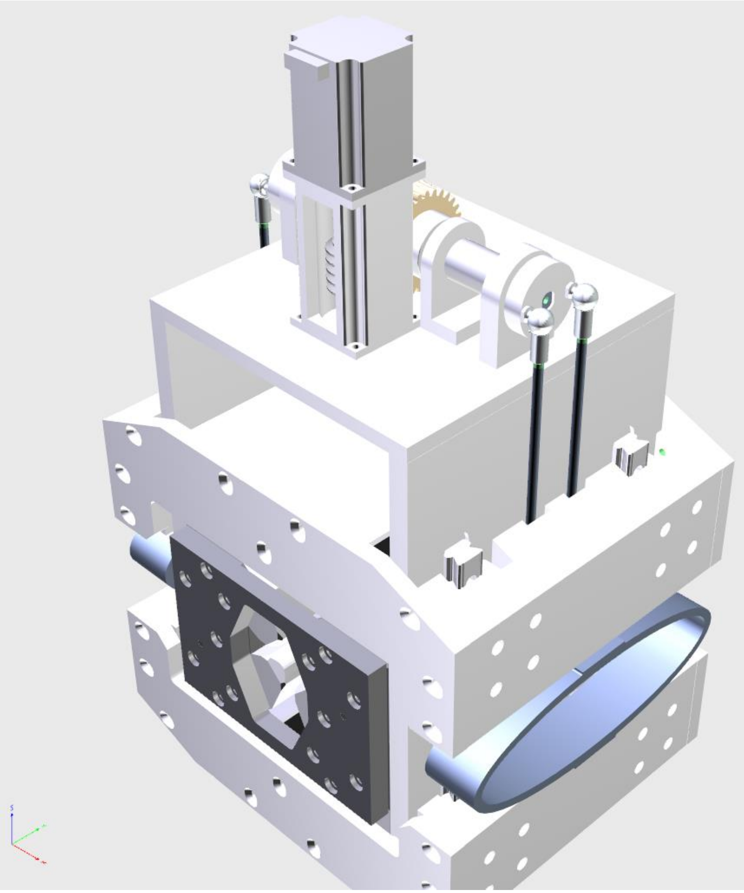


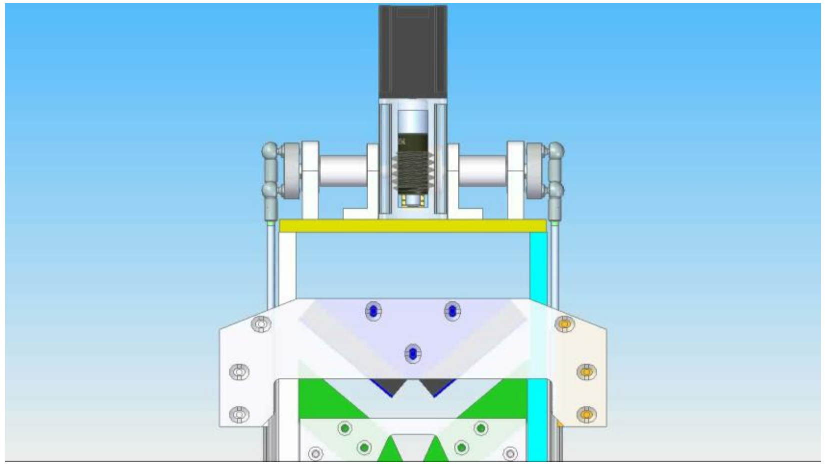
Cost Reduction

- Cost breakdown of ZEPTO tunable quadrupoles (high strength)
  - Single prototype units
  - Production run of 25k units (for CLIC 3 TeV) and 4120 units (for CLIC-380)
- Highest cost subassemblies with estimated % of total cost for production:
  - Drive system (motor + gearboxes) 27%
  - Ferromagnetic poles 25%
  - Permanent magnet 21%
  - Ballscrew 10%

Cost Reduction: Motion System

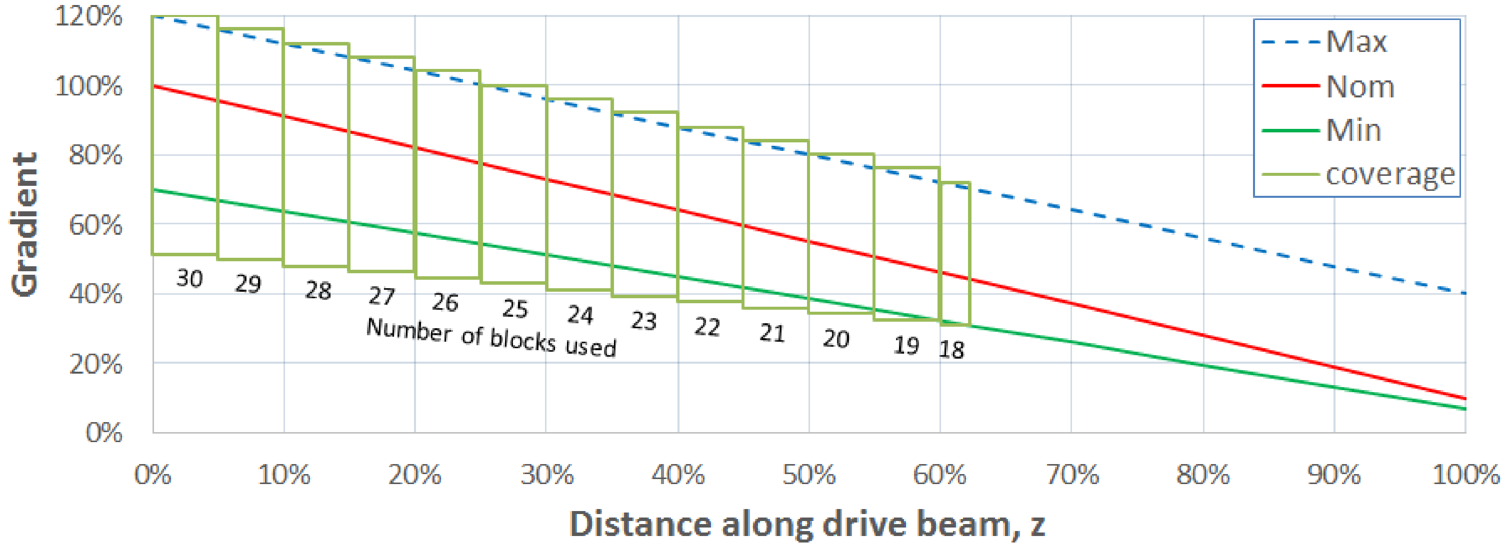
- High cost of prototype motion system due to:
  - Complex gearboxes
  - Large stroke (60-75 mm)
  - Large forces (14 kN)
  - High accuracy (3 µm)
  - Radiation hard motor
- Reduce stroke to 32 mm by using different numbers of PMs (see previous slide)
- Balance out forces using a leaf-spring system
- Replace motor/gearbox/ballscrew with off-the-shelf stepper motor / worm drive





Cost Reduction: PM

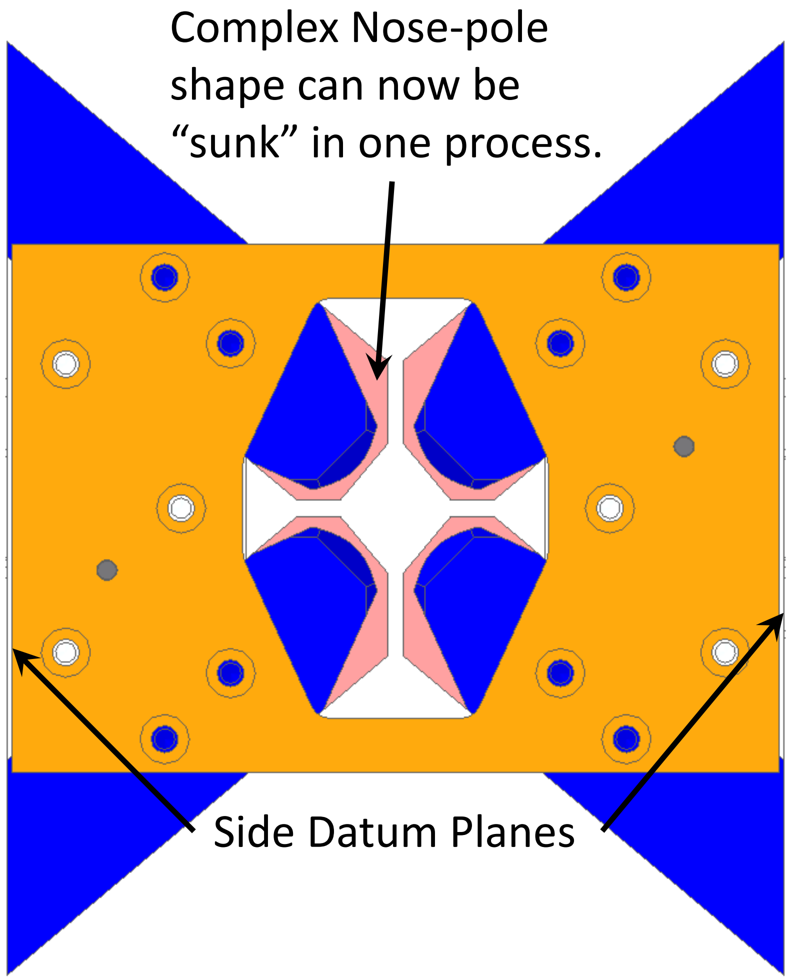
- Prototype quadrupoles used very large PM blocks and large stroke
- Reduce amount of PM used
- This can then be modular – use larger number of subgroups with reduced stroke to cover tuning range



- Only looked at high-strength version so far
- Other cost reduction strategies:
  - Increase block magnetisation tolerance
  - Procure unmagnetised blocks, and magnetise them at assembly time

Cost Reduction: Pole Assembly

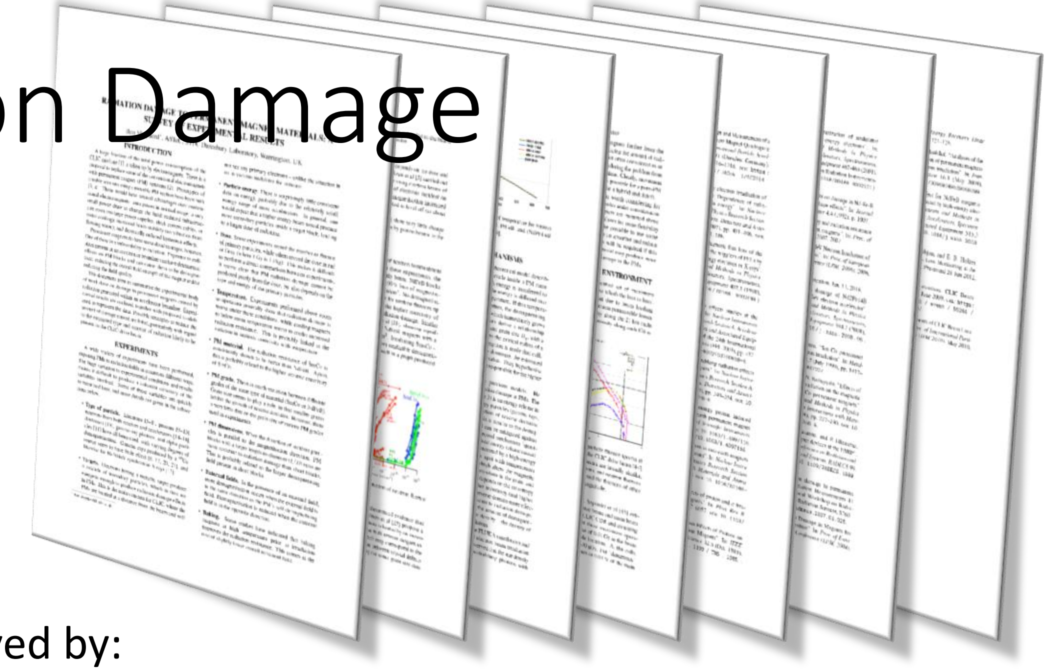
- Complicated due to ‘floating’ poles connected by non-ferromagnetic supports
- Prototype assembly:
  - Manufacture four poles with accurate tolerances
  - Assemble poles and aluminium supports
- Proposed assembly technique:
  - Manufacture poles with coarse tolerances
  - Assemble magnet
  - Carry out accurate EDM machining of pole faces
  - Quicker and more accurate



Cost Reduction: Conclusions

- Largest savings can be achieved by changing:
  a. The Drive system (e.g. motor and gearing principle) – based on smaller stroke
  b. The Linear Motion System (e.g. Rails and carriages)
  c. Pole manufacturing process
  d. Permanent Magnet arrangement
- Original design: £8.3k-£11.5k for 25000 units
- Revised design: **£5.6k-£7.8k** for 4120 units
- Asymmetric cost range: -10%/+25%
  - Saving of **33%**

Literature Survey: PM Radiation Damage



- Many studies have been carried out into effects of radiation on permanent magnets
- To date, no large meta-analysis has been done to bring it all together
- Many contributing factors and experimental variables:
  - Particle type
  - Beam energy
  - Total dose
  - Target material
  - Magnet size
  - Magnet material
  - Magnetisation direction
  - Temperature
  - External fields
- Report completed; awaiting approval from CLIC Accelerator Steering Committee before publication as a CLIC Note
- Hopefully will be a useful reference in this field!

From the conclusion:

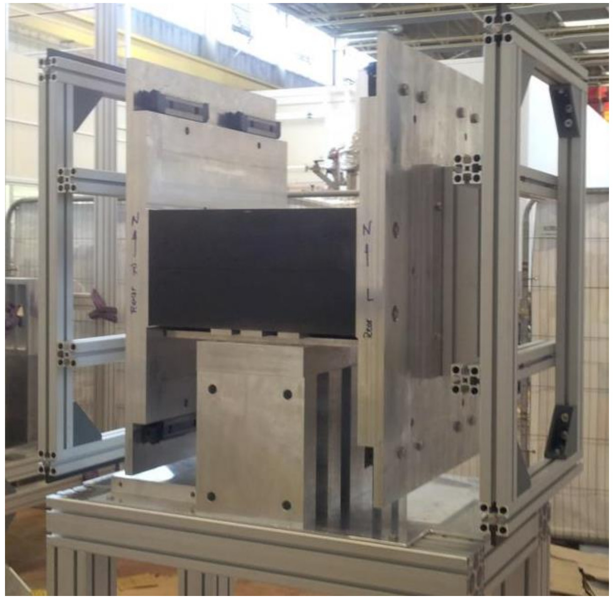
Radiation resistance is improved by:

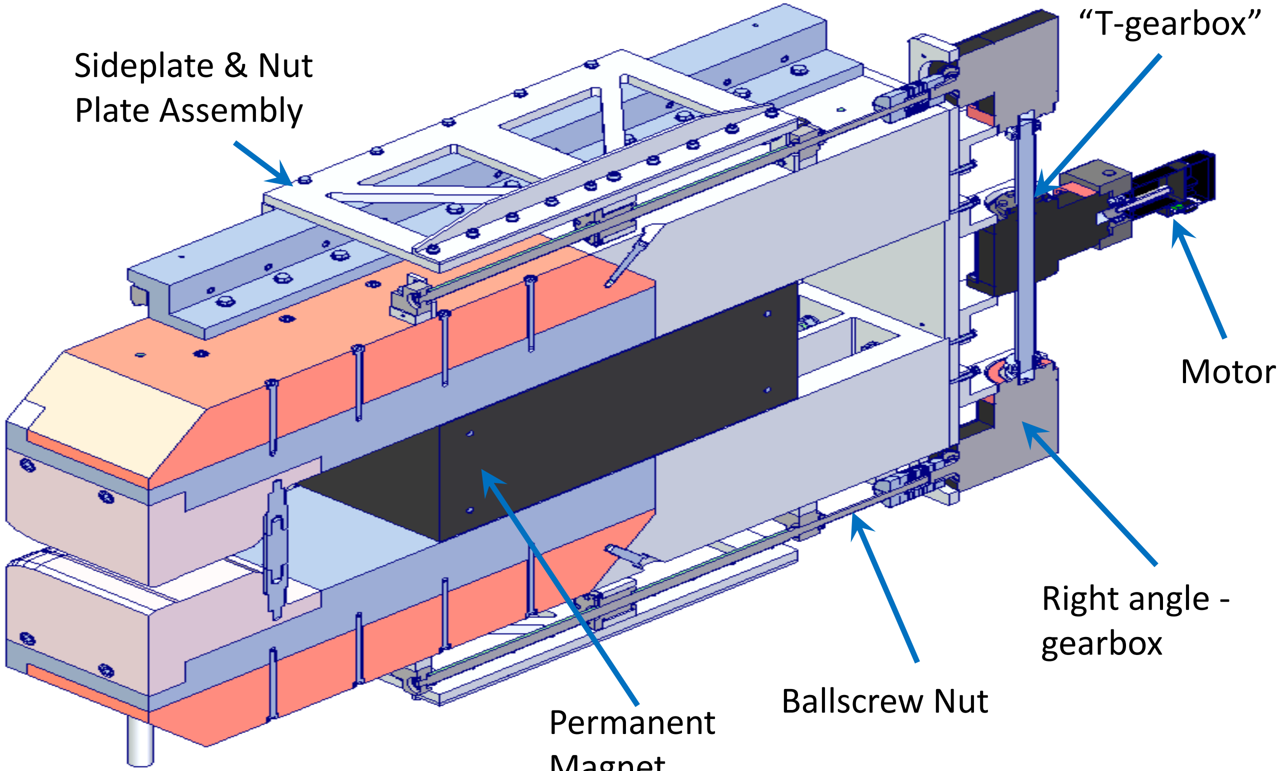
- Using a material with higher **coercivity** (including replacing $Nd_2Fe_{14}B$ with Sm_2Co_{17})
- Increasing the **permeance**, either by altering the shape of the magnet or the geometry of the magnetic circuit
- Decreasing the **ambient temperature**, thereby increasing the material's coercivity
- **Pre-baking** magnets to thermally stabilise them
- Moving magnets away from the beam and introducing **shielding** materials

It is clear that the dose deposited in the magnet is a poor predictor of demagnetisation. The species and energy spectra of particles present need to be considered, and in particular the density of hadronic elastic and inelastic collisions (the star density) may be a useful predictor.

PM Dipole Construction

- PM dipole prototype for CLIC DB-TAL:
  - 0.5-1.1 T
  - 400 mm movement range
  - 40 mm gap
  - 10^{-3} field quality over ±15 mm
  - 500x400x200 mm PM
- Construction under way at Daresbury





Conclusions and Next Steps

- Successful value engineering of the ZEPTO-Q1 high-strength quadrupole prototype
  - Reduction of costs for production run: 33%
- Completed radiation survey literature survey – CLIC note soon

- Next steps:
  - Complete construction and verification of PM dipole prototype
  - Value engineering of ZEPTO-Q2 low-strength prototype
  - PM-based magnet designs for other CLIC-380 magnet types