Estimation of the Force on the Syringe Tie-rods from Fringing Magnetic Fields

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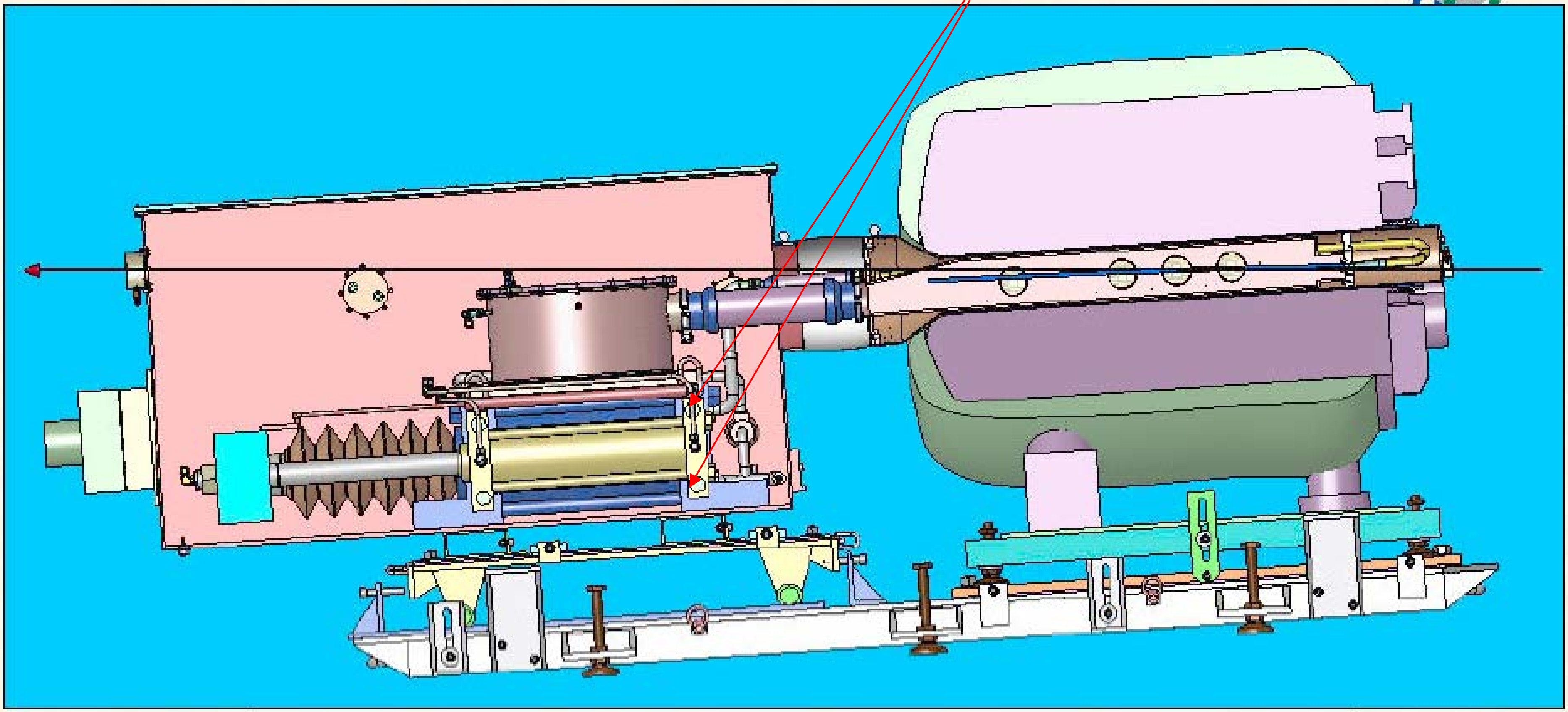
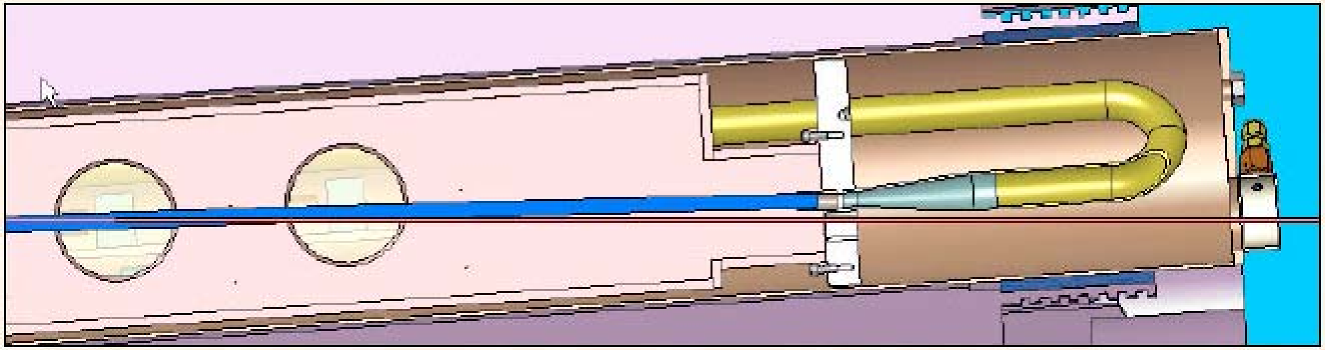
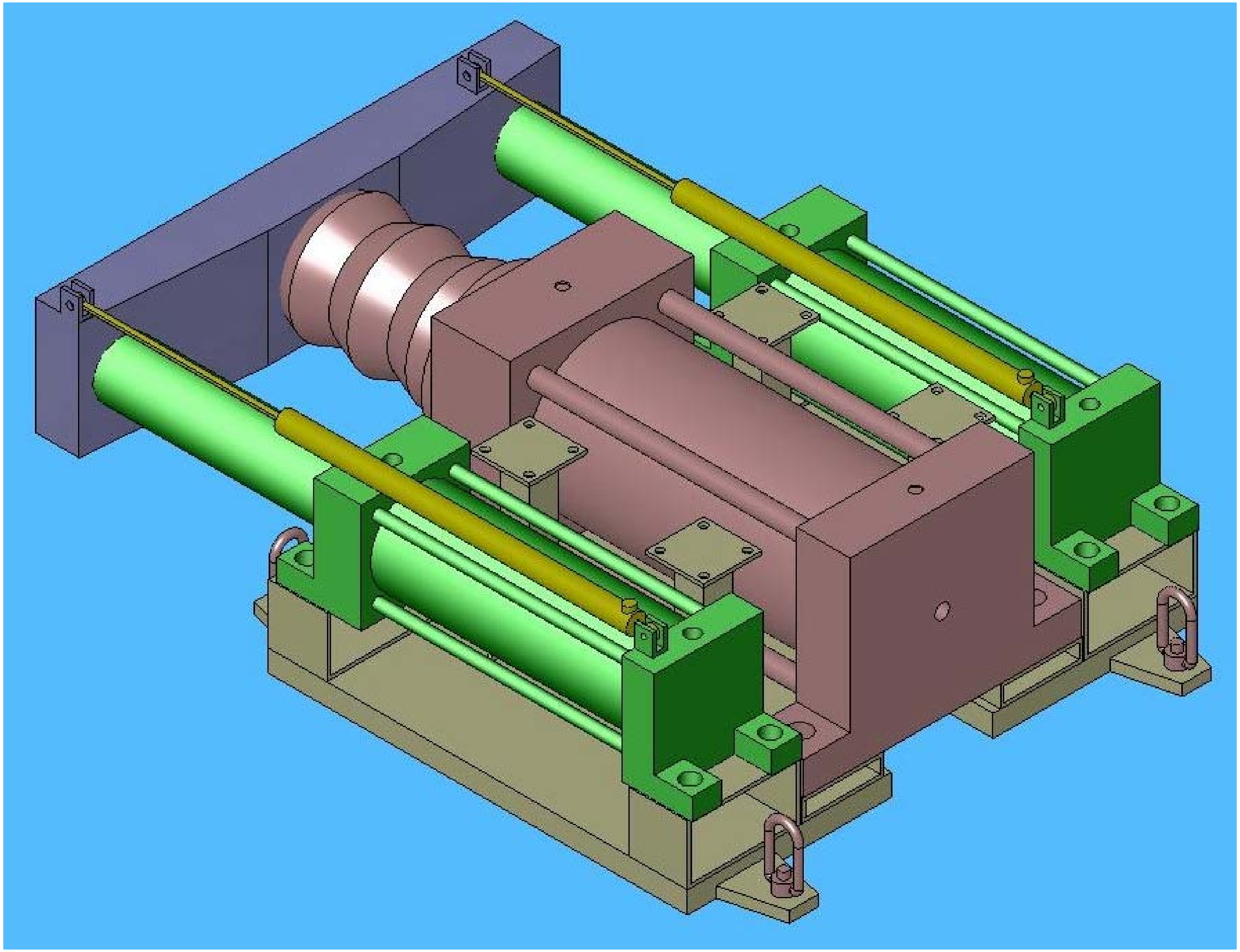
MERIT Side View







Tie-rod Specifications Indicate that They Should Be Non-Magnetic

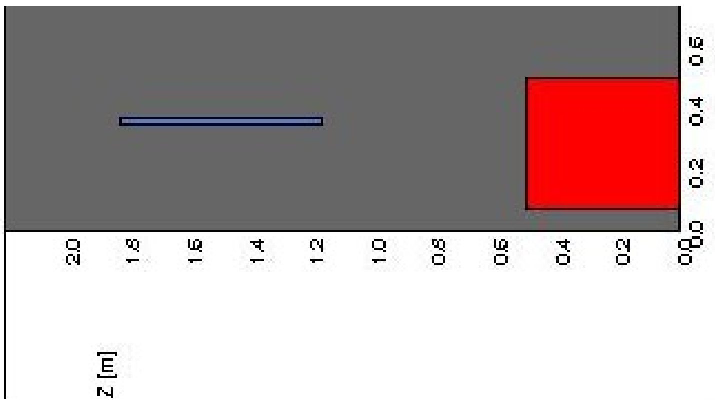
- *1.1.1* ***Tie Beam***

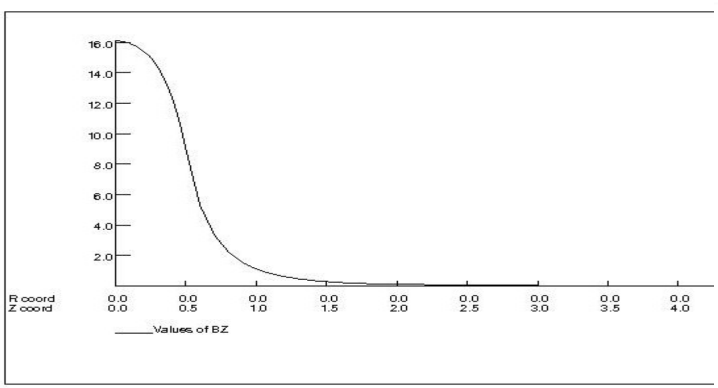
1.1.1.1 The tie beam shall be a demountable, rigid attachment joining the drive cylinder and the pump cylinder rods so that all three move simultaneously.

1.1.1.2 The tie beam shall be fabricated from SS304L or SS316L.

- However Stainless Steel 17-4 PH was used.
  - This stainless steel is martensitic in structure.
  - It is significantly stronger than SS304:
    - Yields at 110 Kpsi instead of 25 Kpsi for SS 304L
  - It is however *Strongly Ferromagnetic in all conditions. (*Allegheny-Ludlam's description).
- Can we use this material for the Merit syringe system or do we send it back and risk schedule delays?

Calculate the Field at the Tie-rods





- The upper figure shows the geometry of the solenoid:
  - Coils in red
  - Tie-rod is in blue
    - Tie-rod is assumed to have the B-H properties of 1010 steel for these calculations.
- The lower figure shows the falloff of the field along the axis.
- The field at the front edge of the tie-rod (closest to the magnet) is
  - B_Z=0.49 T
  - B_R=0.25 T

  These are the fields with out the presence of iron which will distort the fields locally.

The Force Can Be Obtained by Integrating the Maxwell Stress Tensor on a Surface Surrounding the Steel

- The force from the Maxwell stress tensor is given by the following equations where the integration is performed over a surface that surrounds the steel:

$$F_Z = \int_S (B_Z \vec{H} \cdot \hat{n} - \tfrac{1}{2} \vec{B} \cdot \vec{H} \hat{n} \cdot \hat{z}) dS$$

$$F_R = \int_S (B_R \vec{H} \cdot \hat{n} - \tfrac{1}{2} \vec{B} \cdot \vec{H} \hat{n} \cdot \hat{r}) dS$$

- Since we have a 2D (cylindrically symmetric) model, the force is reduced by a factor that corresponds to the circumference subtended by the tie-rods.
  - I have assumed that all eight tie-rods are at the same radius which over estimates the force.

Summary of Force Results

- Force along the axial direction:
  - The total force on the “iron cylinder” is –36123 newtons.
  - The tie-rods subtend 20 cm (8 one inch rods) on a 220 cm circumference.
    - This is an over estimate since half of the tie-rods are at a larger radius.
  - This gives a total force on all the tie-rods of -2580 newtons. Minus sign means toward the magnet.
- Radial Force:
  - Total radial force on “iron cylinder” is –19715 newtons.
  - The force on each tie-rod is -224 newtons. Minus sign means forward the axis.