Bore Tube Status and Plans

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Current bore tube design has several potential problems that need to be resolved promptly.

1. Fracture toughness of Nitronic 40 at 4 K temperature is questionable.
2. The calculated quench pressure are high comparative to capability of current bore tube configuration.
3. Analysis of combined operational and assembly loads lack quality commensurate with required function (importance).

Requirement Summary

1. Provide maximum aperture compatible with current conceptual design physics requirements.
2. Tube to withstand the following operational loads and conditions:
   a. The operational Helium pressure and temperture gradients
   b. Quench generated helium pressure and temperature
   c. Eddy current induced loads
   d. Assembly loads
   e. Cyclic loading both thermal and structural.
3. Tube material to have less than .004 magnetic susceptability

4. Vacuum - integreity and low desorption of the inside surface

5. High conductivity of front surface RRR > 50

6. Manufacturability

Solution Steps

1. Refine loading conditions (stated in #2 above).

2. Construct analytical model to include realistic loading, geometry and material properties. Analytical model to give results usable for definitive design purposes and shall include structural and thermal effects.

3. Establish failure criteria. ASME-ANSI

4. Re-examine quench pressure and temperature analytical model and improve where necessary.

5. Calculate thickness and geometry to meet structural design criteria for candidate materials.

    a. Nitronic 40

    b. 304 LN SS

    c. Aluminum

    d. High manganese steel (Japanese)

6. Examine candidate material (literature search) compatible with loads, operational temperatures and fabricability considerations.

7. Examine magnetic susceptability requirements (Quantize).

8. Examine desorption and high conductivity requirements of inside layer (if required).

9. Test best candidate to verify properties and include instrumentation in magnet detail to verify analytical model.

Method of Solution

The problems outlined are multi-faceted. It requires structural analysis to determine the stresses and deformation, thermal analysis to determine the interior temperatures and failure analysis to relate the former types of analysis with design criteria. In order to perform the structural and thermal analyses, the material properties must be known. Since the materials have not been finalized, the effects of different candidate materials shall be evaluated.

A two-dimensional finite element model (to begin with) will be constructed using the program called MAZE (an Input Generator). A program called TOPAZ2D (TOPAZ3D is also available) will be used to determine the temperature distribution as function of time and position. Transient and steady state temperature fields can be determined. Material properties may be temperature dependent and either isotropic or orthotropic (Kevlar may be treated orthotropic if we can obtain data). The boundary conditions are both time and temperature dependent NIKE2D (NIKE3D is also available), utilizing the results of TOPAZ2D and superimposing additional boundary conditions - forces and displacements, will be used to determine the stresses and strains as a function of time and position. NIKE2D - A vectorized, implicit, finite deformation, finite element code for analyzing the static and dynamic response of 2-D solids reads the temperatures obtained by TOPAZ2D to determine the thermal stresses and displacements. When additional forces are applied, it couples these forces and displacement with the thermal components. As the title implies, NIKE2D includes non-linear effects and requires non-linear material properties data. TAURUS, a post-processor program, is available to process and evaluate the data (including making a movie of some of the results).

These codes MAZE, TOPAZ, NIKE, TAURUS, developed by LLNL, are running on the CRAY computer available to SSC via LBL's VAX. Similar problems were analyzed by LLNL, and since then codes were then updated to extend their capability. Some of the equations used in TOPAZ and NIKE are identical to the basic equations we are using to date for evaluation of bore tube survival. The advantage of these programs is to permit evaluation of the entire system utilizing all the relevant time dependent boundary conditions and the complex geometry simultaneously. In addition, non-linear material descriptions and large (non-linear) deflections of certain components are permitted, as well as friction and gaps between components.

Using the above, the solution steps given in the previous section can be followed. It will be a simple matter to, for example, evaluate the effect of different materials that we will be bound to encounter. In addition, since 3D versions are also available, it will be possible to evaluate the effects along the tube. In both the 2D and 3D versions, large deflections, voids, and sliding can be included. Most of the limiting assumptions now employed, especially regarding the interfaces, are not required in applying these programs.

The following figures provide the geometry. The bore tube detail is given in Section A. Solution will treat entire cold mass assembly.

Time dependent loads and temperatures can be specified along any boundary (surface). The cases to be evaluated are as follows:

1. Assembly
    a) pressure f(t).
    b) deflection g(t).
    c) frictional forces (μn)
    d) winding forces (on Kevlar)
2. Normal Operation (includes 1 above)
    a) pressure (vacuum, 4 atm, 22 atm).
    b) temperature (80°K then 4.5°K)
    c) eddy current forces (B, Bo, E, μ, t cu) 0.3 sec
    d) Lorentz Force
3. Cool down (includes 1 and 2 above)
    a) pressure
    b) temperature
4. Quench (include 1 and 2 above)
    a) Worst case - Fire heaters, temperature, 4.5°K in milliseconds to 400°K, .3 sec., Pressure
5. What if Problems

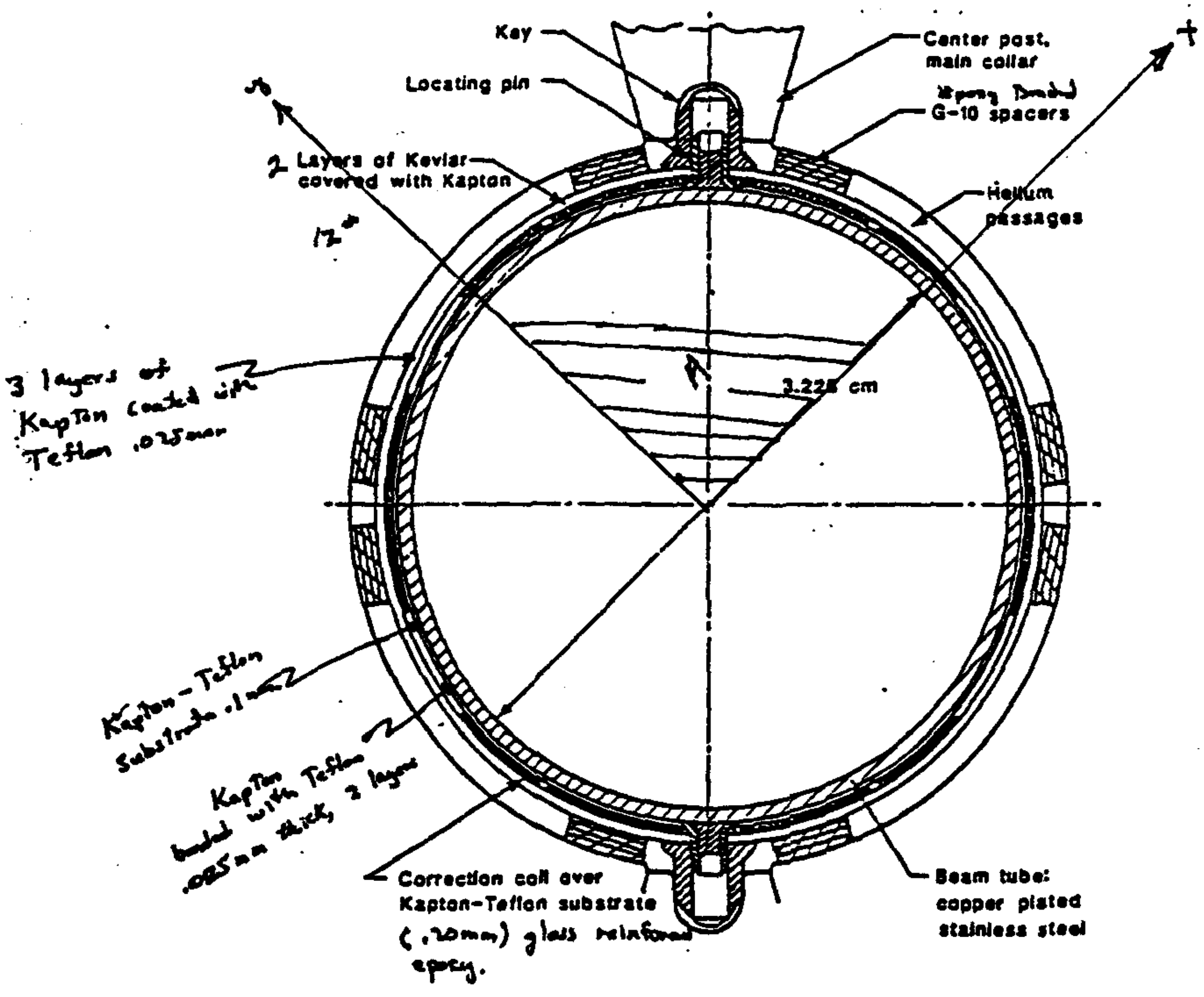
Key
Locating pin
Center post, main collar
Epoxy bonded G-10 spacers
2 Layers of Kevlar covered with Kapton
Helium passages
12°
3 layers of Kapton coated with Teflon .025mm
3.225 cm
Kapton-Teflon substrate .1mm
Kapton bonded with Teflon .025mm thick, 2 layers
Correction coil over Kapton-Teflon substrate (.20mm) glass reinforced epoxy.
Beam tube: copper plated stainless steel

Fig. 1

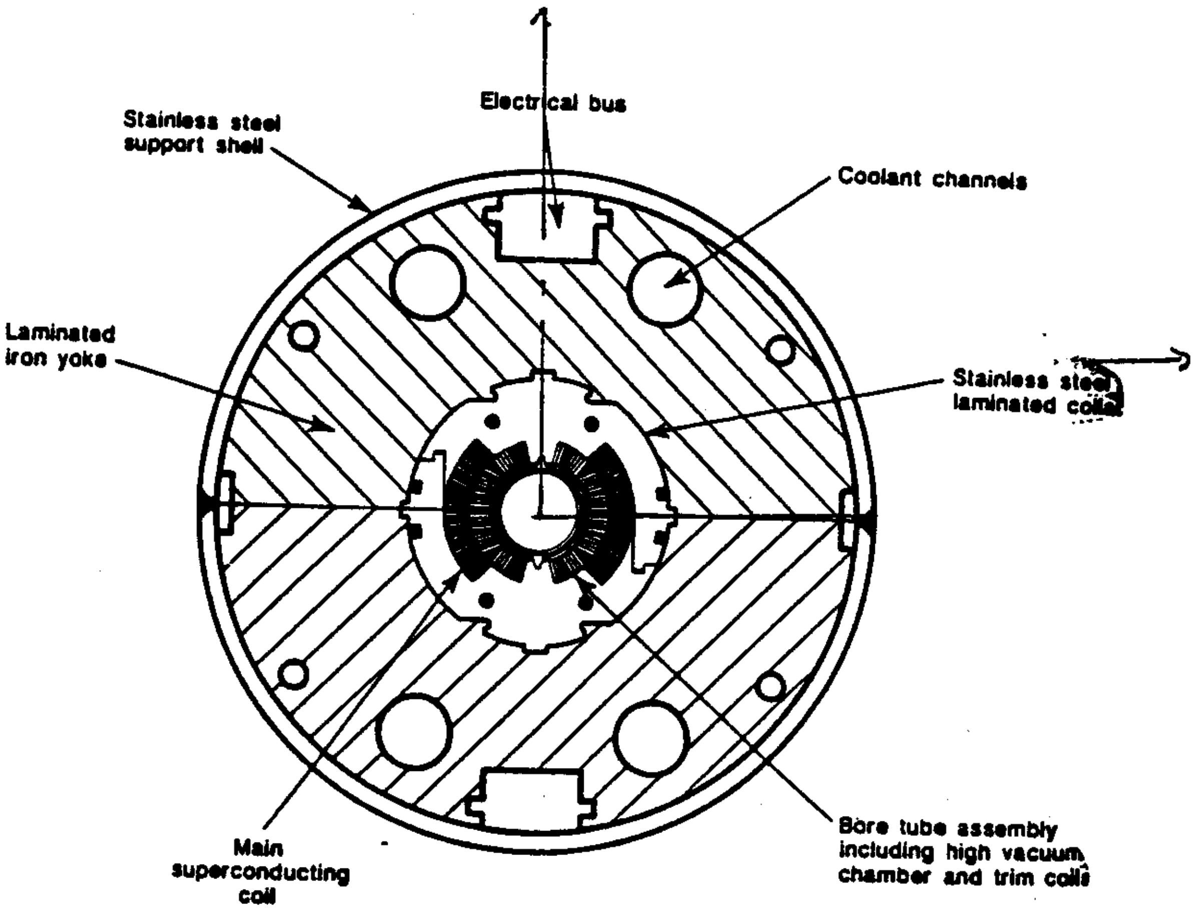

Fig. 2 Overall cross section of dipole showing coil, collars, iron yoke, and yoke support tube

NIKE2D - A Vectorized, implicit, finite deformation, finite element code for analyzing the static and dynamic response of 2-D (3-D) solids.

TOPAZ2D (3D) - A two-dimensional (three-dimensional) finite heat transfer code.

TAURUS - An interactive post processor for the analysis codes NIKE3D, DYNA3D, TACO3D, and GEMINI.

MAZE - an input generator for DYNA2D and NIKE2D.

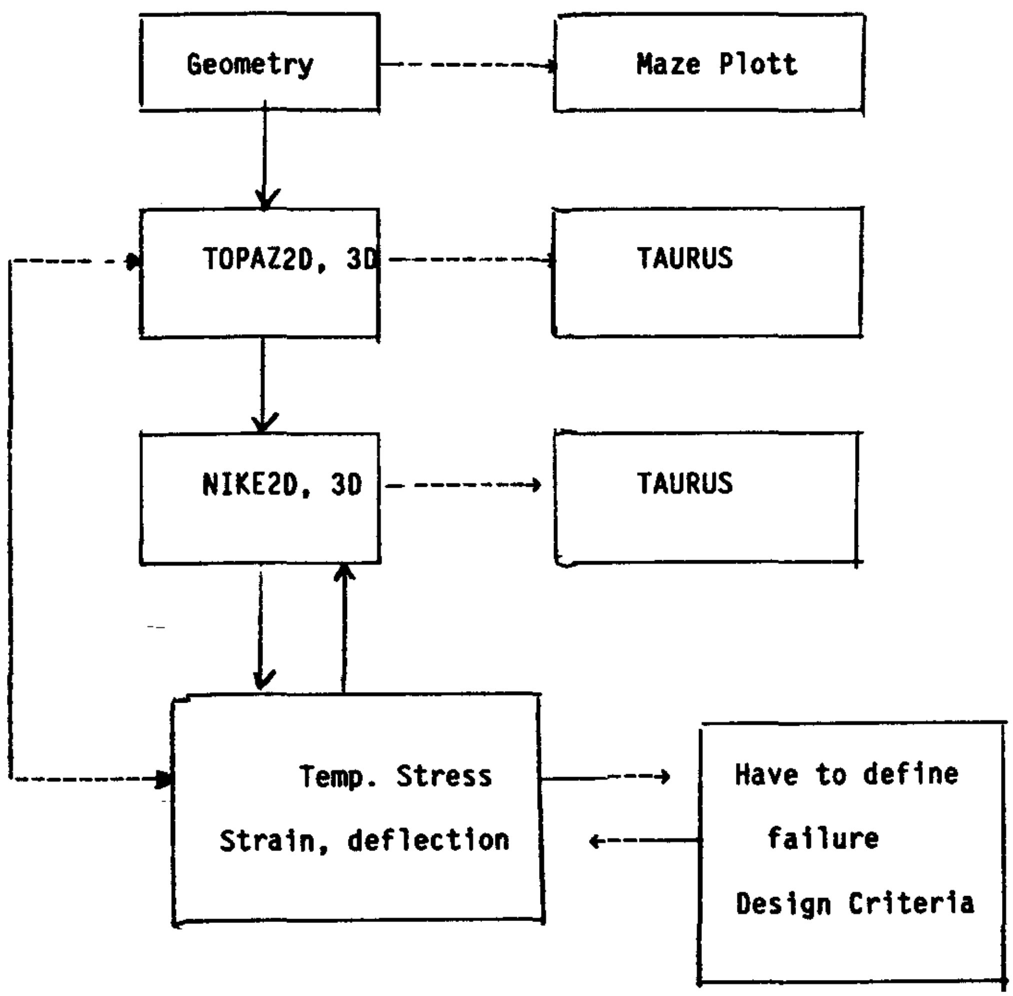

Fig. 3 Flow chart indicating procedure followed.