Poloidal Field Coils Studies Using 2G-HTS Tape for Demo
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Abstract
One of the important technologies to be used in future Tokamak is Superconducting magnetic coils due to high magnetic field requirement for plasma initiation, Ohmic heating, inductive current requirement in plasma driving, shaping, equilibrium, and stability control. Recent development in High Temperature Superconductor (77K HTS) and availability of 2nd generation has proven that HTS can produce higher magnetic field than conventional Superconductor (4 K). This will not only reduce the size of the Demo/fusion reactor but also have effect on cost. However the HTS is rather new technology, therefore following steps/checks are required before there use in Demo/reactor [1]:
- High current conductors/cables development
- Development of advanced magnet structural materials and structural configurations
- Development of cryogenic cooling methods for HTS magnets
- Development of joints for demountable coils
- Coil fabrication technology

We made some initial study of poloidal field coils of moderate size using 2G HTS tape (12 mm width, critical current > 650 A and LN2 cooling). Simulations are performed with varying radius and distance between the coils. Work/study is divided in to two parts, numerical simulation and experimental work. A comparison of experimental results with simulation is made.

Introduction
Currently there are several concepts for DEMO power plant based upon tokamak fusion. One of them is using HTS magnets combined with low aspect ratio spherical tokamak based Demo plant/pilot plant to minimize the reactor size. The parameters of proposed ST pilot plant by Menard et al [2] are:
- Major radius (R) = 3 m
- Aspect ratio (A/n) = 2 (to have space for small HTS Central solenoid for plasma current anitipation)
- Elongation (κ) = 2.5
- Triangularity (B/a) = 0.5
- B=1.1
- JN=4.2
- PST = 500 MW
- Fp=560 MW

Continues TF coils with no joints
All PF coils are HTS and are out side TF coils
Spherical Tokamak (ST) is a low aspect ratio magnetic confinement device whose aspect ratio (A/Ra) is equal or less than 2. Spherical Tokamaks research have received great attraction due to natural elongation, high B (1/1A) and being economical.

Role of Poloidal Field coils in Tokamak
Poloidal field coils are important for tokamak equilibrium, elongation, plasma shaping and divertor configuration etc. Working Principle of Equilibrium and Elongation (PF) Coils is illustrated below:

High Temperature Superconductor (HTS)
Recent development of a new generation of High Temperature Superconductors (2G HTS) opens promising opportunities for high field magnets in Spherical Tokamaks, where space in the central stack is very limited.
HTS tape have very low conductivity at room temperature. It shows superconducting behavior at 77K (Liquid Nitrogen temperature) Conventional superconductor needs 4 K (Liquid He temperature)

Advantages: Low power consumption Low cooling power consumption as compared with LTS

Types of 2G-HTS conductor
- YBCO (Yttrium, Barium Copper Oxide) Ic≥500A
- GdBCO (Gadolinium, Barium Copper Oxide) Ic≥600A

Cable fabrication at different institutes
Transposed, scalable to 50–100 kA, designed for B < 12 T
Uglietti et al. EPFL – CRPP, HTS Fusion 2015
Designed for segmented magnet and BJJ (no transposition, rotation of conductor to match the field direction, 100 kA).
Bruzzzone, EPFL – CRPP, HTS Fusion 2015

Conductor On Round Core van der Laan et al., Advanced Conductor Technologies & University of Colorado

Mathematical Model for Poloidal Field
According to Ampere law:
\[ \nabla \times E = -\frac{\partial B}{\partial t} \]
\[ B = \frac{\mu_0}{2\pi} \frac{I}{r} \]

It can be written in term of vector potential as:
\[ \nabla \times A = -\frac{\partial \mathbf{E}}{\partial t} \]
\[ \mathbf{E} = \mathbf{\nabla} \times \mathbf{A} \]

Ampere law can be re-written after inserting the value of B
\[ \nabla \times \mathbf{A} = -\frac{\partial \mathbf{E}}{\partial t} \]

Where K and E are complete elliptical integral of first and second kind. Radial and axial component of Magnetic field can be given as [3]

\[ B_r = K \int_0^\infty \frac{\mathbf{E}}{r^2} \, dr \]

\[ B_z = E \frac{\partial}{\partial z} \]

No Insulation (it helps to avoid quenching and hotspot formation)
- No of coils 1
- No. of turns 37
- Diameter of coil 600 mm
- Thickness of HTS tape 0.16 mm
- Width of HTS tape 12 mm

The joints are made with the silver solder at 150°C to reduce joint resistance

Observations/Discussion
- It was expected to get more current 37×650A from the coil. However measured current is 2000A which is far below
- The current profile of the wire and coil is different. This difference comes due to the fact that Superconductor response differently at the high frequency current as compared to the continuous DC current
- As the HTS conductor is without any insulation so the possibility of current leaking across the turns does exists
- Further investigation is required

References

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