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Design of the Magnetic System of Pakistan Spherical Tokamak (PST) for Steady State Operation

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ABSTRACT

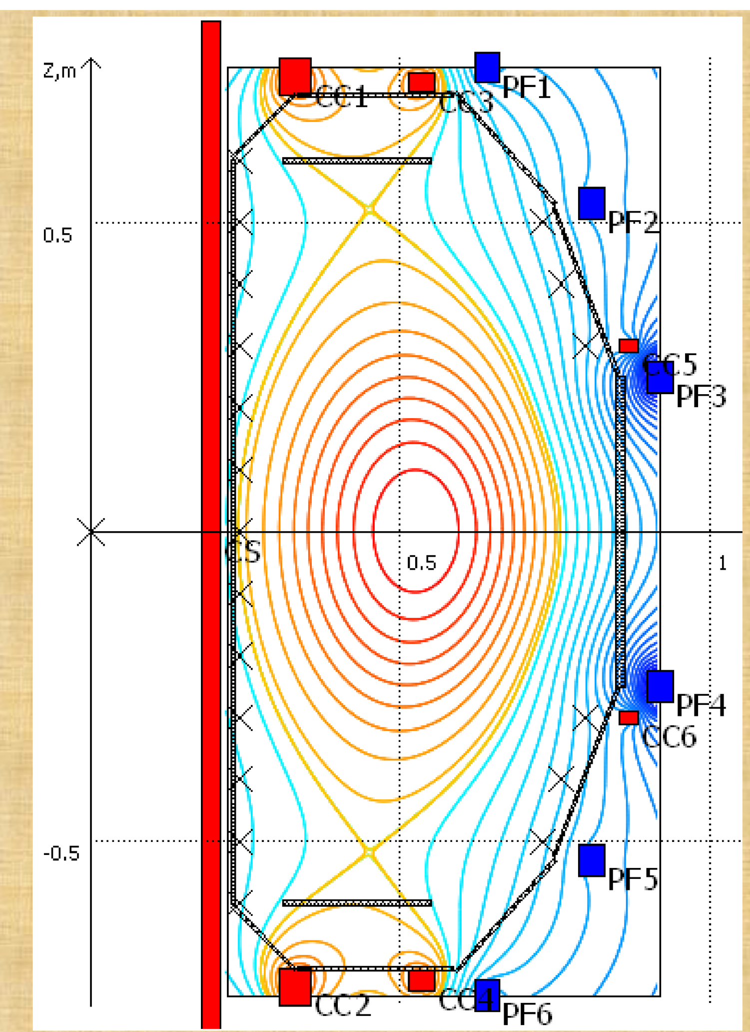
- Spherical Tokamak (PST), a medium size tokamak, is in the conceptual and physics design phase. Purpose of this device is to explore plasma parameters for Steady State Operation in the limit of aspect ratio (A=2).
- To meet the volt-sec requirement, current in CS is estimated. Whereas using TOKSCEN code, equilibrium is generated to estimate location, current and number of turns in compensation and poloidal field coils..
- Two different configurations of TF coils are used as case study. In this study the ripple factor is calculated using FEM method for both TF assemblies by varying location of outer limbs of TF from 80 cm, 85 cm, 90 cm, 95 cm and 114.5 cm.

BACKGROUND

- Spherical Tokamak research gained attention due to natural elongation, high β (∝1/A) and being economical..
- Pakistan Spherical Tokamak (PST) some of its basic parameters are; major radius R = 0.5 cm, minor radius a = 0.25cm, Aspect ratio A = 2.0, Elongation κ = 2.0, Toroidal Magnetic Field B_T=0.5T..
- There are mainly three coils systems in PST; central solenoid (CS) along with compensation coils (CC) used to produce toroidal E-field, poloidal field (PF) coils to keep the plasma in equilibrium and away from the tokamak walls, and toroidal field (TF) coils to stabilize the plasma.
- Toroidal magnetic field has importance due to the fact that volumetric fusion power density varies with ~ B_0^4.
- Present study focuses on the design of magnetic coils system of PST considering plasma equilibrium in tokamak.

CS and PF COILS SYSTEM

MHD safety factor, qa = 2.5 is considered which is well above the disruptive Kink safety limit. With this safety factor and toroidal field, the plasma current is estimated as 310 kA. Similarly plasma beta (β) is estimated as 9% with incorporating effect of elongation (κ). Equilibrium is generated using TOKSCEN code. Double null equilibrium configuration with up down symmetry has been generated considering elongation 2. In this equilibrium configuration CS and CC are connected in series so that the similar current with similar profile will flow from these coils which will be helpful in reducing error field. Additionally this configuration will help in reducing the nos. of power supplies. The simulation is performed with top bottom divertor, inner and out limiter and vacuum vessel.



Coil	Location		MA*Turns
	R (m)	Z (m)	
CS	0.195	0	2.55
PF1	0.64	0.75	-0.03
PF2	0.83	0.53	-0.005
PF3	0.92	0.25	-0.062
PF4	0.92	-0.25	-0.062
PF5	0.83	-0.53	-0.005
PF6	0.64	-0.75	-0.03
CC1	0.33	0.735	0.153
CC2	0.33	-0.735	0.153
CC3	0.535	0.725	0.068
CC4	0.535	-0.725	0.068
CC5	0.86	0.3	0.024
CC6	0.86	-0.3	0.024

Equilibrium of PST tokamak for optimizing current and location of coils

TF COILS SYSTEM

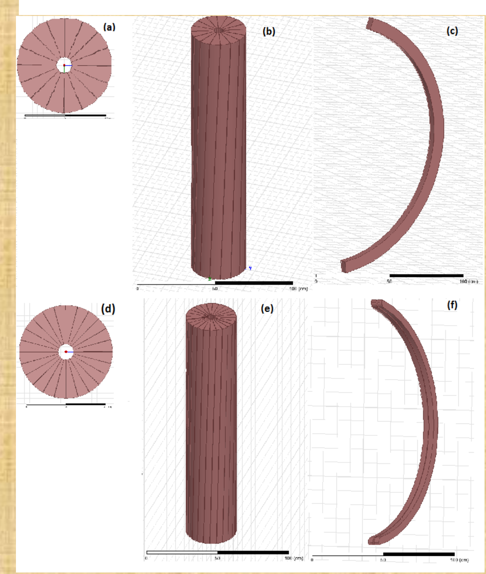
Demountable, water cooled, copper made, Toroidal field coils with twisted center stack are proposed which helps in easy joints and provide additional loop voltage for start-up. The twisted inner leg adds novelty in the design. Two different configurations of TF coils are used as case study. In one configuration single layer 16 turn equi-spaced coils are used whereas in other configuration 12 turn double layer equi-spaced coils (12x2) are used.

TF RIPPLE FACTOR

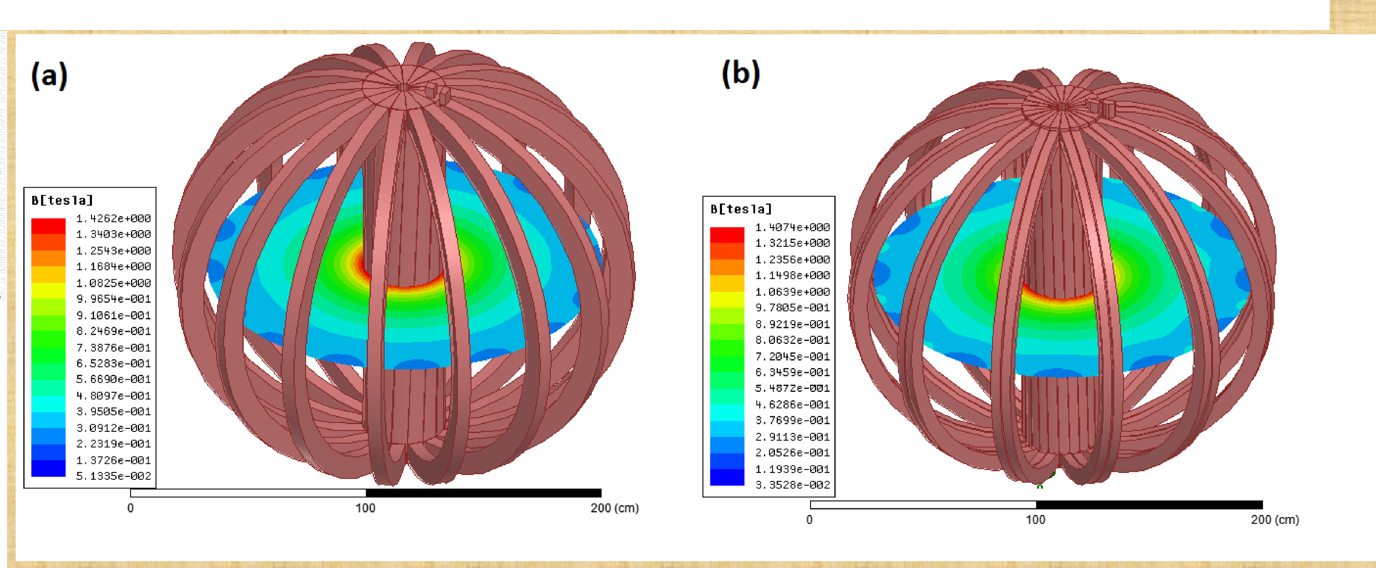
TF coils study mainly focuses on the ripple factor in spherical tokamak. The relation for the ripple factor is .

$$\delta = \frac{B_{max} - B_{min}}{B_{max} + B_{min}}$$

B_{max} is the field at the mid position of coil width, and B_{min} is the field between two adjacent coils. The ripple factor is calculated using FEM method for both TF assemblies by varying location of outer limbs of TF from 80 cm, 85 cm, 90 cm, 95 cm and 114.5 cm.



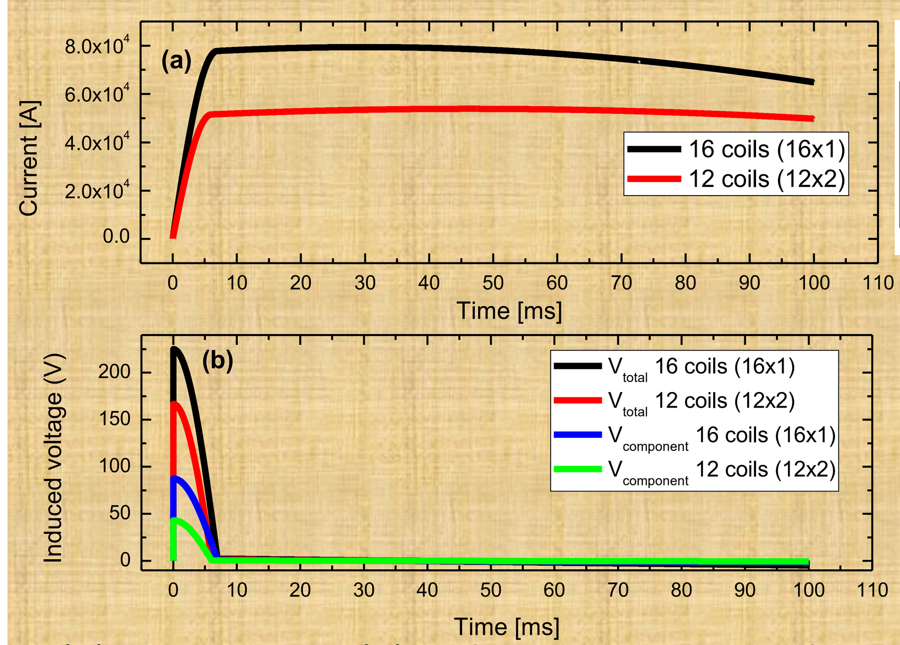
TF coils (16x1) and 12 TF coils (12x2) system.



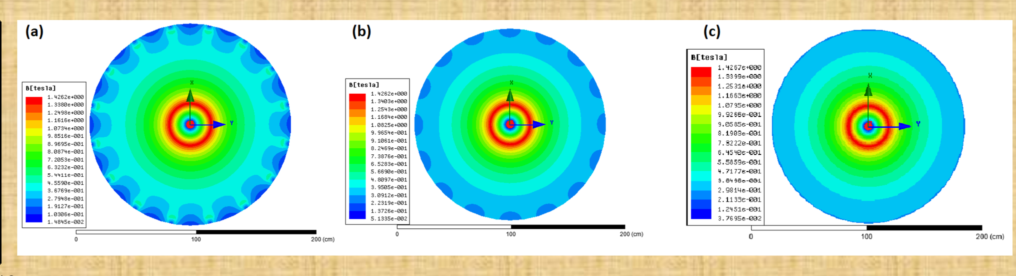
Magnetic field pattern at mid plane (a) 16 coils (16x1) and (b) 12 coils (12x2) of toroidal field coil system.

No. turns of TF	Physical parameters	114.5 cm	95 cm	90 cm	85 cm	80 cm
16 coils (16x1)	δ at plasma centre	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0.001
	δ at plasma edge	0.002	0.0135	0.031	0.063	0.176
	Inductance (mH)	0.219	0.149	0.143	0.136	0.130
	Flux (Wb)	17.17	11.658	11.182	10.683	10.202
	Resistance (mΩ)	0.231	0.208	0.201	0.194	0.191
	Mass(kg)	4865	3736	3655	3584	3494
12 coils (12x2)	δ at plasma centre	10^{-4}	10^{-4}	0.001	0.0016	0.0028
	δ at plasma edge	0.0059	0.0445	0.078	0.144	0.300
	Inductance (mH)	0.505	0.339	0.325	0.311	0.296
	Flux (Wb)	26.324	17.658	16.911	16.203	15.443
	Resistance (mΩ)	0.704	0.555	0.549	0.541	0.522
	Mass(kg)	4076	3109	3055	3001	2929

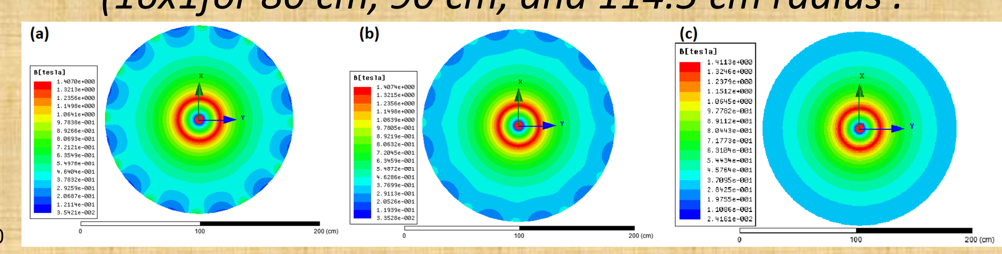
Comparison of parameters of the TF coil having 16 and 12 (pairs) turns



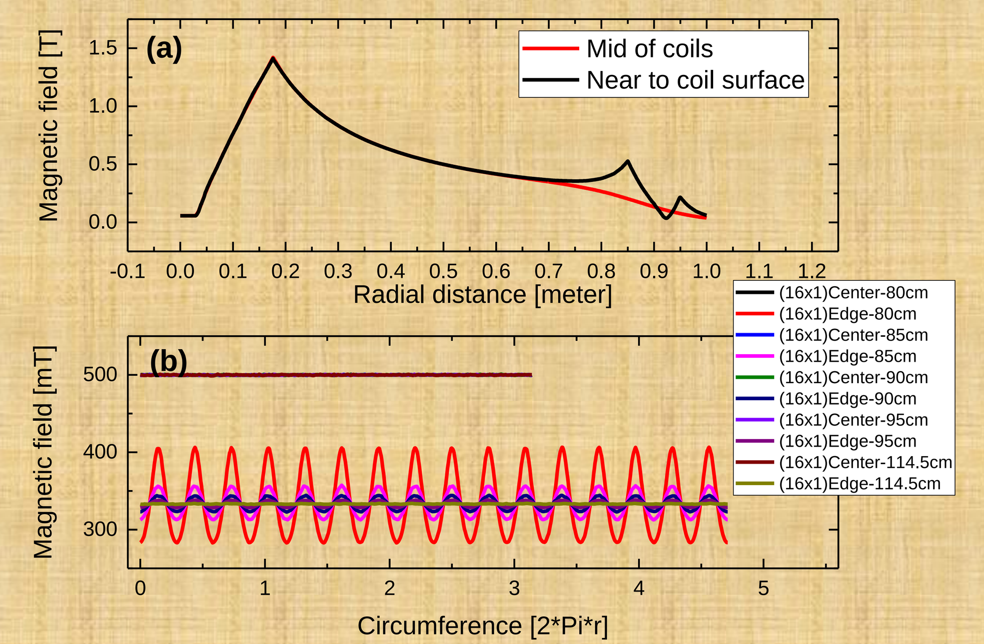
(a) Currents and (b) self-induced voltages for 16 coils (16x1) and 12 coil (12x2) system



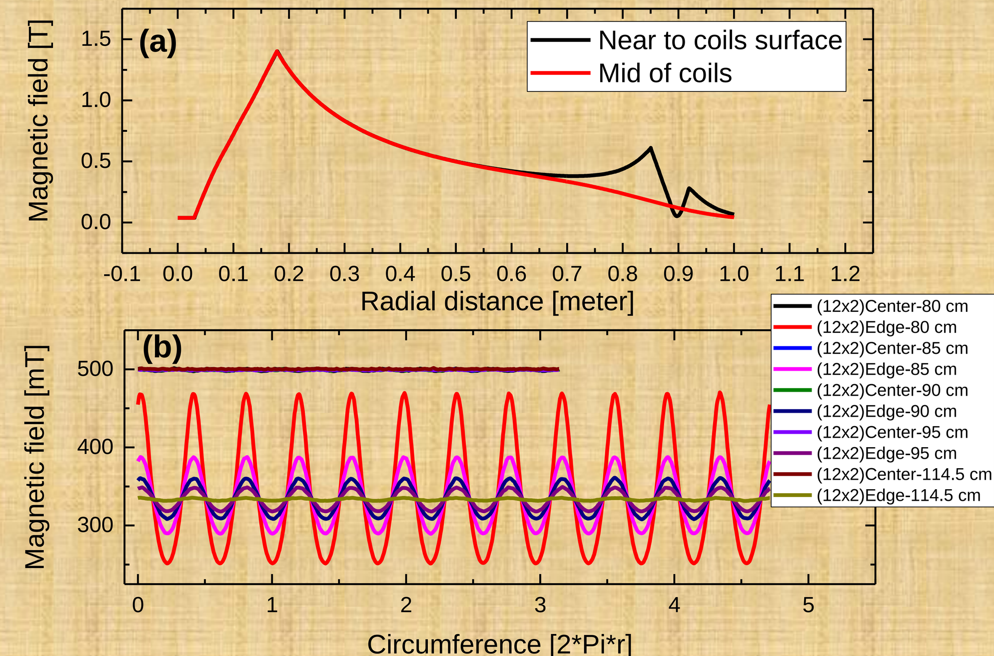
Cross sectional view of ripple pattern of 16 coils (16x1for 80 cm, 90 cm, and 114.5 cm radius .



Cross sectional view of the ripple pattern of 12 coils (12x2), for 80 cm, 90 cm, and 114.5 cm radius



Ripple factor comparison for 16 coils (16x1) at plasma center and plasma edge for 80 cm, 85 cm, 90 cm, 95 cm and 114.5 cm of outer limbs.



Ripple factor comparison for 12 coils (12x2) at plasma center and plasma edge, for 80 cm, 85 cm, 90 cm, 95 cm and 114.5 cm radial distance of coil geometry.

CONCLUSION

- The toroidal field coils have been designed for 0.5 T, the ripple factor for both 16 coils (16x1) and 12 coils (12x2) is within the allowed limit.
- Ripple factor for both coils systems decreases significantly with increase in the radius of outer limb.
- The current 52 kA/turn required for 12 coils (12x2) is smaller than the current 78 kA/turn require for 16 coils (16x1), therefore the 12 coils (12x2) save more energy for the same magnetic field.
- Furthermore under same condition the current profile has more flat top region for 12 coils (12x2) system.
- Hence the 12 coils (12x2) system is relatively more suitable for PST