Magnetic Field Studies in Toroidal – Poloidal Systems

ID: 1342

M. Salvador[1], E. Chapa[1], A. Acosta[1], J.A. Guevara[1], R.M. Chávez[1], V.M. Arredondo[1], L.R. Hernández[1], F.A. Sánchez[2], O.A. de la Garza[2], H.G. Ramírez[2], S. Martínez[1-2]

In memoriam | G.M. Vorobyov

[1]Grupo de Investigación en Fusión, [2]Grupo de Energías Térmica y Renovable

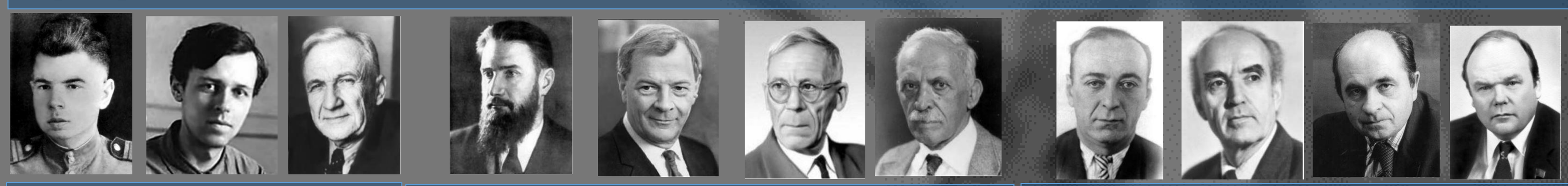
Facultad de Ingeniería Mecánica y Eléctrica, Universidad Autónoma de Nuevo León, México

max.salvadorhr@uanl.edu.mx, emiliochvi@gmail.com

ABSTRACT

- Electromagnetic studies have been carried in the development of a magnetic system.
- Design of "D-shaped" coils for a magnetic confinement device.
- Mathematical analysis of the D-shape form is reached whose solution can be given analytically or numerically to obtain several D-shaped profiles
- Electromagnetic and conductor design considerations to establish properly a robust design.
- Configuration of the toroidal coil design in three dimensions with the help of SolidWorks software (3D CAD design).
- COMSOL Electromagnetic models have been proposed to determine a suitable D-shaped coil to be construct.
- Preliminary study on solenoid design assembling this toroidal-poloidal electromagnetic system.

- This toroidal magnetic configuration is one of the most promising conceptions on nuclear fusion field, since I. E. Tamm and A. D. Sakharov in the time of the Soviet Union in the 50´s published their interesting article on magnetic fusion as so many others in the next decades [1-4].

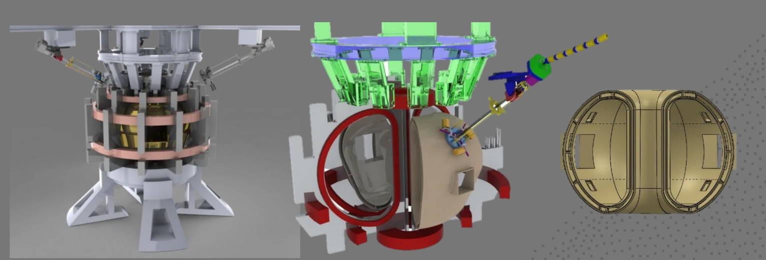


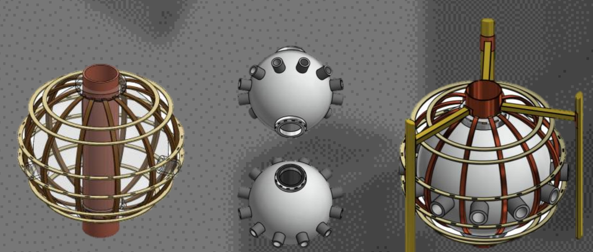
Lavrentiev Shakarov Tamm | Kurchatov Artsimovich Leontovich Golovin | Yablinsky Shafranov Kadomsev Belikov

Tokamak "T": GIF-UANL | México
LAR "T" Tokamak | Spherical Tokamak "T"

Spherical Tokamaks proposed by the GIF-UANL | México

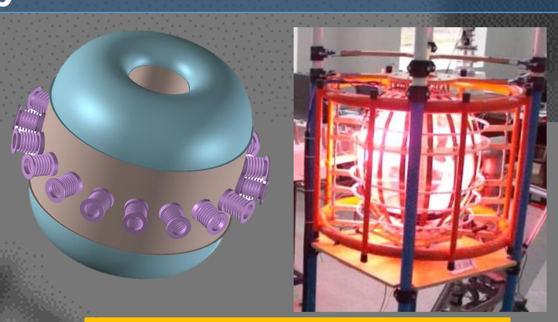
[1] AZIZOV, E. A. 2012





Major radius 41 cm (R), minor radius 18.5 cm (a), aspect ratio 2.2162 (A), safety factor 1.9552 (q), plasma current 277 kA (I_P), toroidal field 1.3 T (B_T), ionic temperature 280 eV (T_i), electronic temperature 516 eV (T_e), electronic plasma density 2−3 × 10^{13} cm^{-3} (η_e).

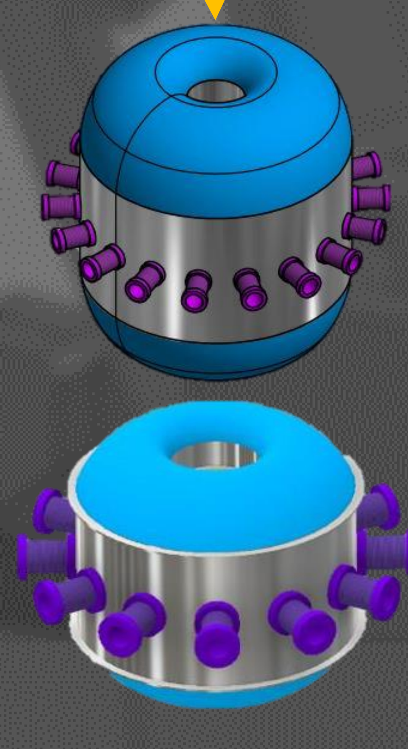
Spherical Tokamaks proposed by the SPbSU: A.B. Mineev – G.M. Vorobyov | Russian Federation



Spherical Tokamaks developed in the course of our High Magnetic Field Program: 0.5 - 3T UANL - SPbSU

Spherical Tokamaks characteristics by the SPbSU – UANL Program 0.5 – 3 T

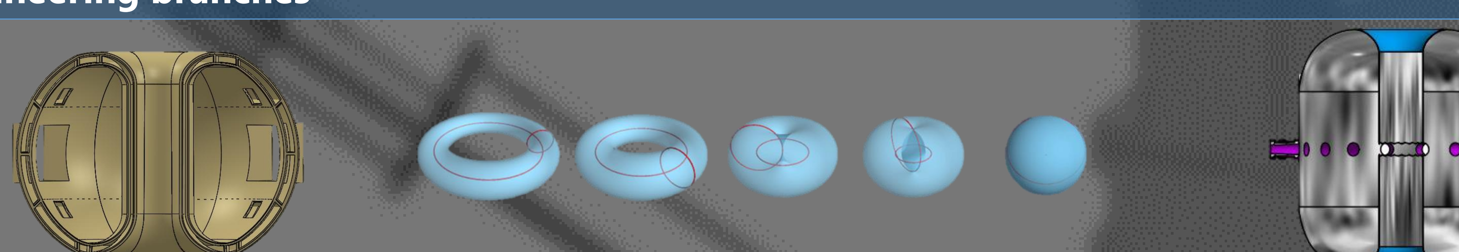
General parameters: UANL-SPbSU	Design
Material chamber	SS 304 LN
Major radius (R)	25 cm
Minor radius (a)	13 cm
Plasma current (I_p)	50 kA first stage 300 kA second stage
Elongation (κ)	3
Toroidal Field (B_T)	0.5 T first stage 3 T second stage
Aspecto ratio (A)	1.9230



In the last year, the UANL with the SPbSU have worked and focused their efforts on the High Magnetic Field Program on Spherical Tokamaks 3 T (two equals small Spherical Tokamaks devices, one for each institution has been projected) but due the actual health worldwide situation the program must be reorganized.

The present results involves the Tokamak "T" design.

- It is well known the improvement on the plasma stability is fundamental in the magnetic confinement field [12-15].
- Design of an appropriate geometry for a D-shaped coil is attractive regarding physics and engineering branches



- Interesting geometries configurations searching appropriate toroidal fields, working on: Aspect Ratio (A), security factor (q) and (β)
- D-shaped coils geometries permit an evolution to the Low Aspect Ratio to the Spherical Tokamaks

Main characteristics of the coil: geometry, winding, insulation, power supply and the load distribution (magnetic, thermal), defining the most adequate type of material to be used, involving the conductor design and its manufacturing process, the electrical energy storage released in short circuit times, etc.

It is well known the total amount of current:

$$I_T = 5\, B_T\, R$$

The present study considers a B_T range of: 1.3 to 1.6 T, Major Radius: 0.41 m | I_T = 2.665 to 3.28 MA

$$I_{TC} = I_T/N;\; j = I_T/2\pi r_i d_i$$

Considerations on 12, 14 and 16 toroidal coils has been used and the following current range for each coil has been obtained: 0.2733 - 0.205 MA for 1.6 T and 0.220 - 0.1665 MA for 1.3 T

APPROXIMATE VALUES OF I_{TC}, CURRENT FOR EACH COIL, AND J, CURRENT DENSITY

R= 0.41 m		I_{TC} (MA)	~j (MA/cm²)	~j (A/mm²)
B_T = 1.6 T, I_T = 3.28 MA	N = 12	0.2733	0.0026101	26.101
	N = 14	0.2342		
	N = 16	0.205		
B_T = 1.3 T, I_T = 2.665 MA	N = 12	0.2220	0.0021207	21.20
	N = 14	0.1903		
	N = 16	0.1665		

Mechanical stress and heat removal are important issues when an applied current flows in a coil.
These considerations are fundamental aspects in the design.
The forces increases considerably respectively to the reactor size.
Stress is proportional to the square of the toroidal field (BT) and the larger radius (R) [13, 16].

$$r\frac{\partial^2 r}{\partial z^2} = \pm\frac{1}{k}\left[1+\left(\frac{\partial r}{\partial z}\right)^2\right]^{3/2}$$

$$k = \frac{1}{2}\ln\frac{r_2}{r_1}$$

It is well known that previous works developed by File, De Michele and Raeder among others has been obtained an operative shape

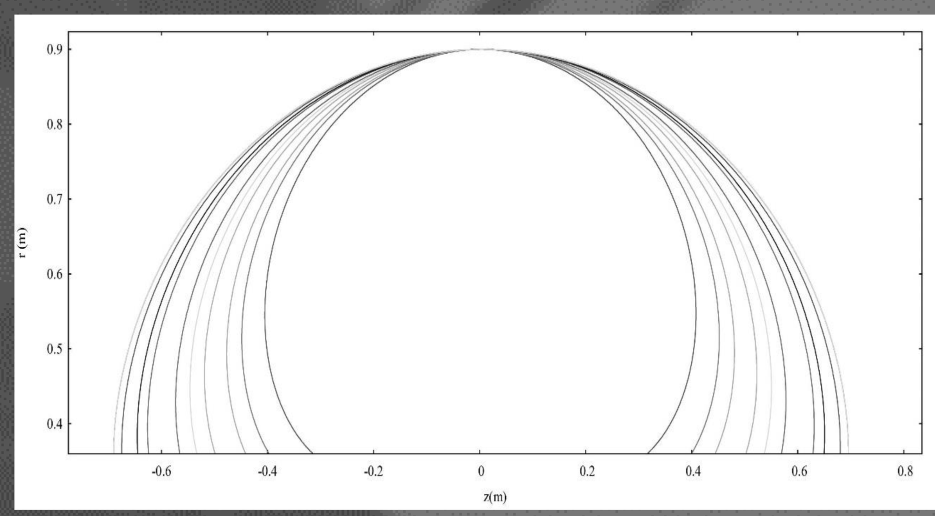


Fig.1.- D-shaped geometries generated with the FORTRAN code for different values of "k" in the interval [0.5,0.92]

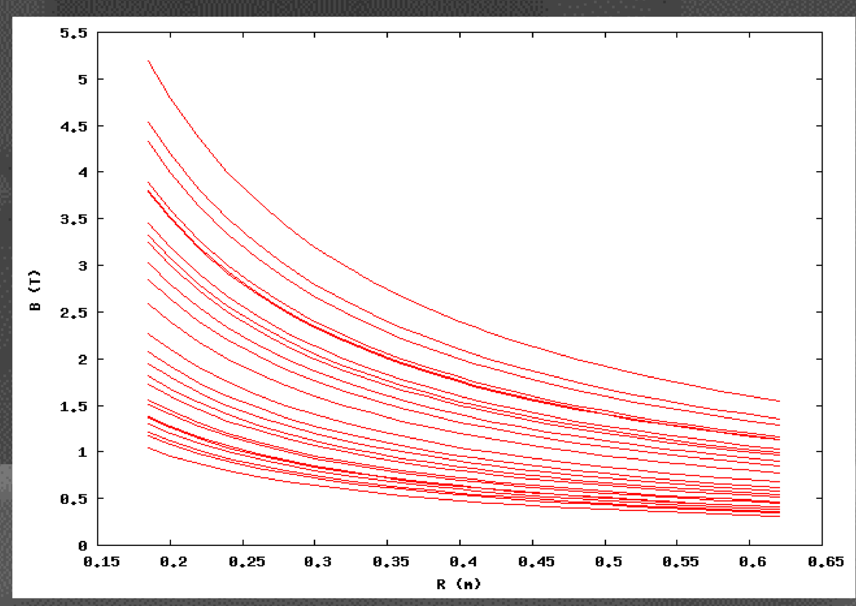


Fig. 2A

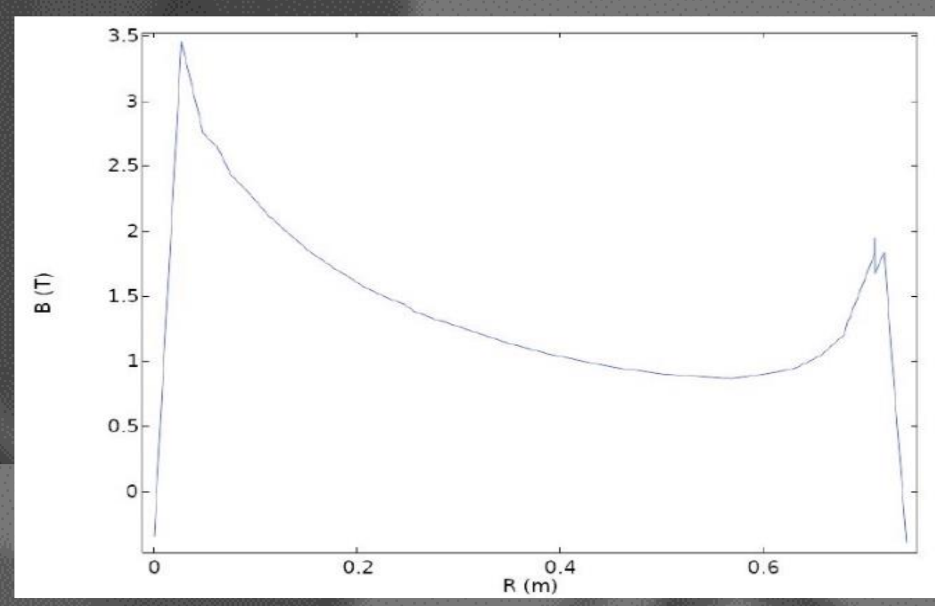


Fig. 2B

B_T = 1.6 T | I_T = 3.28 MA B_{Text}= 2.9155, B_{Tint}= 1.102
B_T = 1.3 T | I_T = 2.3665 MA, B_{Text}= 2.3688, B_{Tint}= 0.895

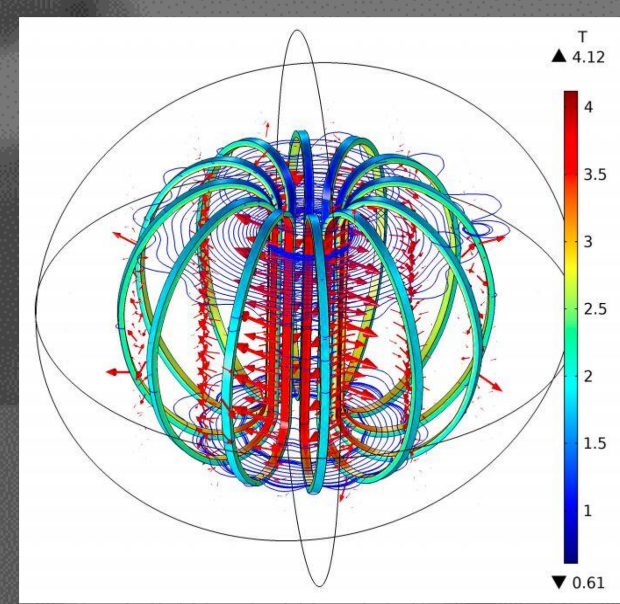
The material to employee on this toroidal coil is copper, the winding is the classic hollow conductor pancake coil: $B_T = \mu_0 NI/2\pi R$, was used to the obtain the graphics in Fig. 2A – 2B

Current range (10,000 – 30,000 A) was established.
Second refined approximation was completed with a flowing current of 10,000 A as operational current value.
The graphs in Figure 3A was obtained with a variation on the number turns (8, 9, 12, 15, 20, 22, 25 and 30 turns per coil), which multiplied by the total number of coils (12, 14 and 16), gives the total turns coil.

Finite Element Method (FEM) was applied in the 3D coil arrangement, COMSOL software was used, this tool allows working with the surface area of the conductors without being strictly wound.

Multiple homogenized turns establish a toroidal magnetic system composed by 12 D-shaped coils, 24 turns (N = 288 turns) with a flowing current of 10 kA. The red arrows in the Figure follows the magnetic flux trajectory created to the current inductions.

The magnetic toroidal field reported at 0.41 cm major radius (0.41 m) in this simulation round a value of BT 1.4 T obtained with the general toroidal equation.



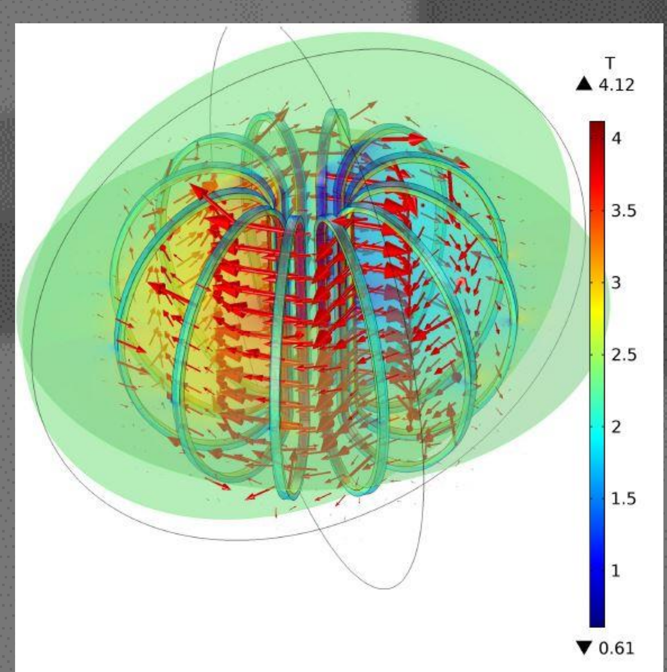


Fig. 3.- Toroidal electromagnetic simulation system: Tokamak "T" configuration

POLOIDAL MAGNETIC SYSTEM

There are specialized functions into the poloidal coils design: to equilibrate plasma in radial direction (shape and position), obtention of elongation (κ) and triangularity (δ) necessary parameters to develop ST configurations. The poloidal field into one ohmic system, involves directly the solenoid design.

CENTRAL SOLENOID DESIGN

An operational range was established considering general studies with solenoids using air and iron cores, because the capacity of flux generation and consumption/balance is important to establish the magnetic field inside the solenoid $B_{CSO} = \mu_0 I_{CS}/L_{CS} \cdot 1/(1+4\, r^2_{CS}/L^2_{CS})^{1/2}$ and the total magnetic flux: $\Delta\Psi_{CS} = 2\pi r^2\, B_{CSO}$ to determine the discharge ramp scenario in a magnetic confinement device.

CONCLUSIONS

The GIF-UANL researchers recognize that international collaborations have an important aspect to address interesting and complex research topics, the scientific agreement with SPbSU has allowed a correct evolution developing interesting ST configurations. The next step that the GIF-UANL has ahead is the evolution from its Low Aspect Ratio Tokamak "T" to one Spherical Tokamak, called Spherical Tokamak towards "T" (TEA-T) from 1.6 T to 3 T as maximum toroidal field, starting with 0.5 T in first stage to the last one, this ST device will reinforce the effort realized in the Tokamak "T".

ACKNOWLEDGMENTS

The Fusion Research Group greatly appreciate the friendship, support, orientation and guide of Professors A.B. Mineev and G.M. Vorobyov, at the moment to develop excellent physics and remarkable engineering on this fusion effort.

GIF-FUSIÓN fusion@uanl.mx

https://www.fusion.uanl.mx