Morozov Rings for Plasma Diagnostics and Refueling[1]

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Outline

1. Morozov's idea.
2. Examples of Magnetized Morozov Rings (MMR).
3. Gyroscopic stabilization.
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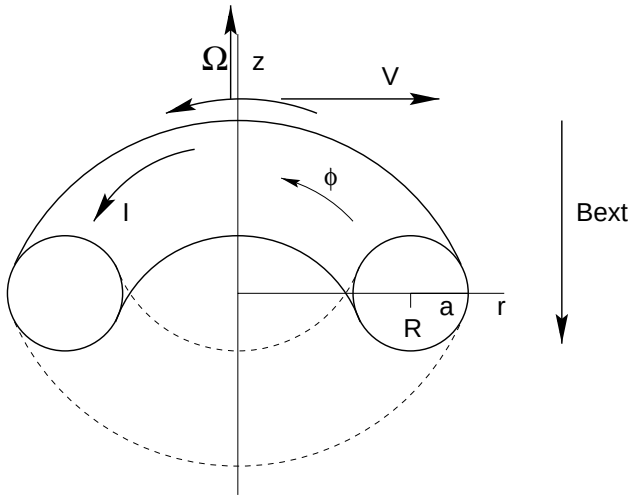
5. Some physics.
6. Summary.

1 Morozov's idea of autonomous magnetized probe

A.I. Morozov told me about his idea of autonomous probe for the high temperature plasma in the early days of ITER ($\simeq$ 1988). A.I. has published his idea in Sov.J.Plasma Phys. v.17, p.71, 1991.

The life of the tokamak fusion could be different if it would be possible to create an autonomous probe, which can penetrate into the large volumes of high-temperature plasma without damaging itself or the surrounding plasma.



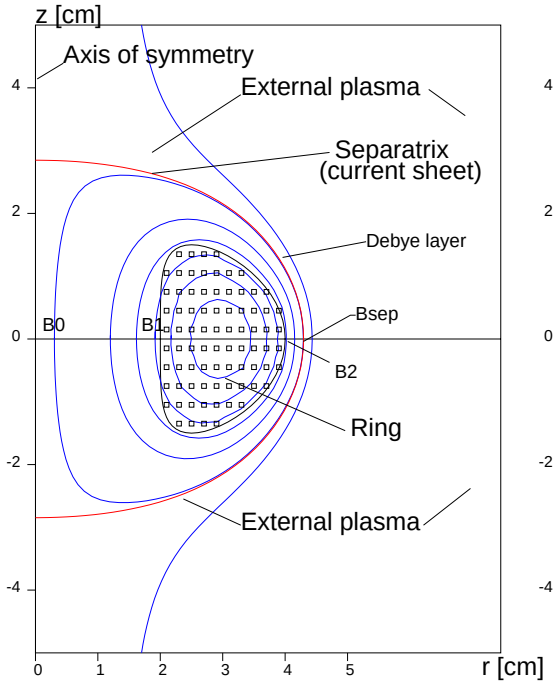
Morozov ring (R$\simeq$ 3 cm, a$\simeq$ 1 cm) with

1. electric current (100's kA),
2. gyroscopic rotation (100 - 1000 Hz) and
3. magnetically insulated from plasma electrons,
4. electrostatically insulated from ions.

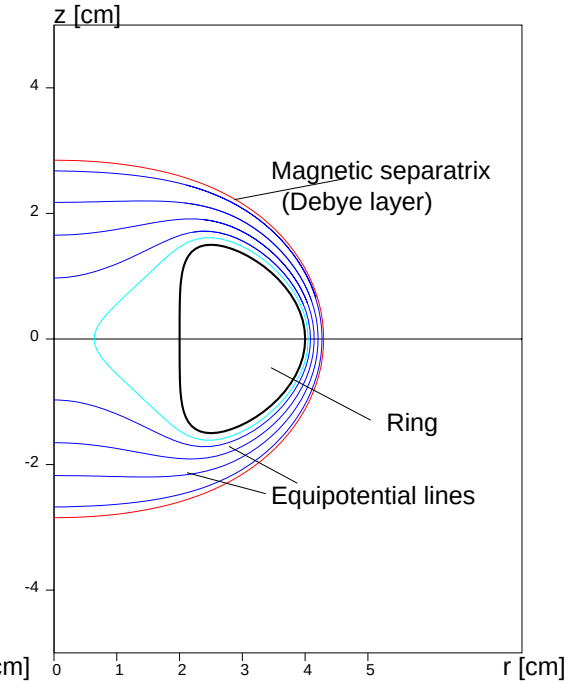
If developed, can travel inside the high-temperature plasma. Can deliver the fuel to any point in the plasma core. Can carry the diagnostics.

2 Example of the superconducting MMR configuration

Poloidal cross-section of the magnetic and electrostatic configuration of the Magnetized Morozov Ring.

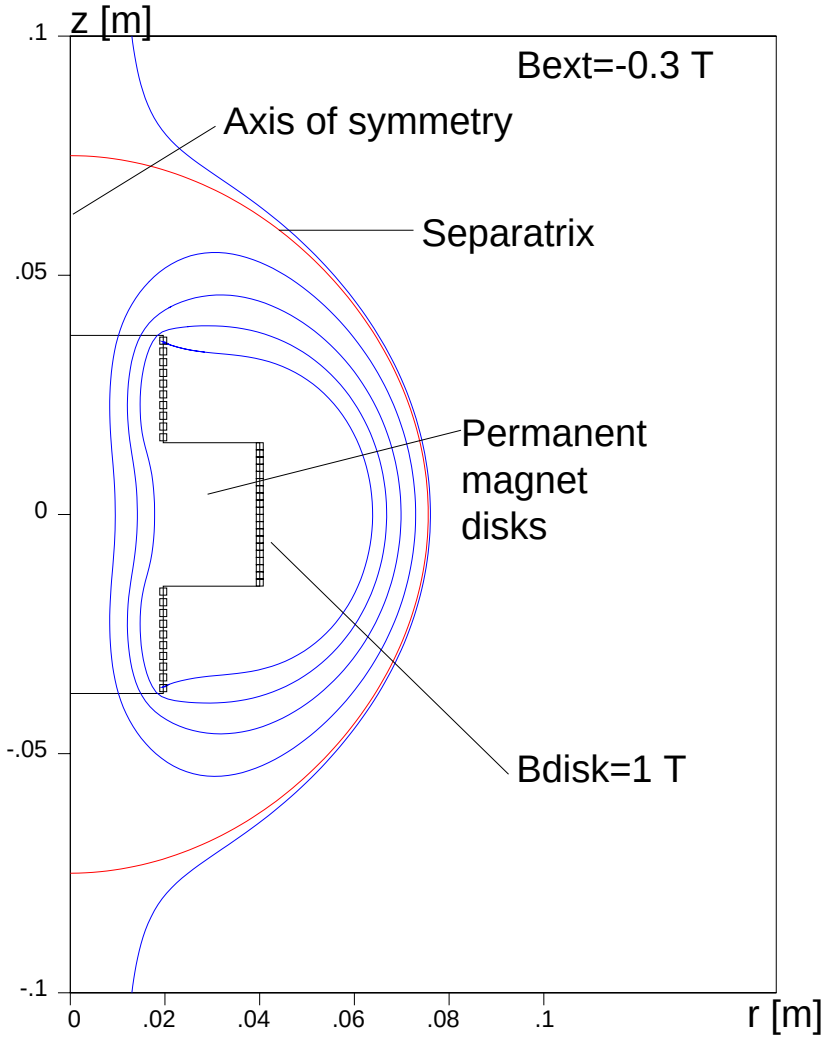


Magnetic and



Electrostatic configuration

R [cm]	3	B_{ext} [T]	-5
a [cm]	1	I [MA]	0.605
b [cm]	1.5	B_0 [T]	7.183
T [kV]	30	B_1 [T]	10.47
ρ_e [cm]	0.0067	B_2 [T]	-9.69
ρ_D [cm]	0.406	B_{sep} [T]	-8.707
ρ_T [cm]	0.497	Ψ [Vsec]	0.0135
ρ_α [cm]	2.195	Ψ_{ext} [Vsec]	-0.0135
U [MV]	1.75	N_α	1.439+14
W_α [J]	80.58	q [C]	4.605e-05



Magnetic configuration of a stack of the permanent magnet disks in an external field

Only electron from a tiny flux tube can reach the body of the magnet

3 Gyroscopic stabilization

In order to have a separatrix of the proper shape, the ring should be oriented in the diamagnetic, unstable, direction with respect to the toroidal magnetic field.

The ring should be gyroscopically stabilized by a fast rotation

$$\Omega \quad [rad/sec] > 10^5 \sqrt{\frac{0.2\pi IB}{M}} \qquad \sqrt{\frac{[MA][T]}{[g]}}, \tag{3.1}$$

$$\frac{\Omega}{2\pi} = \frac{10^5}{2\pi}\sqrt{\frac{0.2\pi \cdot 0.5 \cdot 5}{500}} = 892\ [1/sec] \simeq 60\ 000\ [rpm]$$

4 Engineering problems

Necessary currents in MR are consistent with the critical current densities

$$j_{crit} > 1500\ \frac{MA}{m^2} \quad \text{at } 50^o\ K$$

in the HT Superconductors

1. Limitation on the dB/dt for the superconductor $\propto \underset{\sim}{B^4}$.
2. Gyroscopic spining up at cryogenic temperatures.
3. Force balance in the material of the rings: major magnetic forces are favorable, centrifugal force is not.
4. Dynamics of the flight of the ring in the tokamak magnetic field.
5. Launchers and catcheres of the superconducting rings.

All possible limitations are highly sensitive
to the value of the toroidal magnetic field

The issue is of how far can we go in raising limits on B_{tor}. Is the JET 3.5 T within the reach ???

5 Some physics

Morozov Ring represents a NEW plasma confinement configuration, where the current carrying superconducting or cryogenic ring is insulated from the high-temperature plasma

- The plasma electrons are magnetically confined from reaching the ring
- Energetic ions and the α-particles are electrostaically screened from the ring.

The Morozov Ring contains many common physics with FRC, Levitated rings, which are under studies in special fusion programs.

The BIG difference between Morozov's rings and FRC, Levitrons is that the magnetic configuration of the ring is MHD stable

$$-\frac{d\ln p}{d\ln r} < \frac{4\gamma}{2+\gamma\beta} \tag{5.1}$$

Electrostatic effects are very strong in Morozov Ring configuration.

6 Summary

MMRs may represent one of the most natural application of HTS in physics.

At present, the idea of MMR is just at the starting point of the development.

Still a lot of issues has to be assessed at the most basic level.

If being developed, MMR may serve as the most precise tool for controlling existing machines and confinement studies.

This can open an entirely new range of confinement regimes with the central refuelling of the plasma.

By delivering tiny ammounts of any material to any place in the plasma, Morozov rings may dramatically enhance the diagnostics of the plasma core.

For DT experiments (e.g., on JET), the Morozov Rings may contribute into tritium control in the facility, by eliminating the necessty of tritium in the NB injectors lines.