MHD-DYNAMO EXPERIMENTS

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DYNAMO IN LABORATORY

$$\mathrm{Re} = \frac{UL}{\nu} \quad - \text{Reynolds number}$$

$$\mathrm{Rm} = \frac{UL}{\nu_m} \quad - \text{magnetic Reynolds number}$$

$$\mathrm{Rm}^* \approx 30 - 100$$

$$\mathrm{P}_m = \frac{\nu}{\nu_m} \quad - \text{magnetic Prandtl number}$$

$$\mathrm{P}_m \approx 10^{-5} \ (Na)$$

DYNAMO EXPERIMENTS

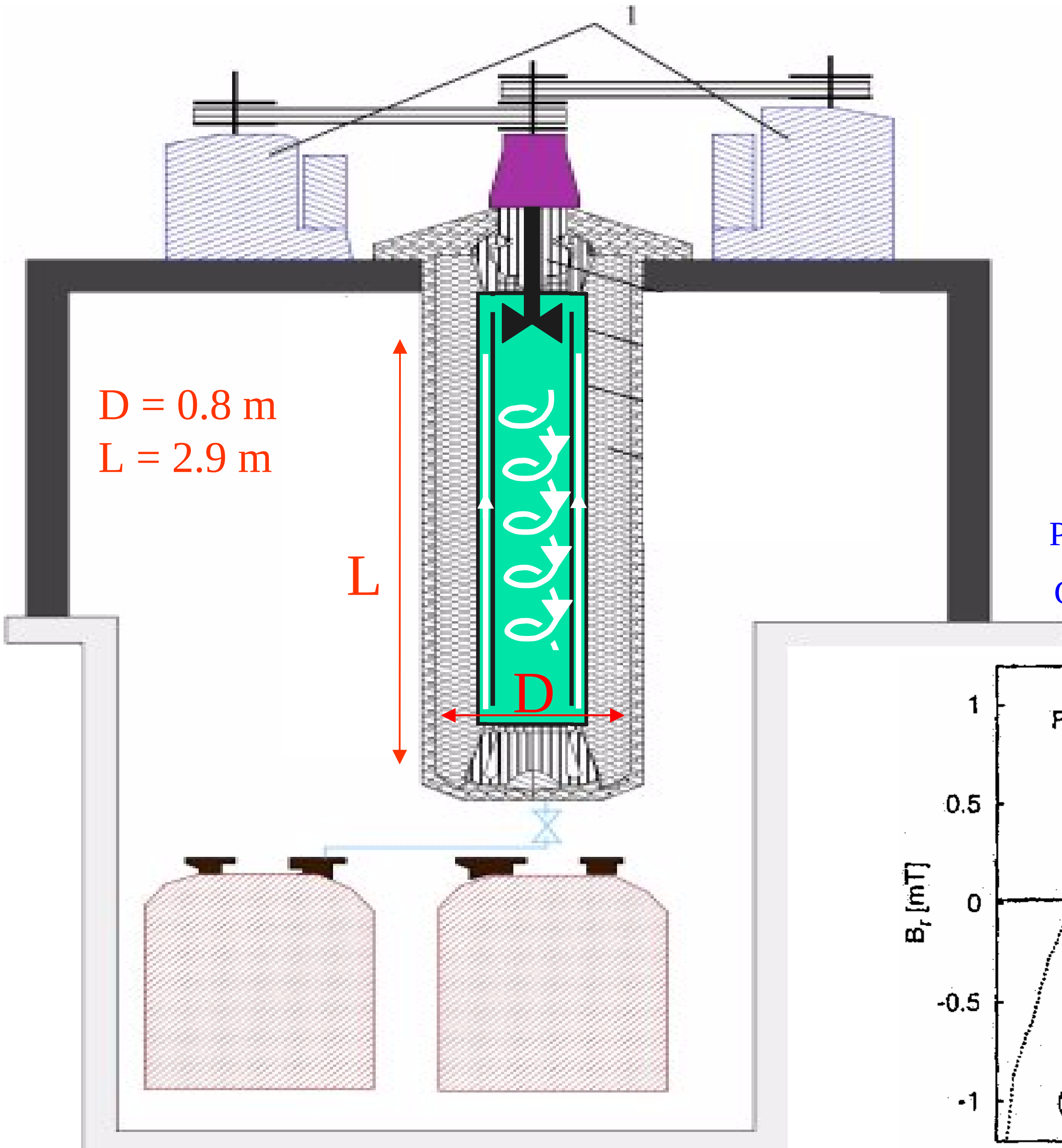
- Riga - cylindrical crew dynamo (2000)
- Karlsruhe – two-scale dynamo (2000)
- Cadaraches – VKS2 (Von Karman flow in a cylinder)
- Madison – S2T2 flow in a sphere
- Mariland – Couette-Taylor flow in a 3m sphere
- Los Alamos – alpha-omega dynamo
- Perm – nonstationary toroidal screw-dynamo

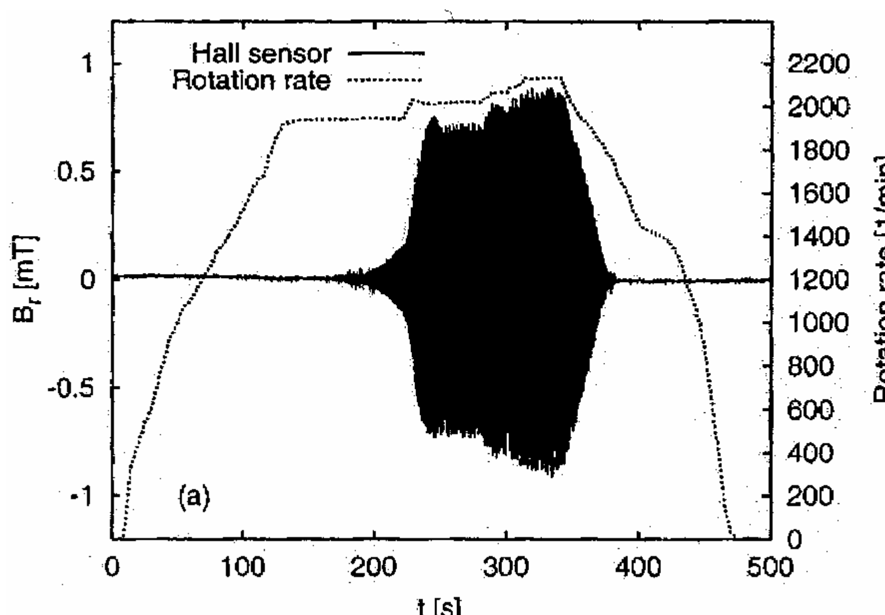
Riga experiment

First fluid dynamo

Ponomarenko J. Appl. Mech. Tech. Phys. (1972)

Gailitis et al, *PRL*, **84**, (2000)

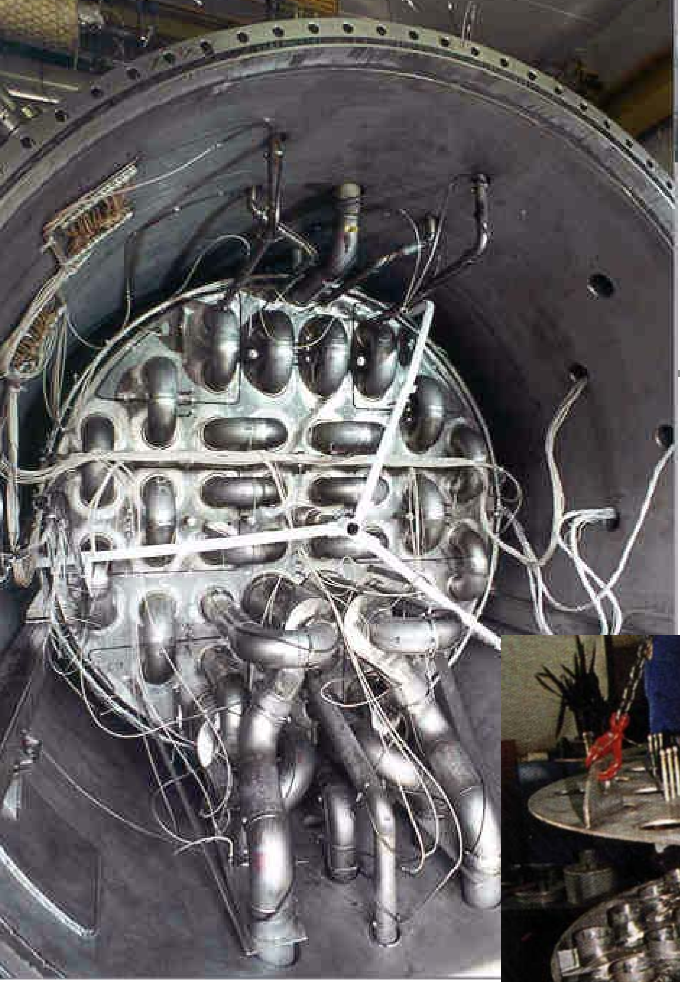


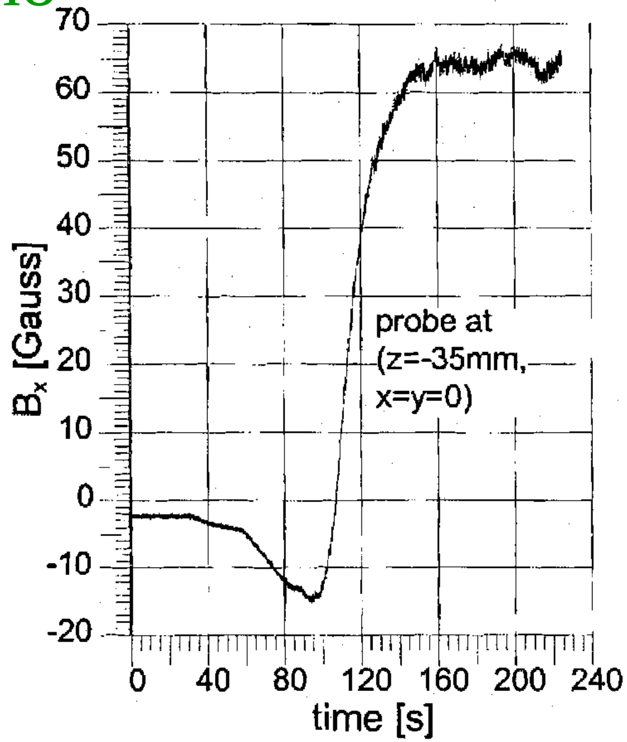



Karlsruhe experiment

Karlsruhe experiment

A two-scale dynamo



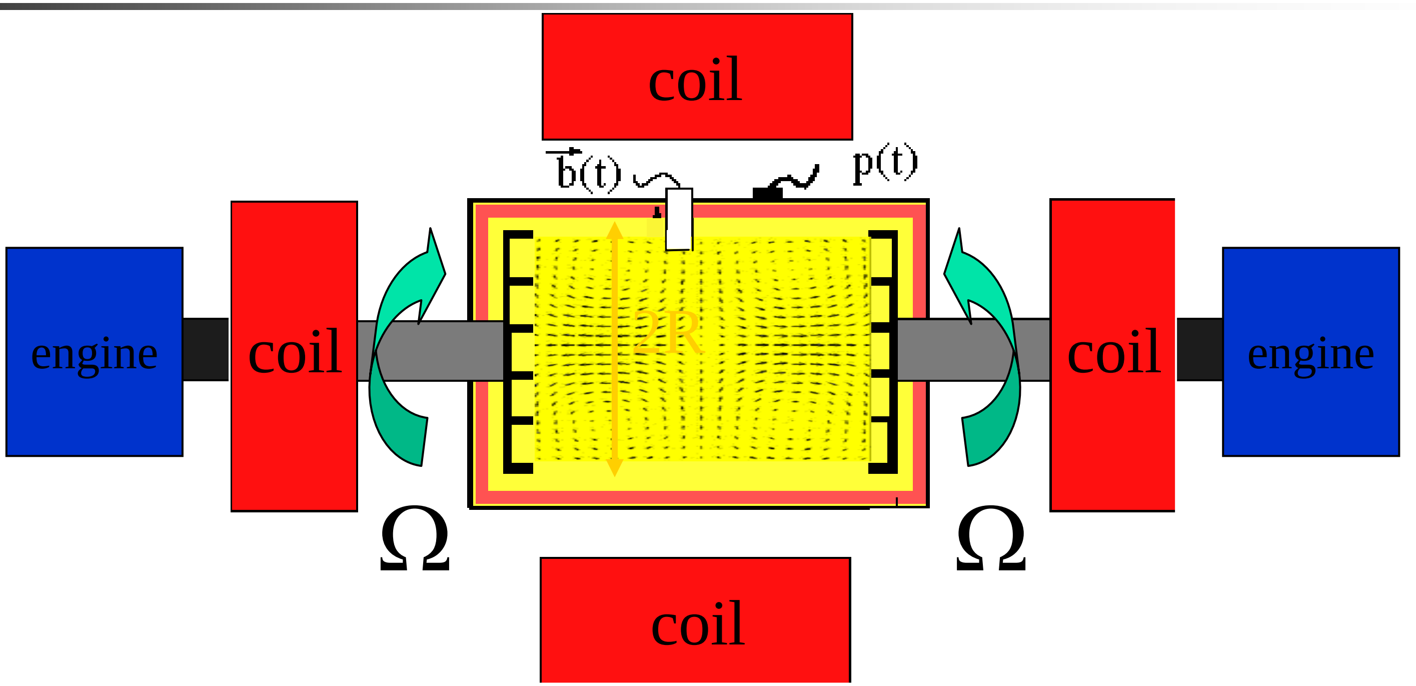


1 mT = 10 gauss

Roberts, *Phil. Trans. Roy. Soc. London* **A271** (1972)

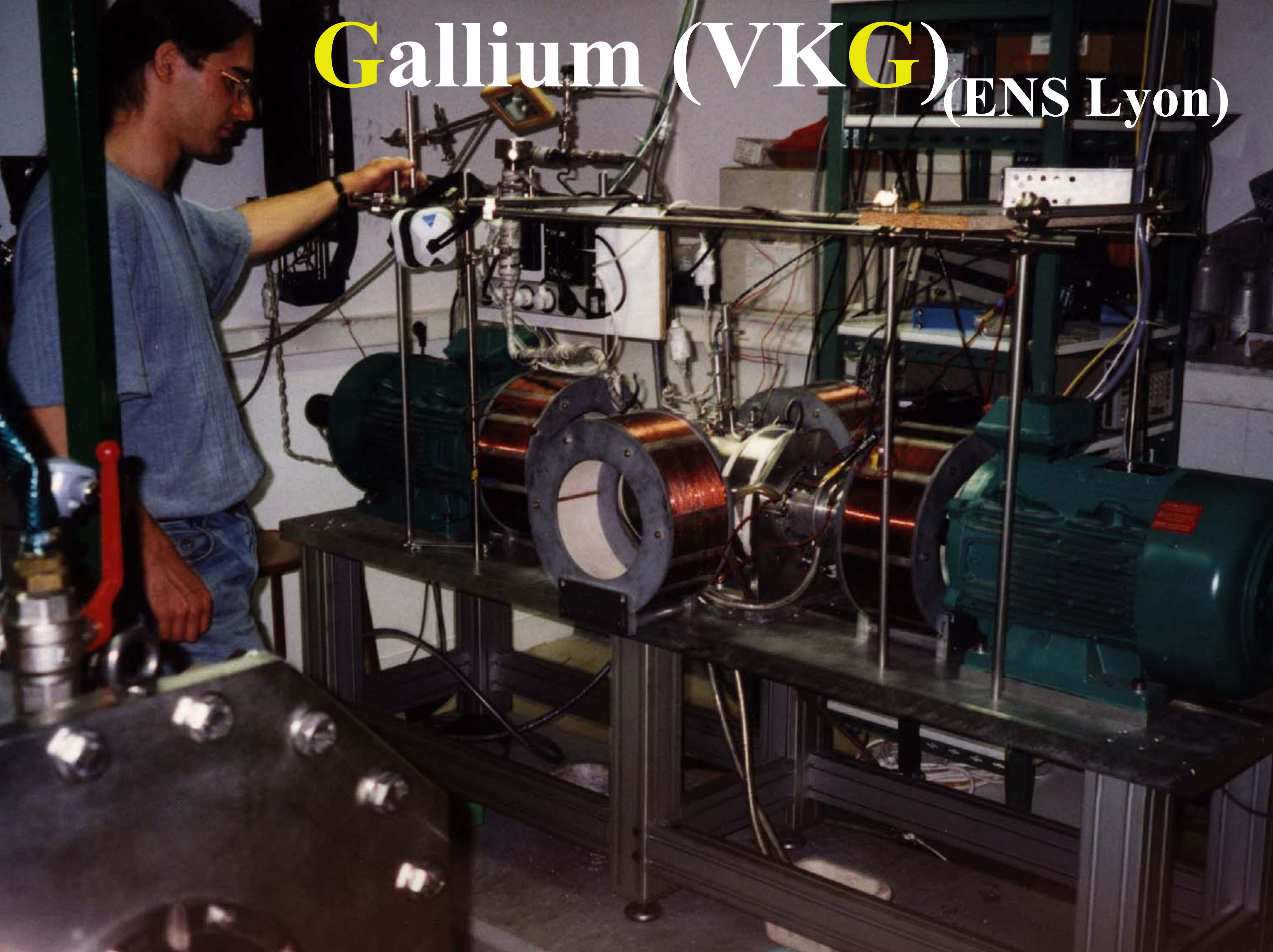
Stieglitz, Müller
Phys. Fluids, **13** (2001)

French Project - the Von Kármán experiments for MHD



$$R_m = \mu_0 \sigma \, LU = \mu_0 \sigma (R)(2\pi R\Omega) = \frac{\text{induction}}{\text{dissipation}}$$

Gallium (VKG)(ENS Lyon)



Sodium (VKS) (CEA Cadarache)

Petrelis et al., PRL 90, 174501 (2003)

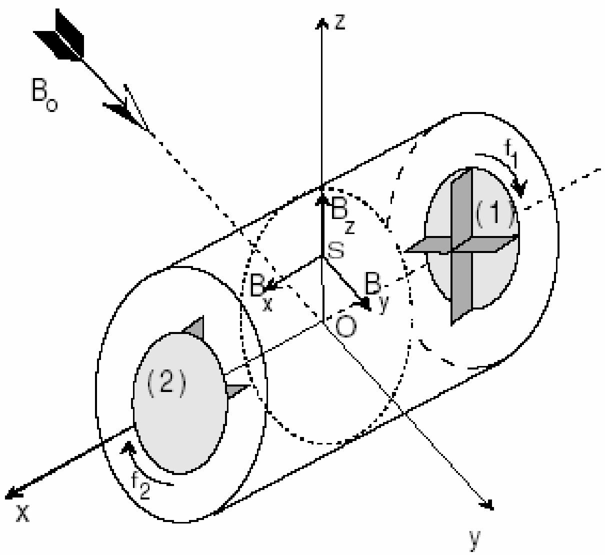


FIG. 1. Geometry of the experimental setup. The flow is generated by rotating only one disk either at position (1) or (2). The magnetic field is measured at position S.

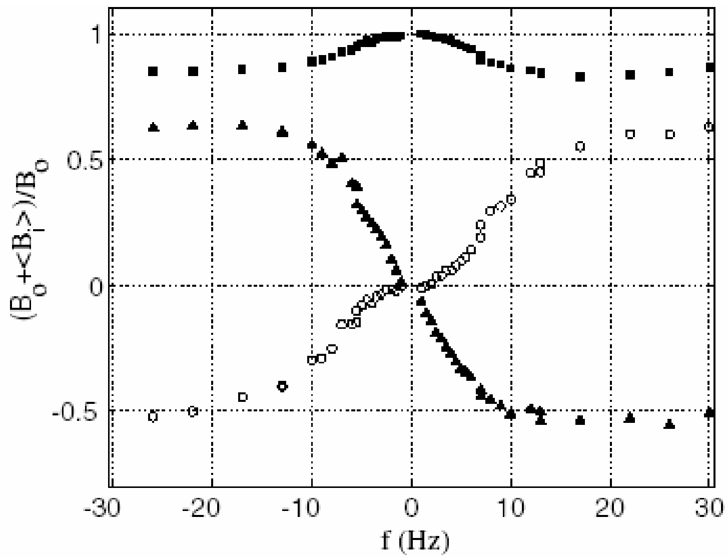


FIG. 2. Components of the total mean magnetic field as a function of the rotation frequency of disk (2). The disk radius is $R = 150$ mm with straight blades. Four baffles are mounted on the inner wall of the cylindrical vessel. The magnetic field is measured at $z = 100$ mm. [(○) $\frac{\langle B_x \rangle}{B_o}$; (■) $\frac{B_o+\langle B_y \rangle}{B_o}$; (▲) $\frac{\langle B_z \rangle}{B_o}$].

Volk et al., PRL 97, 074501 (2006)

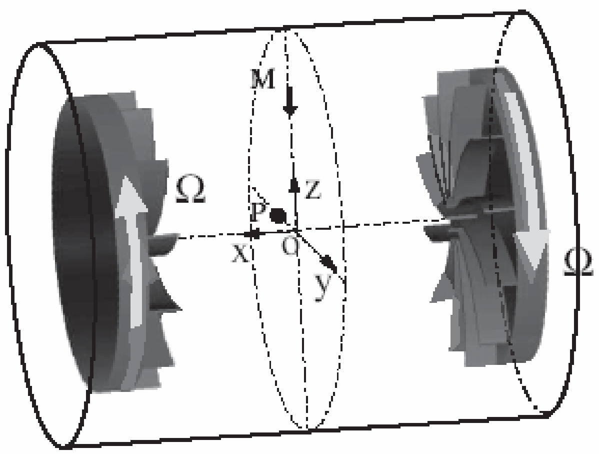


FIG. 1. Geometry of the experimental setup. Location of the magnet (M) and of the Hall probe (P). The magnet can be put in the bulk of the flow if the probe P is removed.

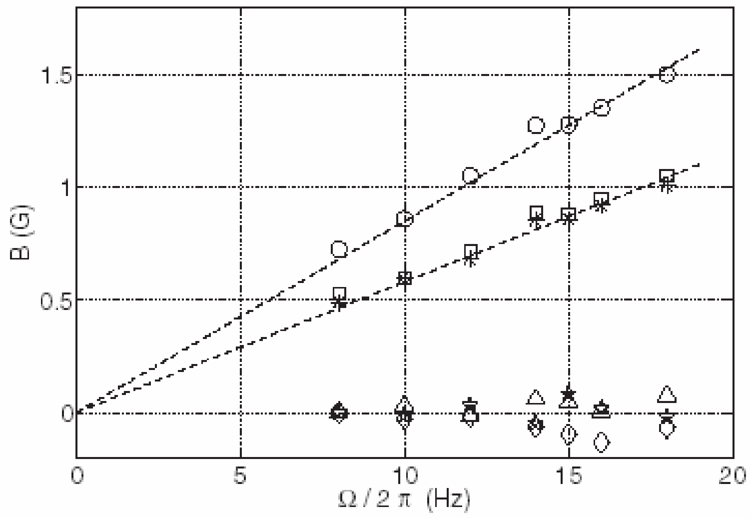
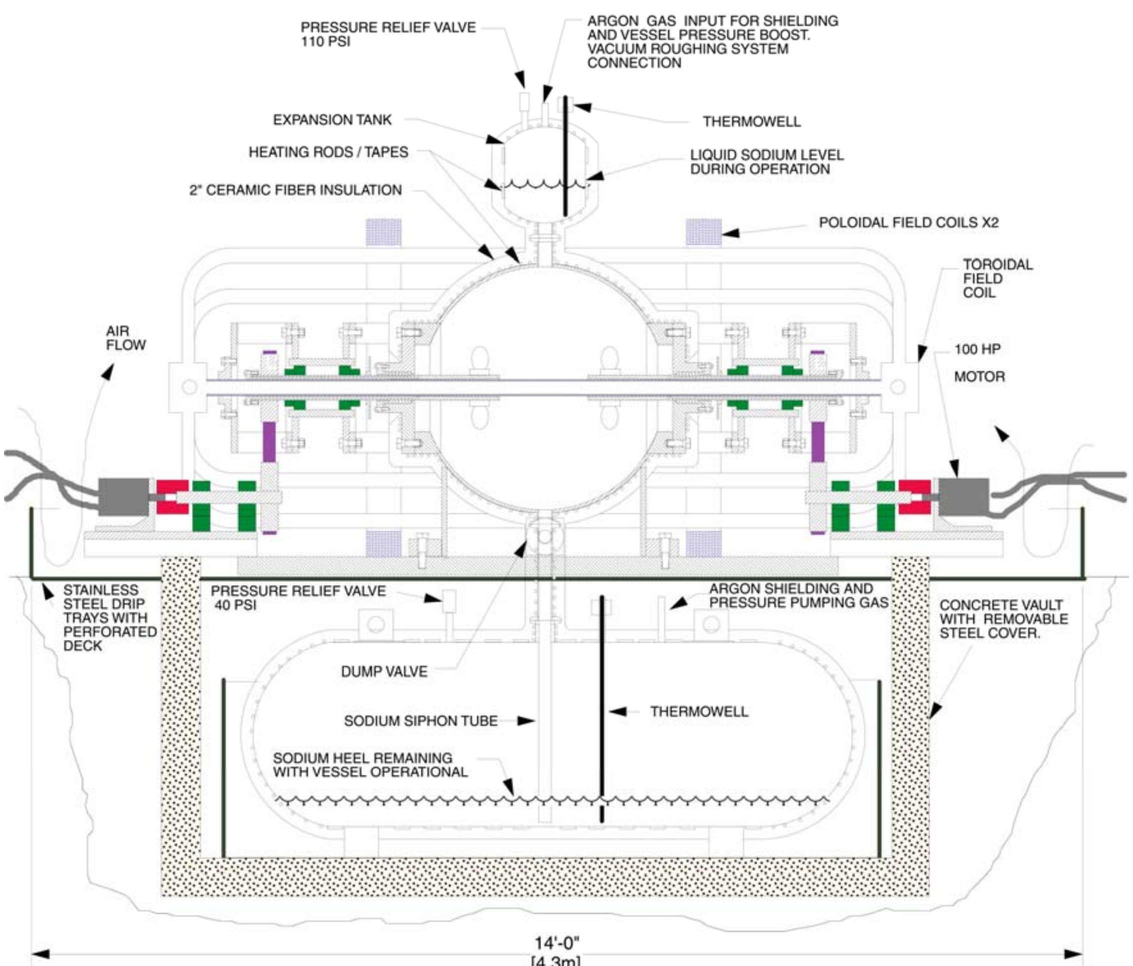
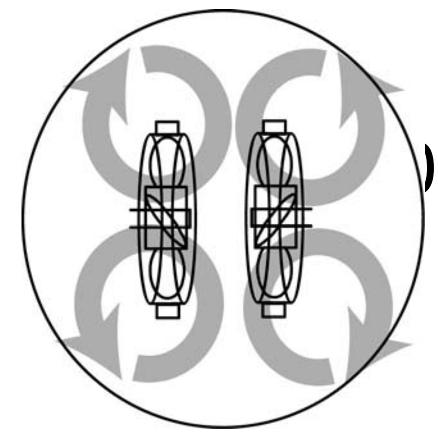


FIG. 3. Evolution with the rotation frequency of the increments of the mean values of components $\langle B_i \rangle(\Omega/2\pi) - \langle B_i \rangle \times (\Omega/2\pi = 8\text{ Hz})$, $\langle B_x \rangle$ (◇), $\langle B_y \rangle$ (△), $\langle B_z \rangle$ (★), and standard deviations, B_{xrms} (○), B_{yrms} (□), B_{zrms} (*). Linear fits of the standard deviations with dashed lines.

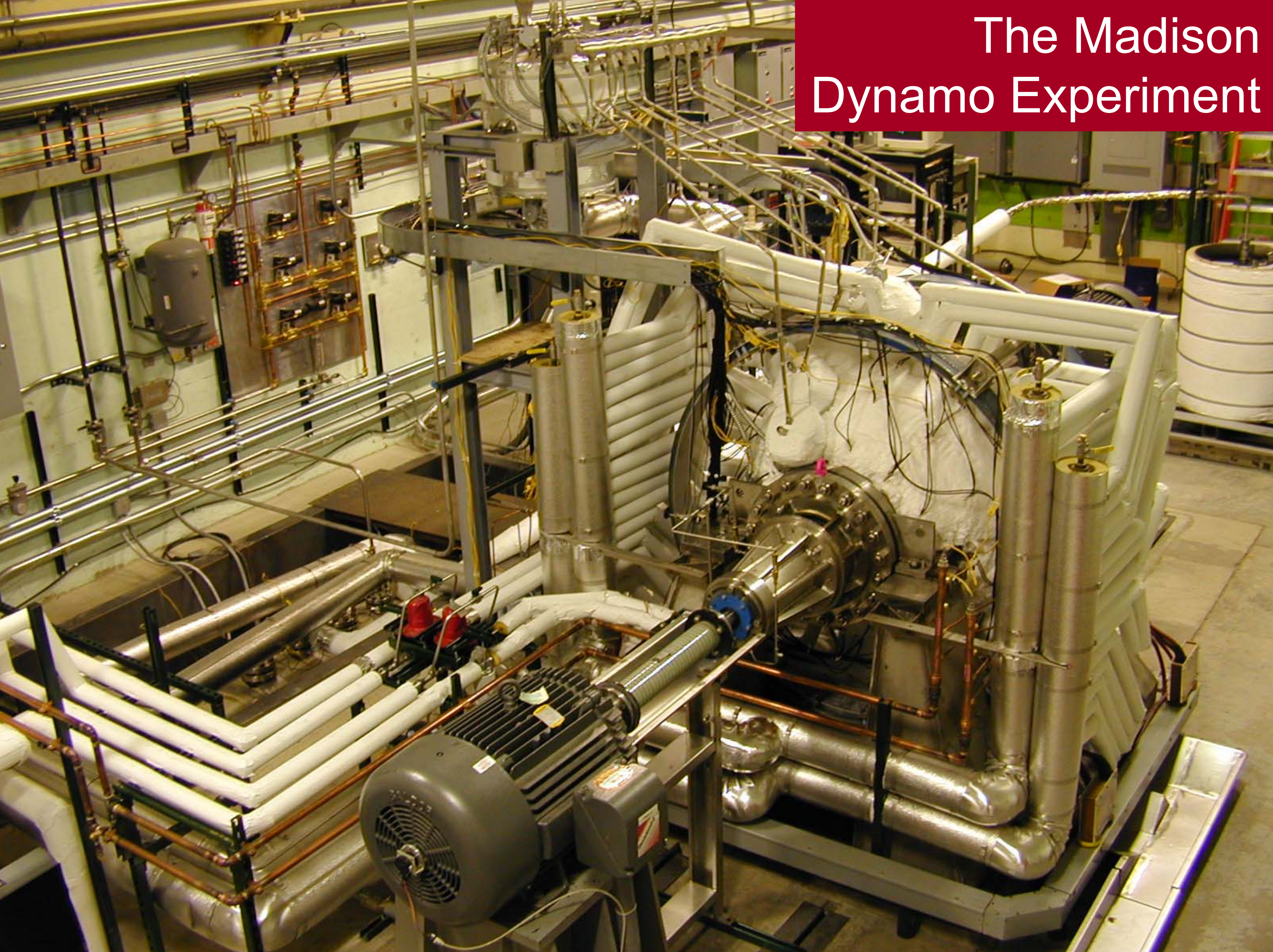
The Madison Dynamo Experiment



- 1 m diameter
- 200 Hp



The Madison Dynamo Experiment



Nornberg et al., PRL 97, 044503 (2006)

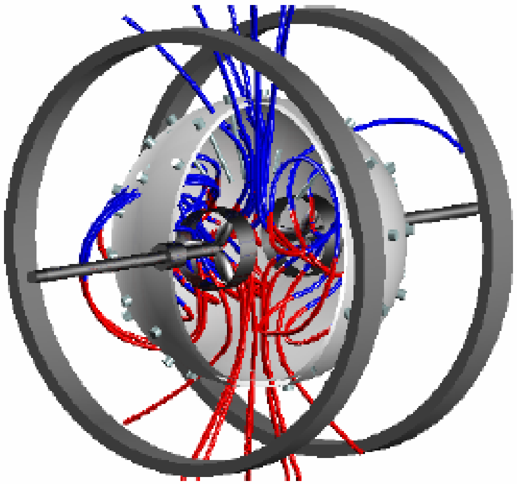


FIG. 1 (color online). A schematic of the Madison dynamo experiment with superimposed magnetic field lines of the theoretically predicted dominant magnetic eigenmode.

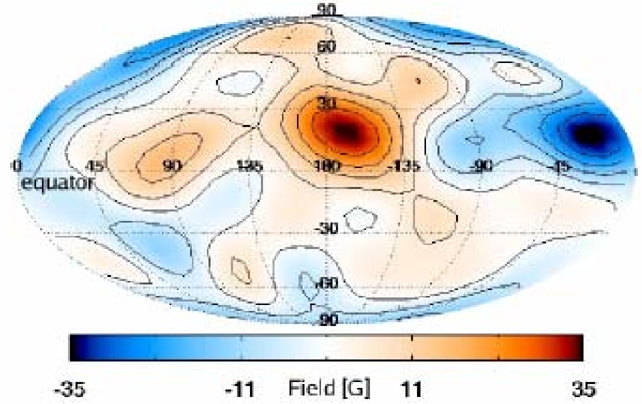


FIG. 3 (color online). Contours of $B_r(\theta, \phi)$ measured on the surface of the sphere. The applied field is subtracted from the measurements. This snapshot of the measured field corresponds to an induced dipole field transverse to the drive shaft axis.

Nornberg et al., PRL 97, 044503 (2006)

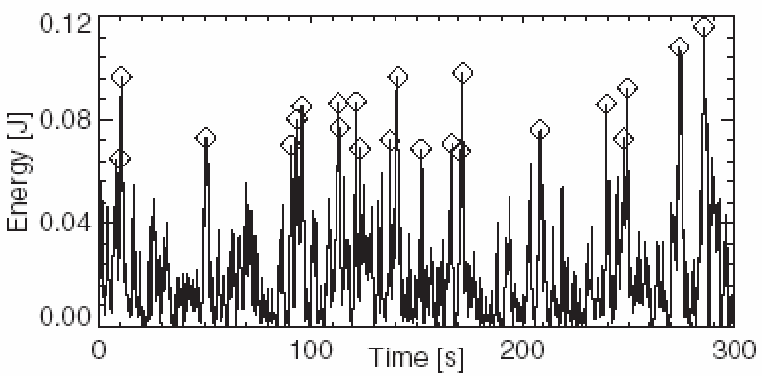


FIG. 4. Time series of the energy in the transverse dipole field for an impeller rotation rate of 10 Hz. The diamonds mark the peak of a burst where the energy exceeds 50% of its maximum value.

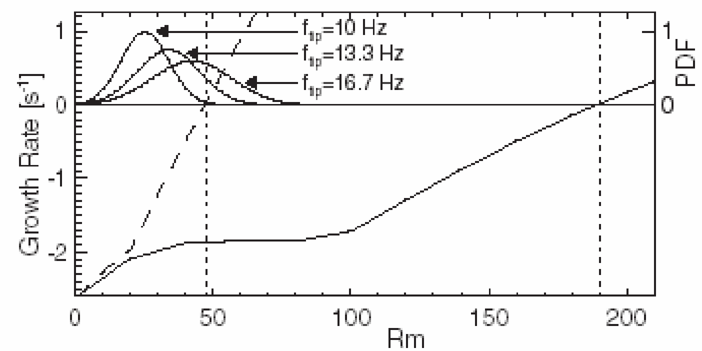
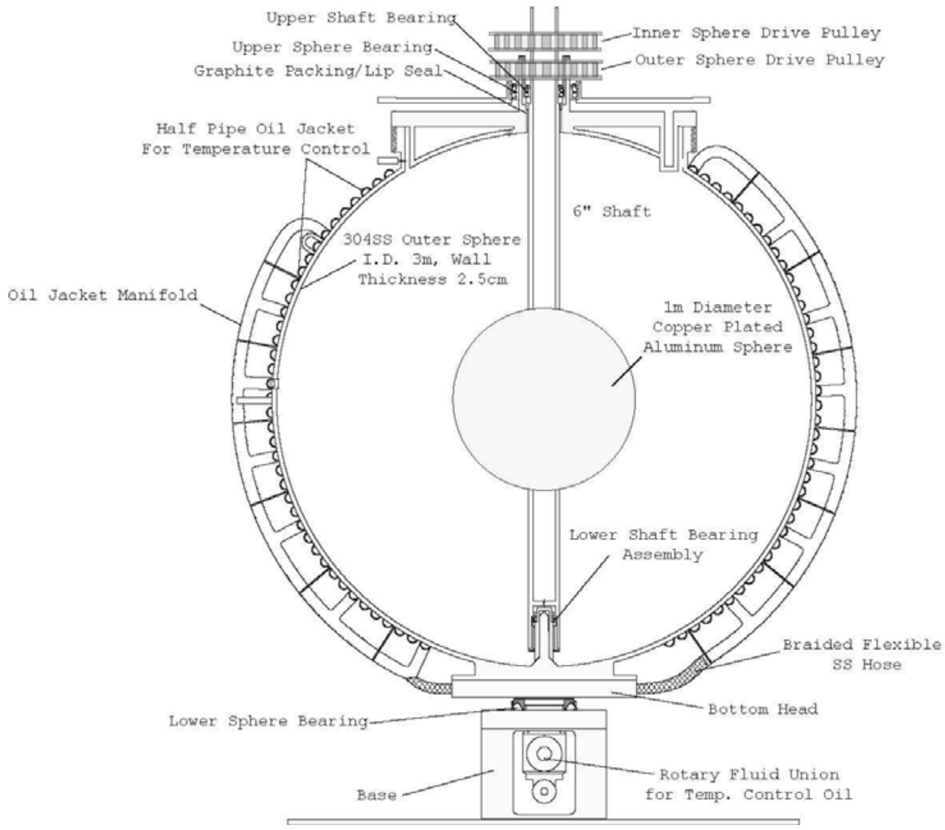


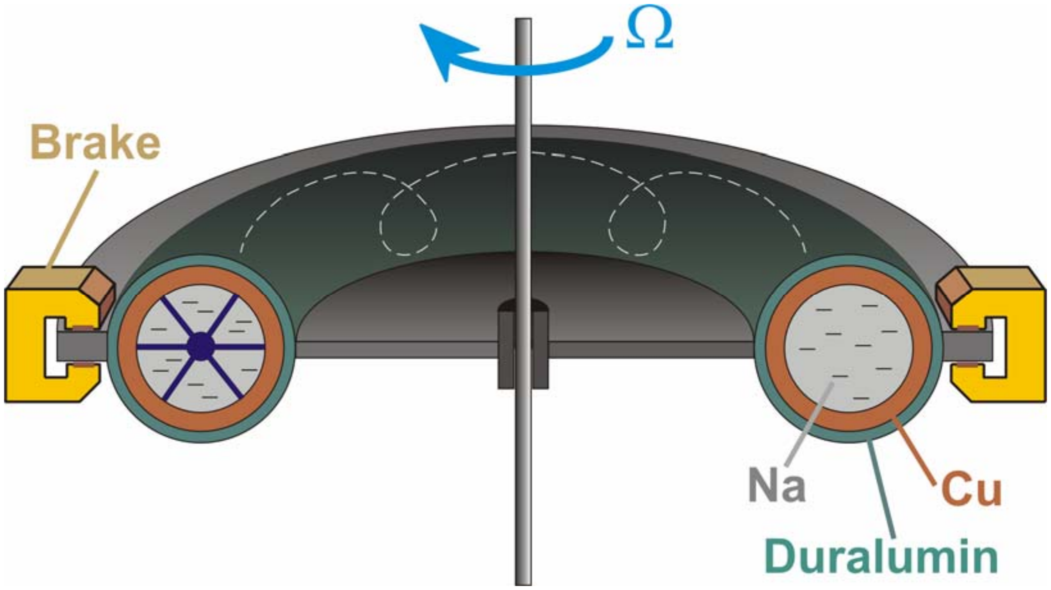
FIG. 6. Kinematic growth rate versus Rm for the mean flow measured in the water experiment (solid line) and an optimized flow (dashed line). The vertical lines identify Rm_{crit} for each case. The PDFs of Rm for flows with three different impeller rotation rates are shown to demonstrate the increasing overlap of the ranges of Rm and Rm_{crit}.

Mariland Couette-Taylor experiment

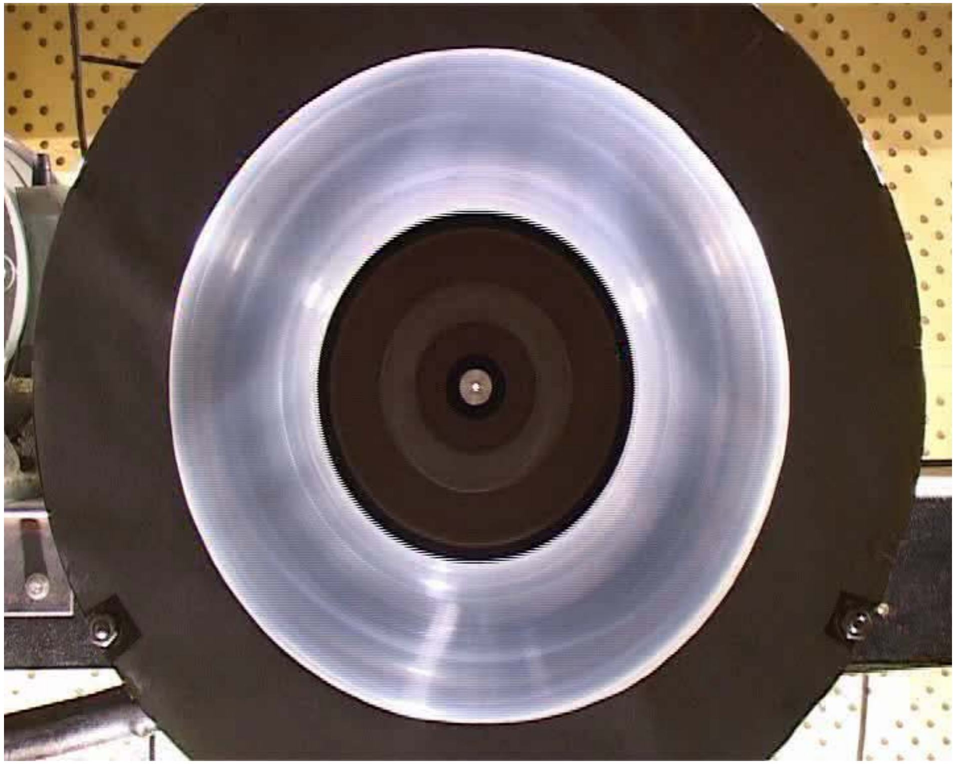


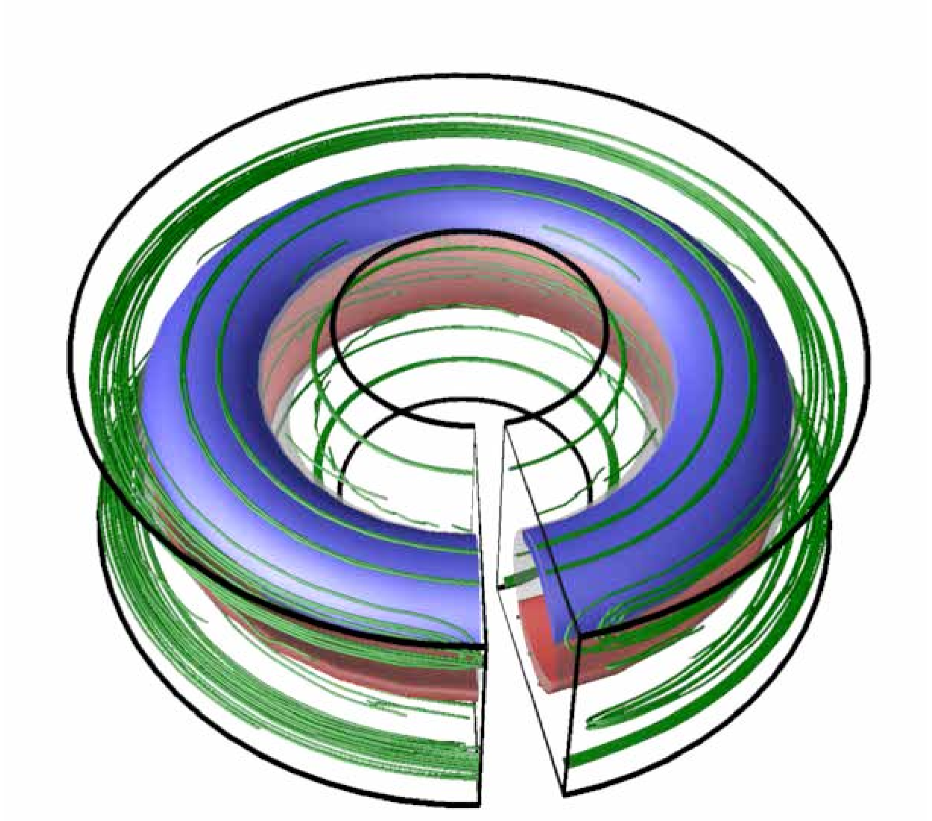
PERM: SCREW DYNAMO IN A BRAKED TORUS

- Energy accumulation
- Pulse screw flow
- Toroidal geometry



GOALS: - peculiarities of Ponomarenko dynamo in a torus;
- nonstationary dynamo action.





Rm = 40

ADVANTAGES:

- small mass of Na;
- low power supply;
- no sealing glands;

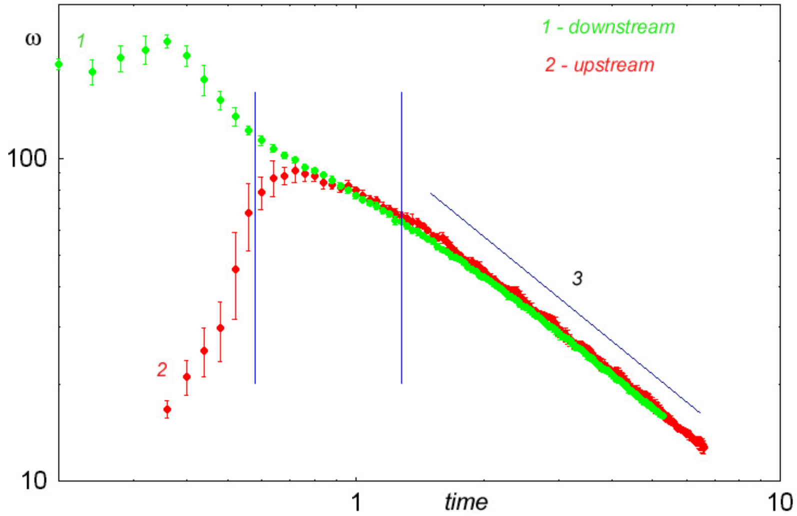
DISADVANTAGES:

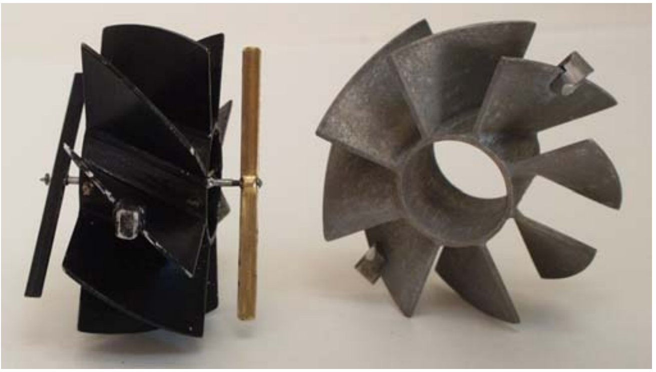
- short duration;
- conducting boundaries problem;
- high power breaking system;
- materials for the channel;
- measurement problems.

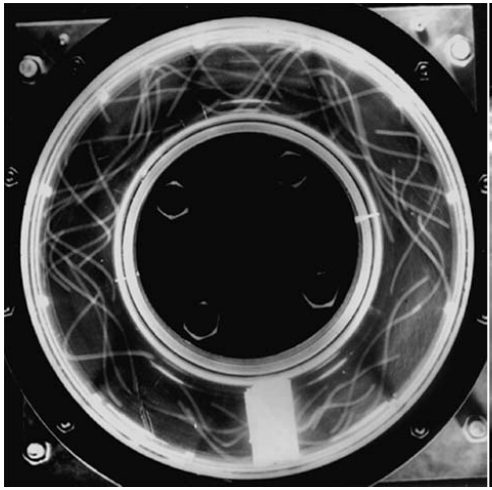
EXPERIMENTAL SET-UPS

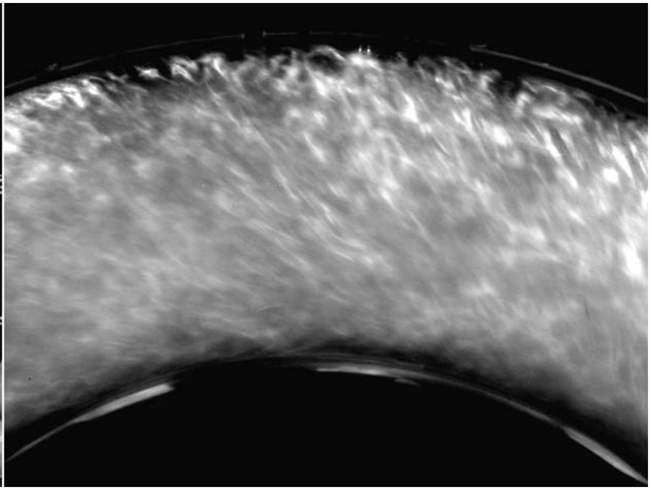
	Water A	Water B	Ga	Na
Radius of the torus, (m)	**0.103**	**0.154**	**0.088**	**0.4**
Radius of the cross-section, (m)	**0.027**	**0.04**	**0.023**	**0.12**
Mass of the channel, (kg)	**5.6**	**24.5**	**15.3**	**300**
Moment of inertia, ($kg \cdot m^2$)	**0.072**	**0.58**	**0.132**	**50**
Mass of fluid, (kg)	**1.25**	**4.86**	**5.58**	**115**
Moment of inertia, ($kg \cdot m^2$)	**0.018**	**0.15**	**0.045**	**20**
Frequency of rotation, ($R.P.S.$)	**50**	**30**	**50**	**50**
Maximal velocity, (m/s)	**32**	**29**	**27**	**140**
Effective Re	10^5	$5 \cdot 10^5$	$5 \cdot 10^5$	$4 \cdot 10^6$
Effective Rm	**-**	**-**	**1.5**	**40**
Minimal braking time, (s)	**0.1**	**0.18**	**0.05**	**0.1**
Energy of rotation, (J)	$4.4 \cdot 10^3$	$17.3 \cdot 10^3$	$6.6 \cdot 10^3$	10^6
Dissipation power, (Wt)	$4.4 \cdot 10^4$	$8.7 \cdot 10^4$	$1.3 \cdot 10^5$	10^7
Temperature, ($^o C$)	**20**	**20**	**20**	**120**

WATER EXPERIMENT





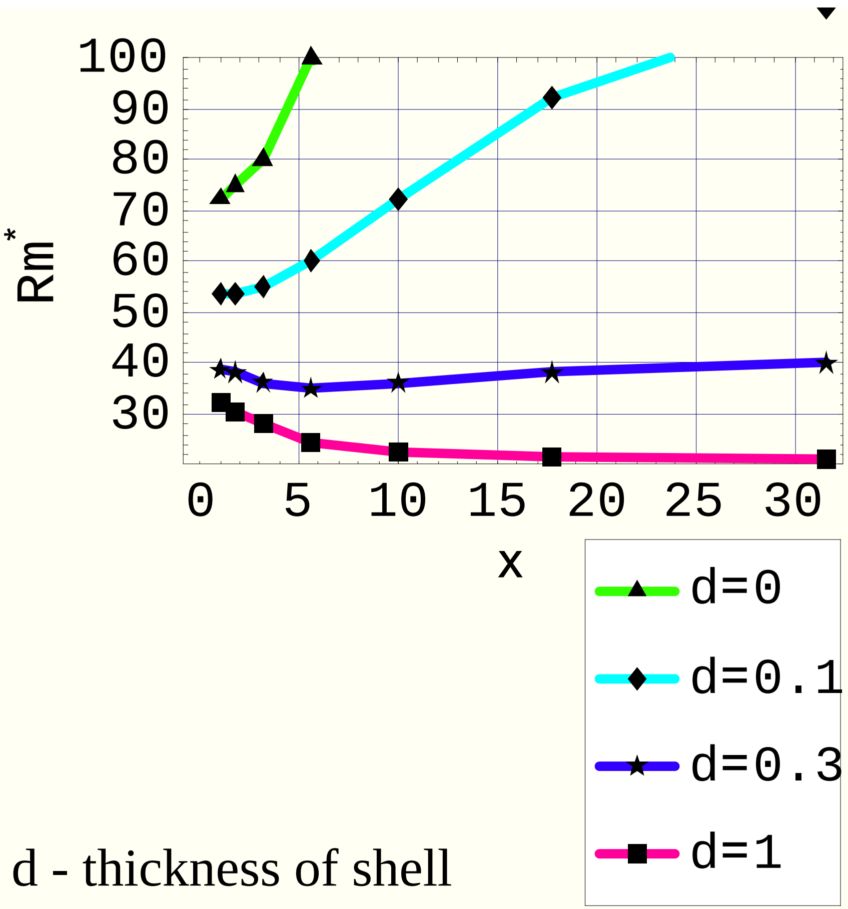




MHD channel: thickness of the wall

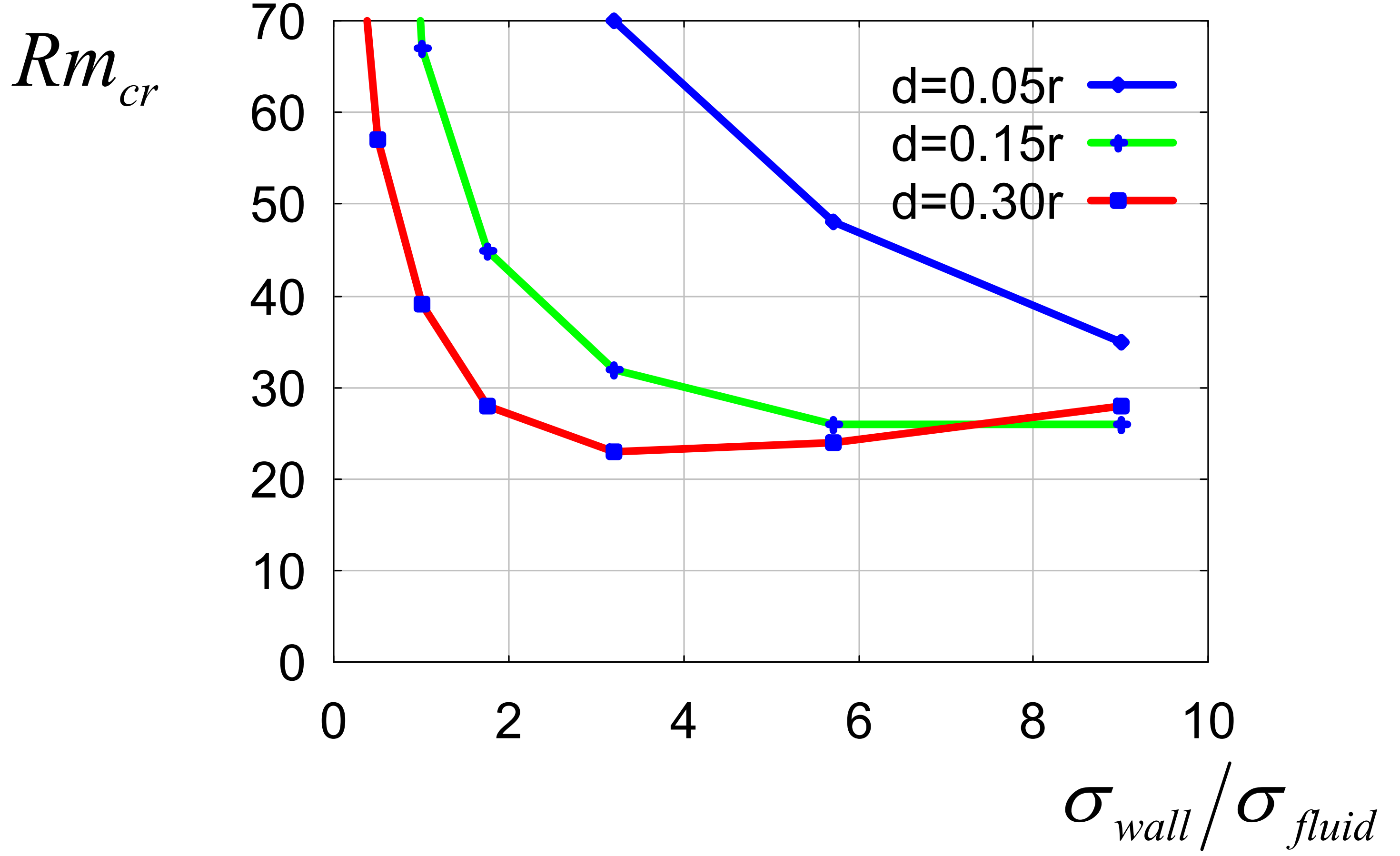
ξ - parameter of velocity profiles

$$v(r) = \frac{\cosh(\xi) - \cosh(r\xi)}{\cosh(\xi) - \cosh(0)}$$



d - thickness of shell

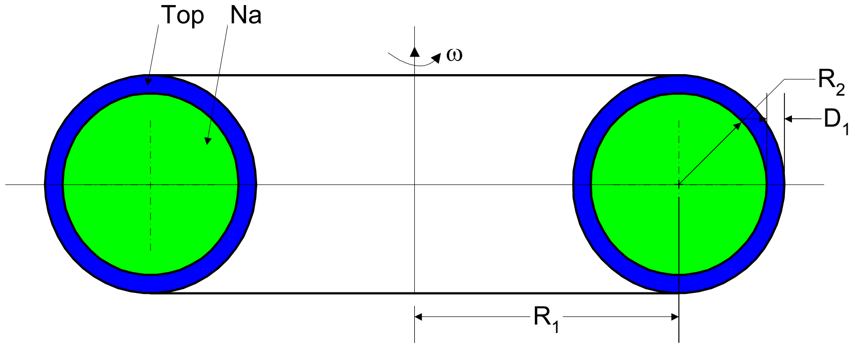
MHD channel: conductivity



$\xi = 18$

Strengths in rotating channel

f =50 R.P.S.
d = 0.015m (Cu)
d = 0.03m (Al)
d = 0.04m (D16)



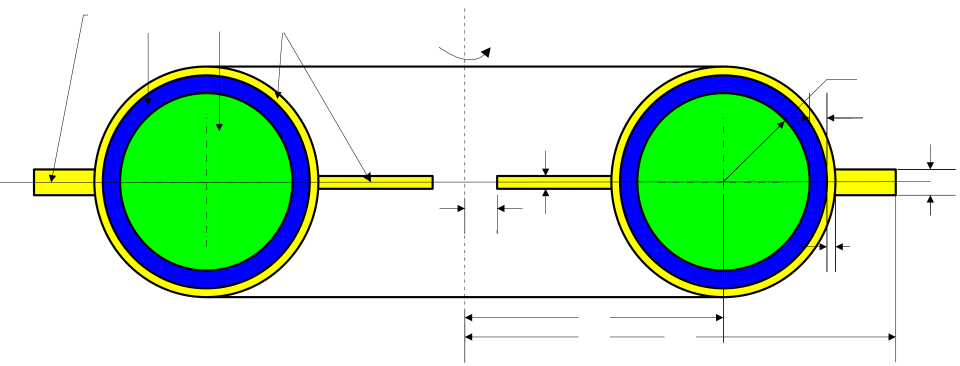
		Cu	Al	D16
Plasticity factor	$\delta_{eqv}^{n} = \sigma_n / \max(\sigma_{eqv})$	**0.36**	**0.34**	**6.2**
Load factor	$\delta_{eqv}^{m} = \sigma_m / \max(\sigma_{eqv})$	**1.12**	**0.78**	**8.0**

Al - is destructed under centrifugal forces
Cu - does not destroy but experiences plastic deformation
D16 - is not destructed and deforms elastically

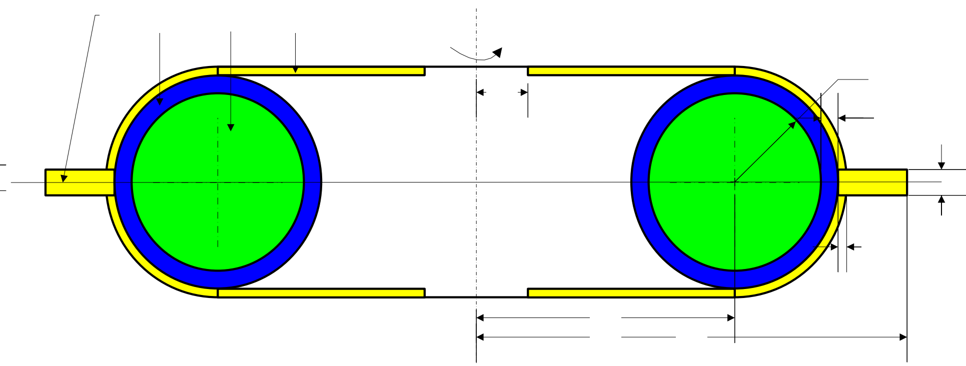
Characteristics of the stress-strain state

(main metal – D16)

Model 1



Model 2

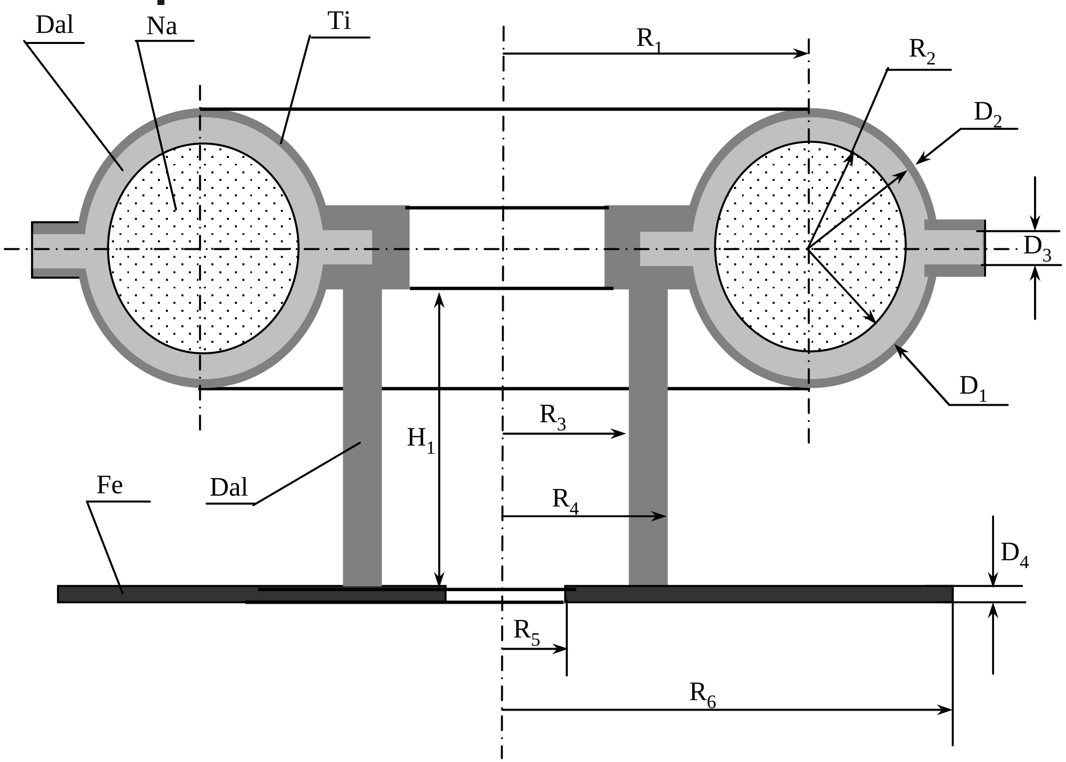


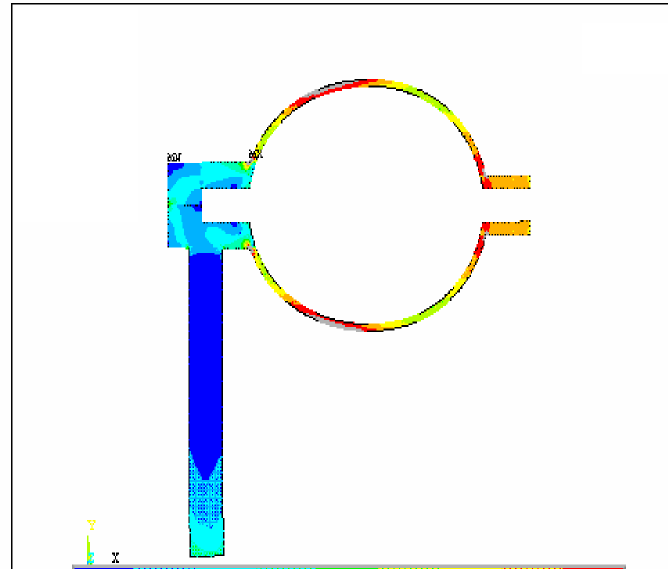
	Sodium (Na)	Toroidal channel (D16)	Shell (Ti)	Brake disc (Fe)	Total
Mass, kg	58	153	31/20	24	266/255
Moment of inertia kg m^2	5.6	17.2	3.6/2.2	6.0	32.4/31
Kinetic energy, kJ	280	850	180/110	290	1600/1530
Mean overheat ,°C				120/114	
Load factor		6.5/10.6	4.3/2.5	4.3/4.6	
Plasticity factor		5.1/8.2	3.7/2.2	3.7/4.0	

*** - Model 1/Model 2**

PROBLEMS: Dal-Na contact, embrittlement

Engineering development and design





δ_{eqv}^{m}	100	65.4	33.7	22.7	17.2	13.7	11.5	9.9	8.6	7.7
δ_{eqv}^{n}	115	75.1	38.7	26.2	19.7	15.8	13.2	11.4	9.9	8.8

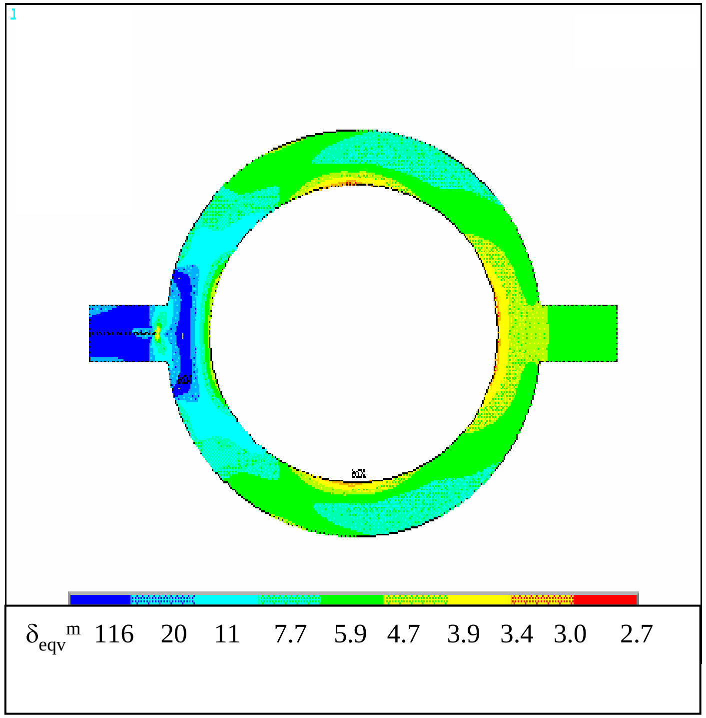
Chromium copper БрХ-1

Properties

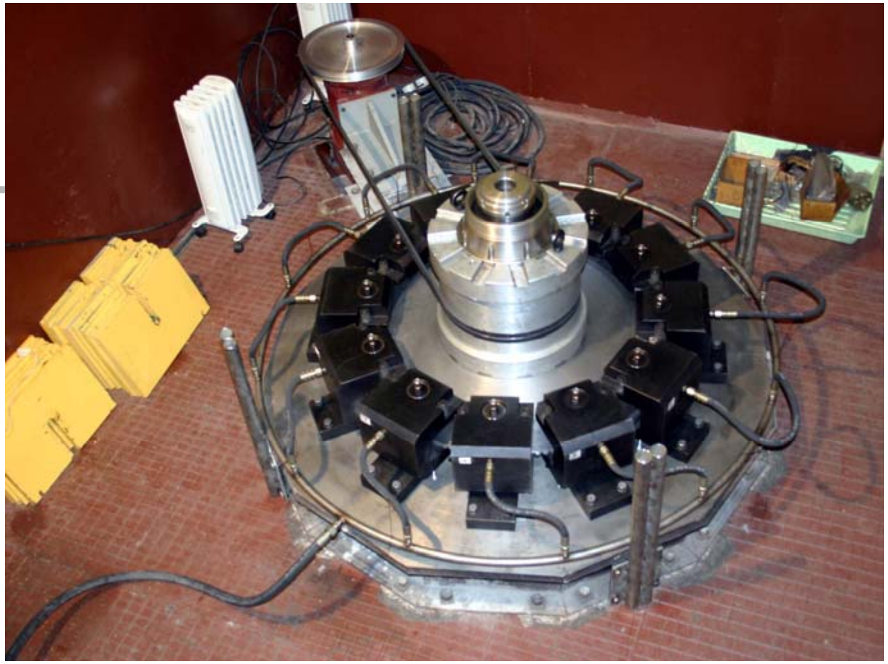
- Conductivity – 86% of pure copper conductivity
- Ultimate stress limit – 450-470Mpa

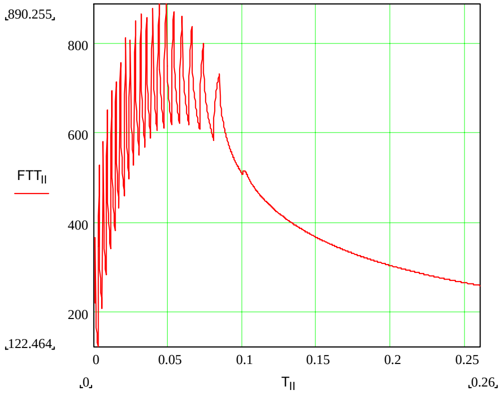
Technology

- Fusion
- Hot Rolling
- Hardening
- Cold Rolling
- Artificial deterioration (ennoblement)



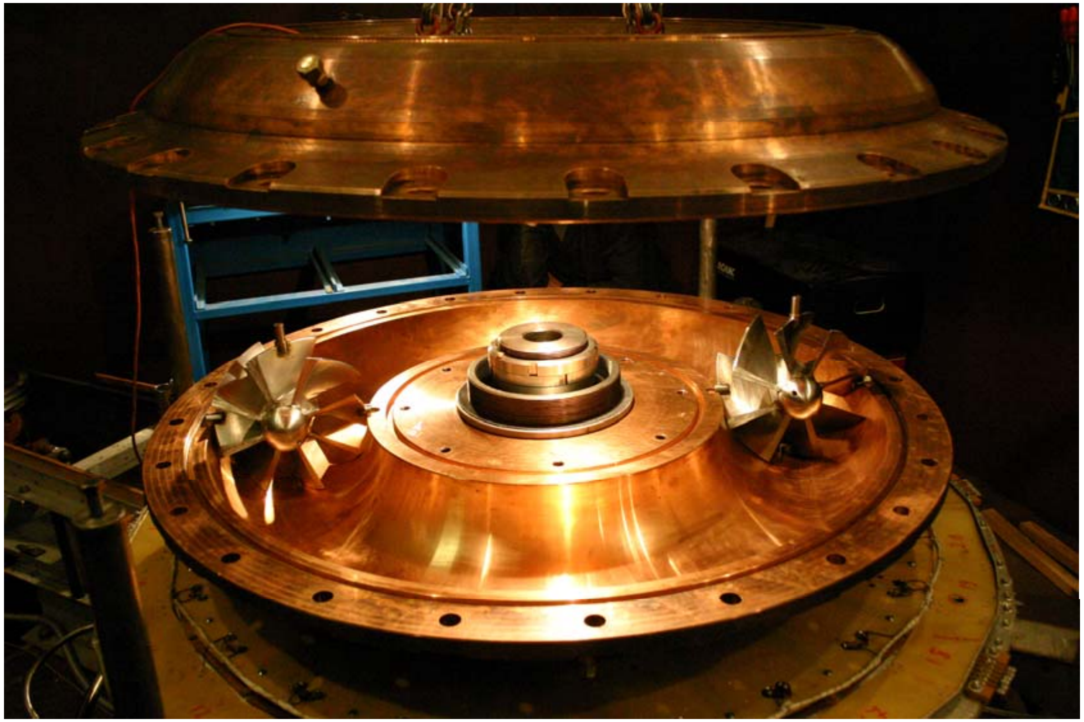
The breaking system



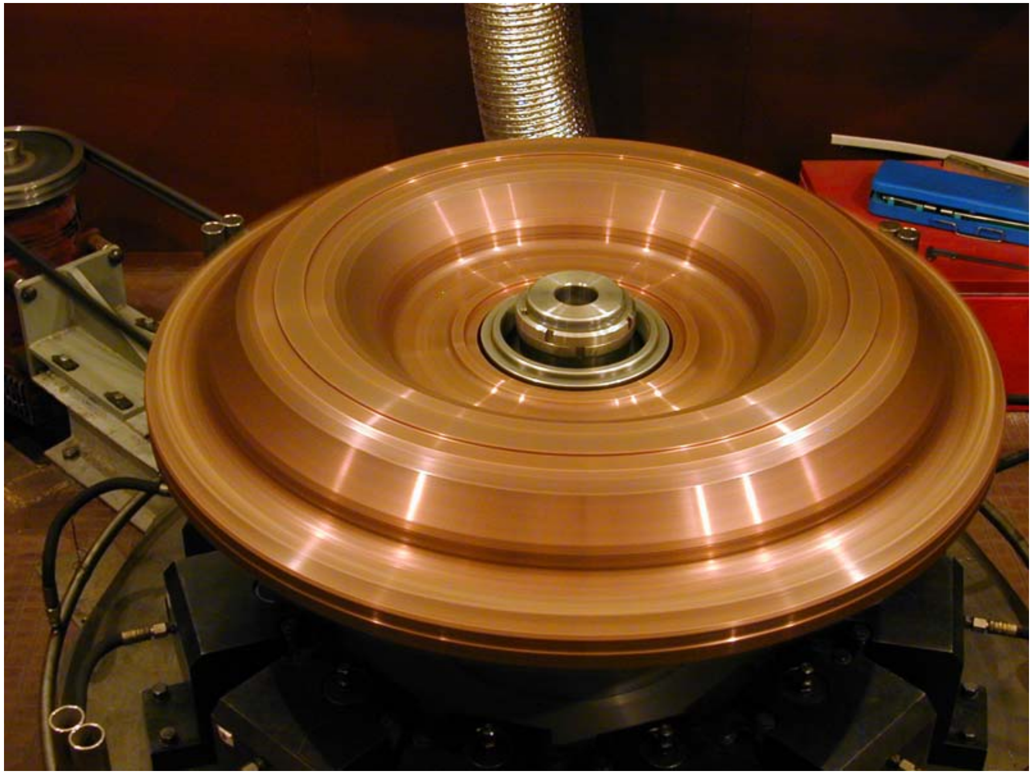
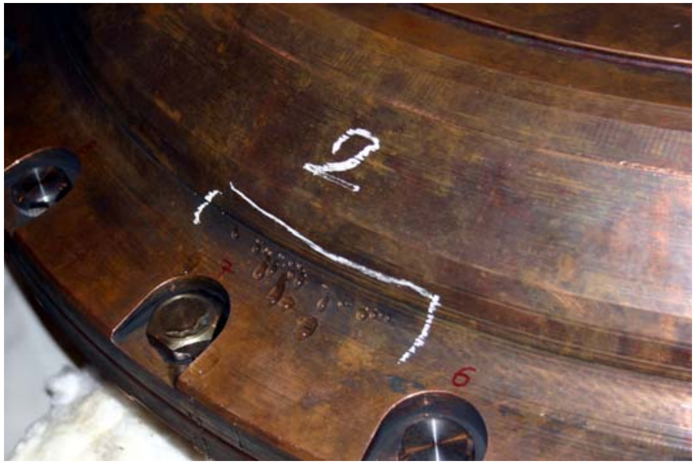


Temperature of the disk surface

The torus



The torus



GALLIUM EXPERIMENT

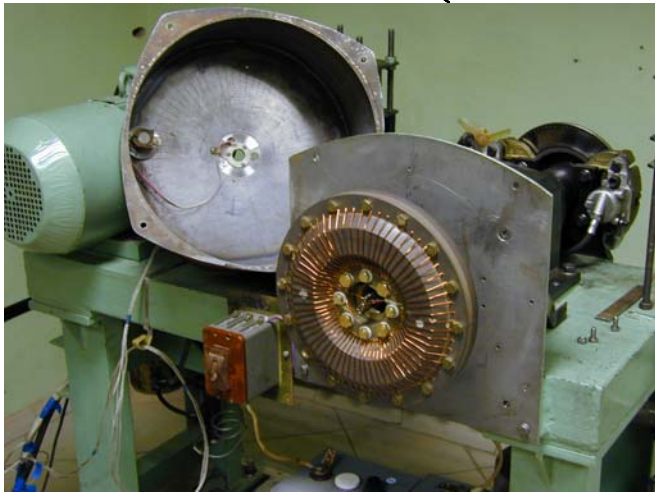
$$R_0 = 0.0875m$$

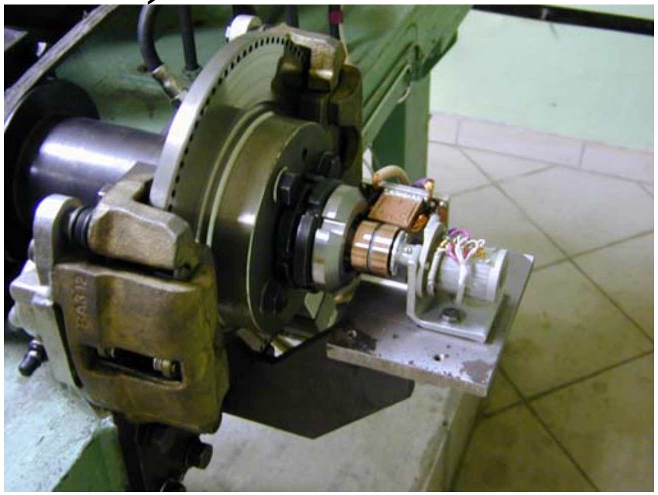
$$r_0 = 0.0225m$$

$$M_{Ga} = 5.58kg$$

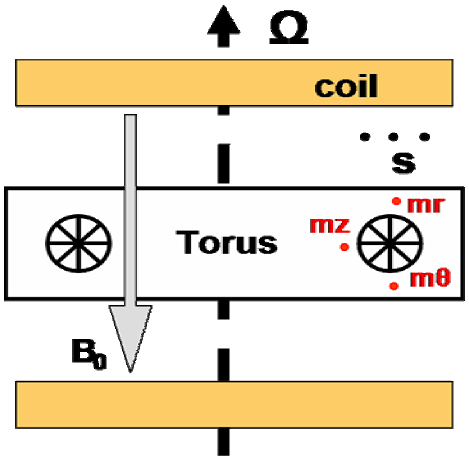
$$I_{\max} = 2kA$$

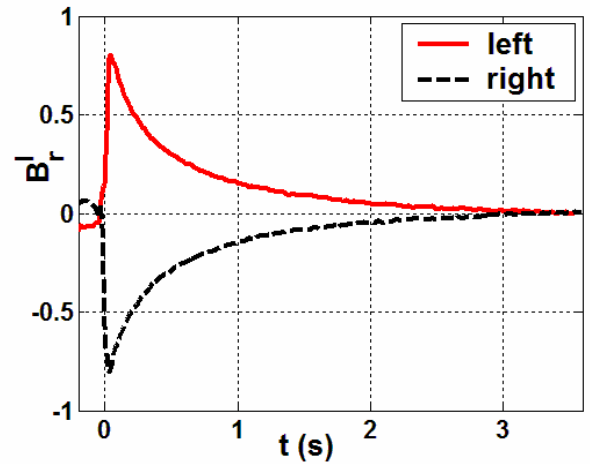
$$(DC\ and\ AC)$$

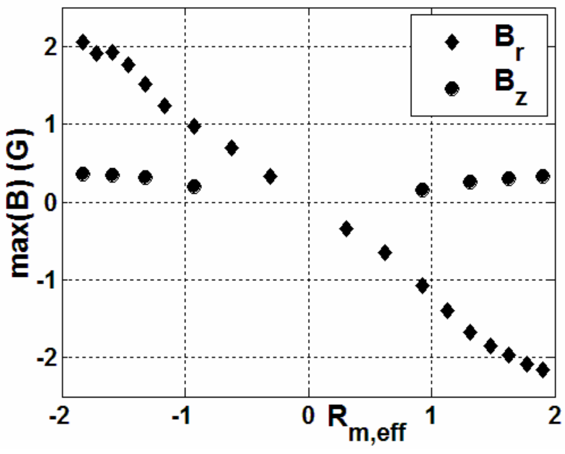


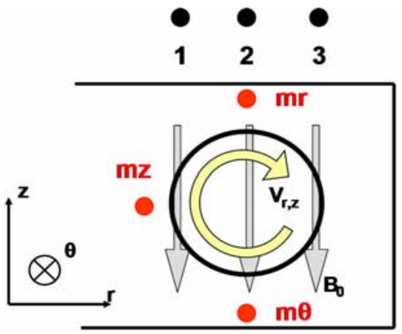


Transverse field 50Gs





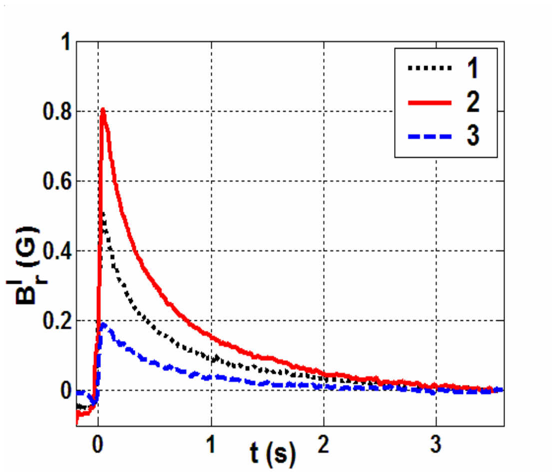


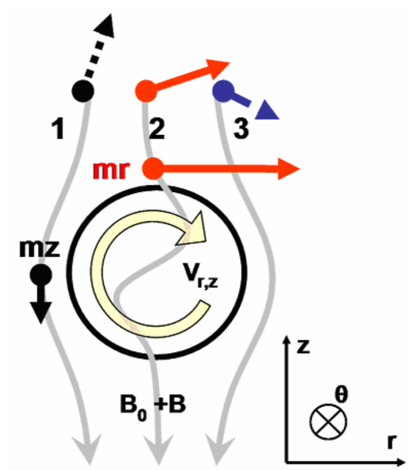


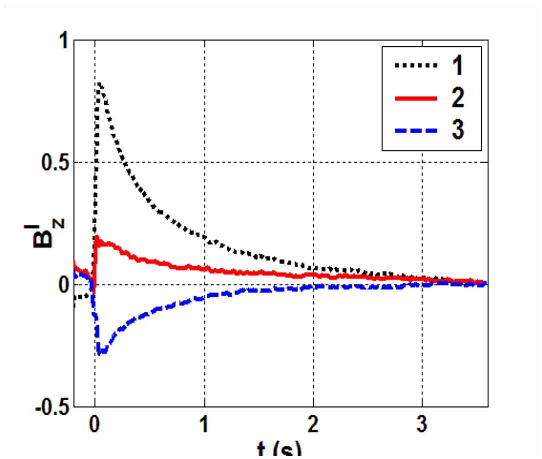
-typical time evolution of the radial component *Br* measured by the 3D static probe at location 2 for different diverters;

- Maximal values of *Br* (mr probe, diamonds) and *Bz* (mz probe, dots) versus *Rm* (left diverters).

Transverse field 50Gs

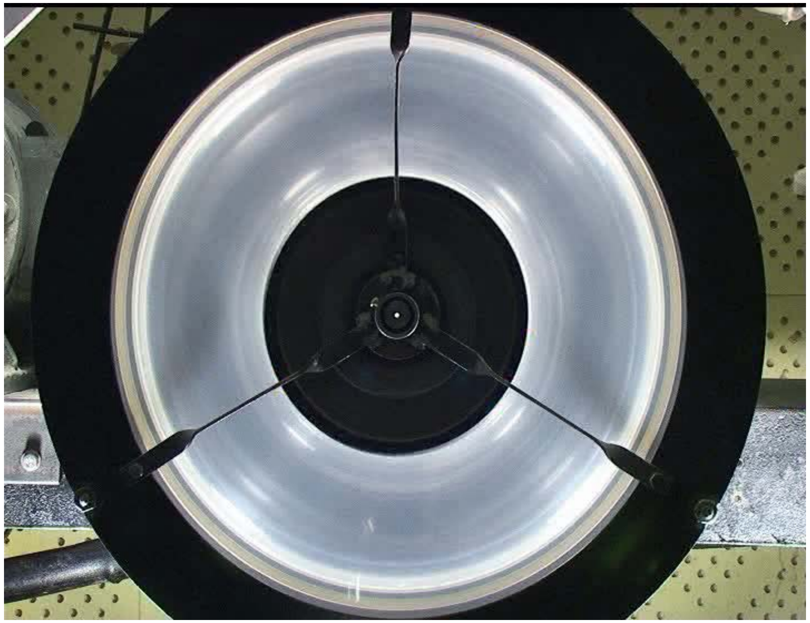


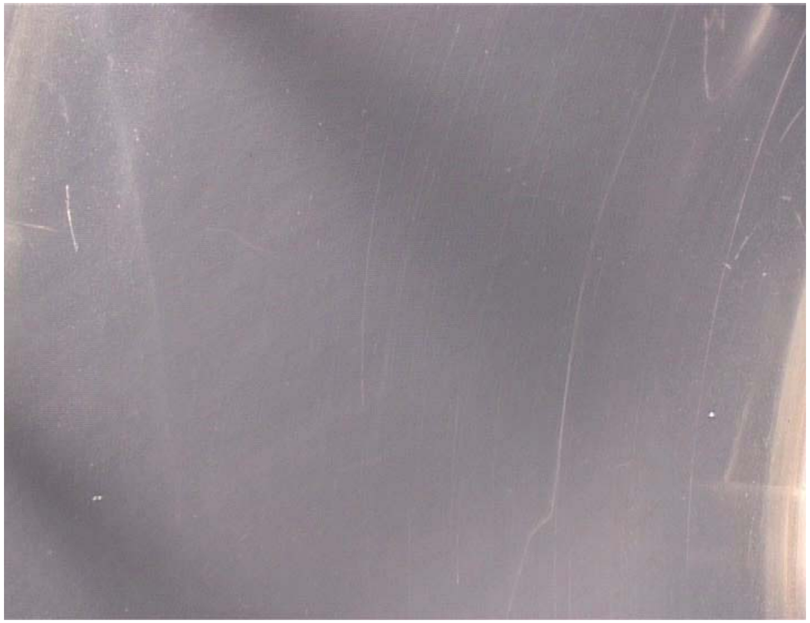




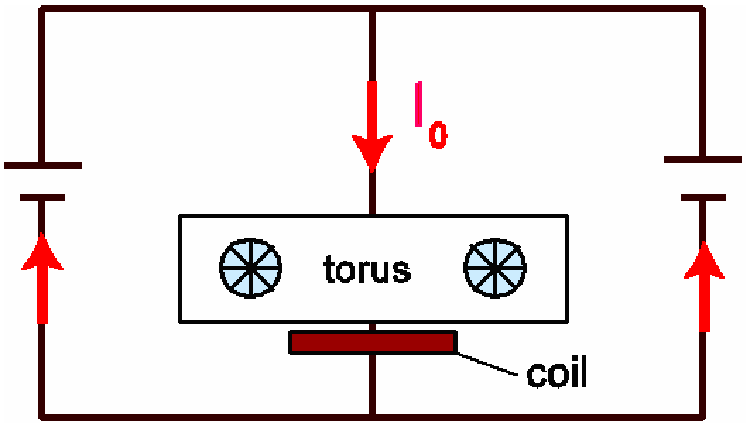
- B_r component measured at locations 1, 2 and 3 for negative rotation and left diverters;
- sketch of the field induced by the poloidal vortex;
- B_z component measured at locations 1, 2 and 3 for negative rotation and left diverters.

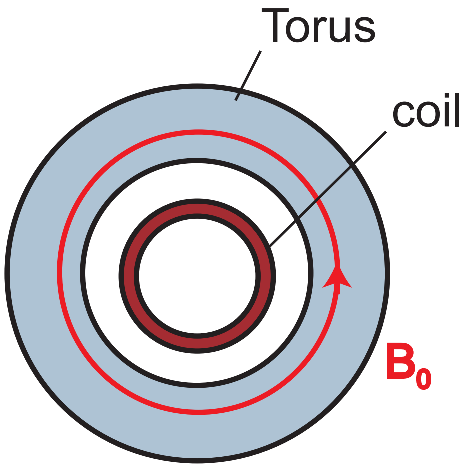
small-scale helicity





Toroidal field 35Gs

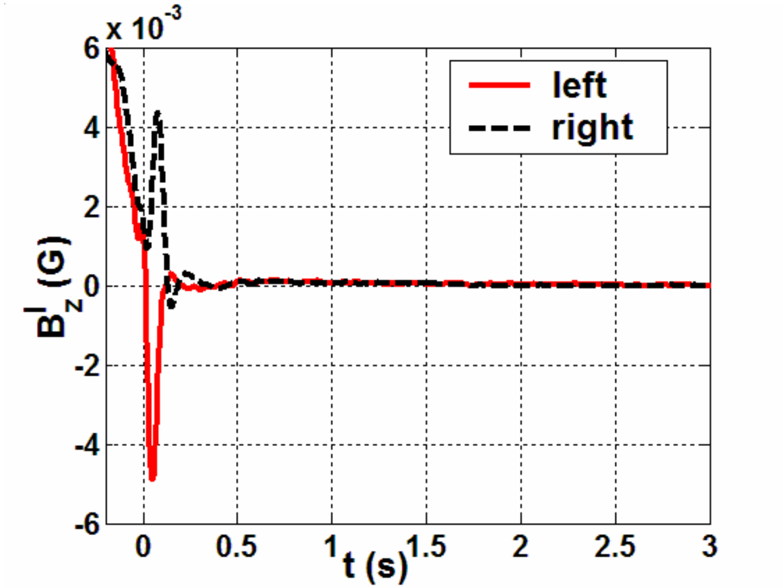


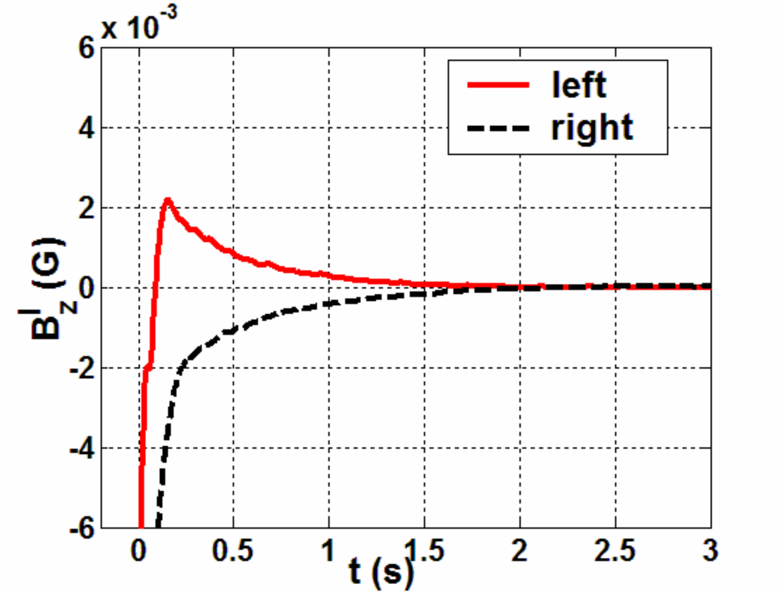


$$B_{even} = (B_Z(\mathrm{Rm}) + B_Z(-\mathrm{Rm}))/2$$

$$B_{odd} = (B_Z(\mathrm{Rm}) - B_Z(-\mathrm{Rm}))/2$$

Toroidal field 35Gs

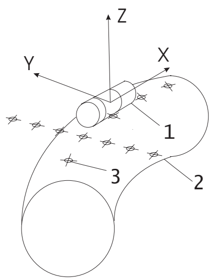


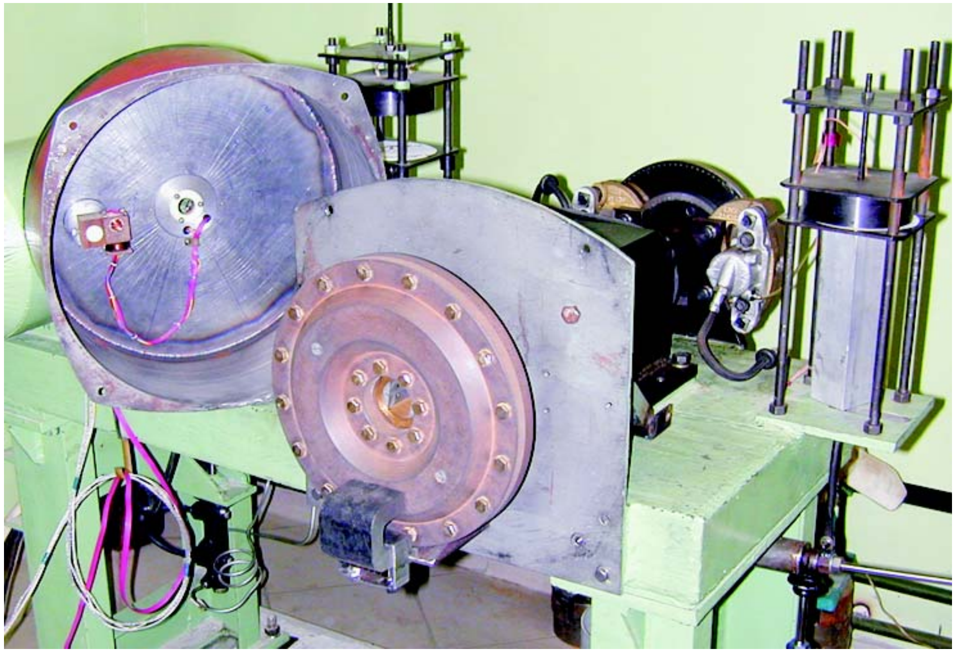


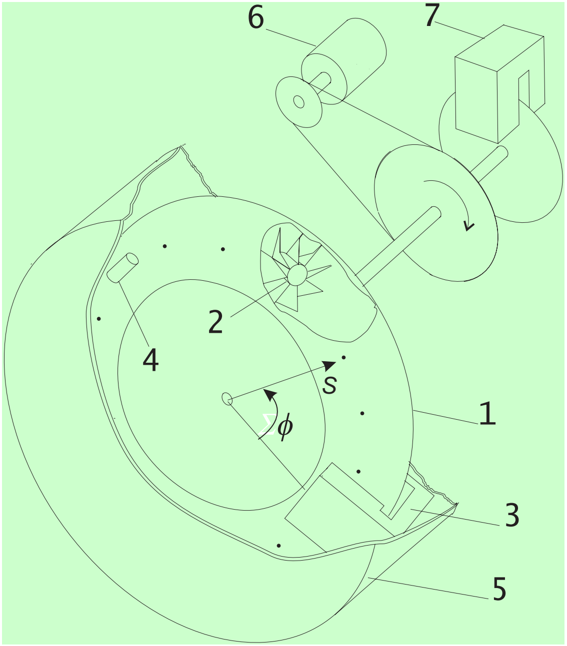
-Time evolution of the even part of the induced magnetic field measured by the coil (left and right diverters);

-corresponding curves for the odd part.

Local transverse field in Ga flow



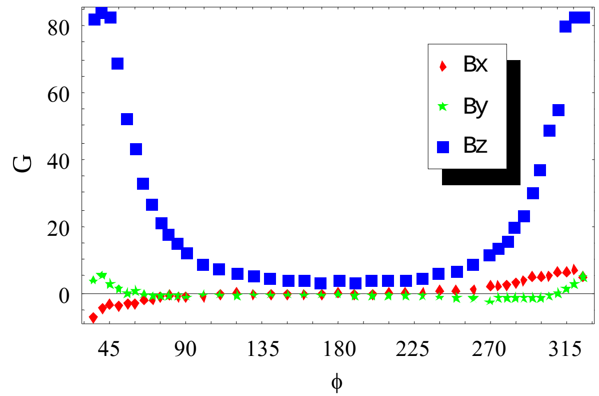




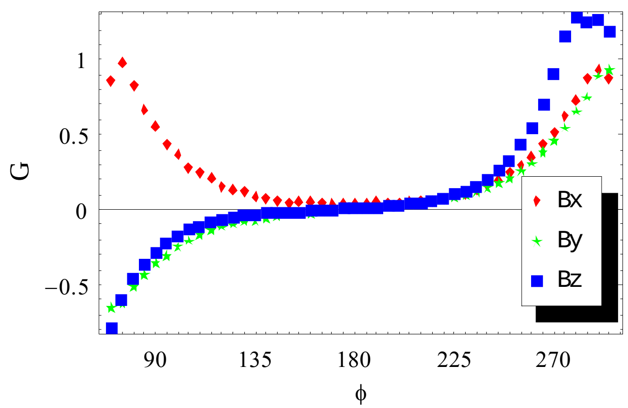
1 – channel
2 – diverter
3 – magnet
4 – 3D probe
5 - box
6 – motor
7 - brake

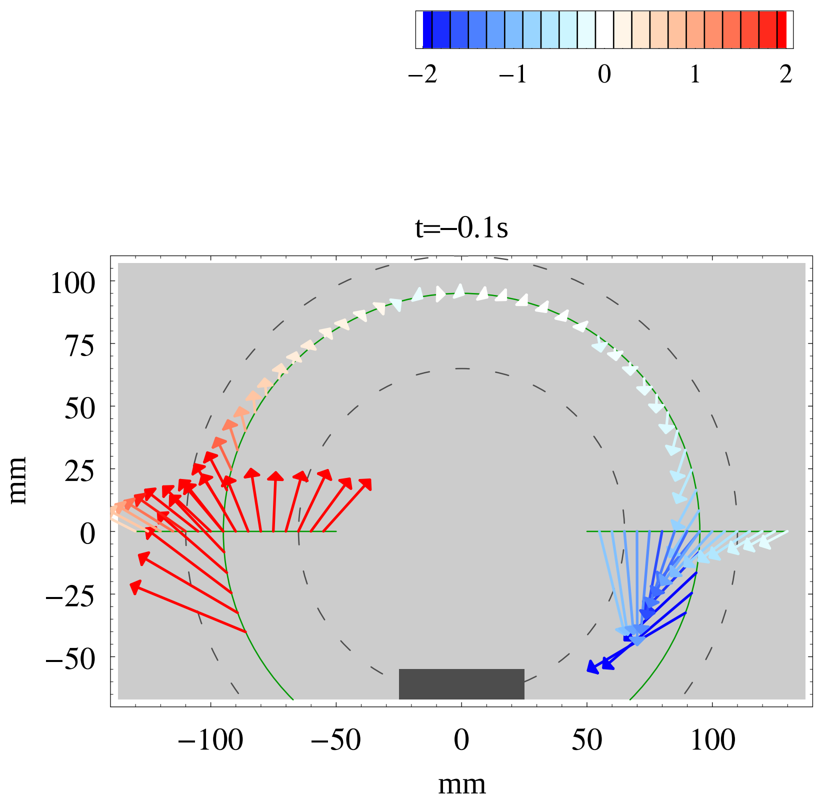
Solid rotation

Imposed field

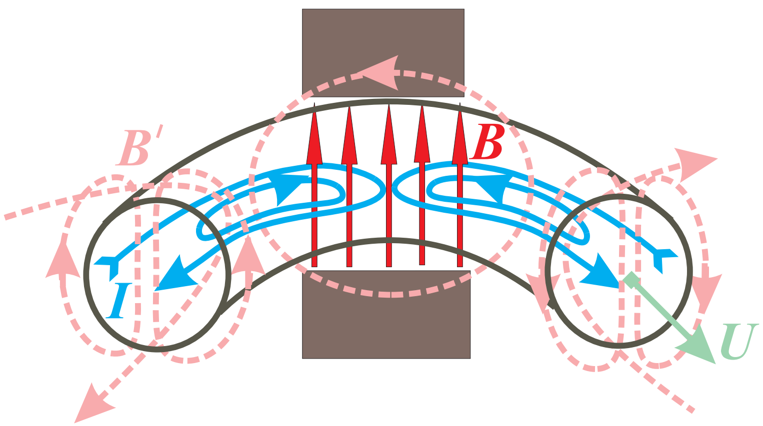


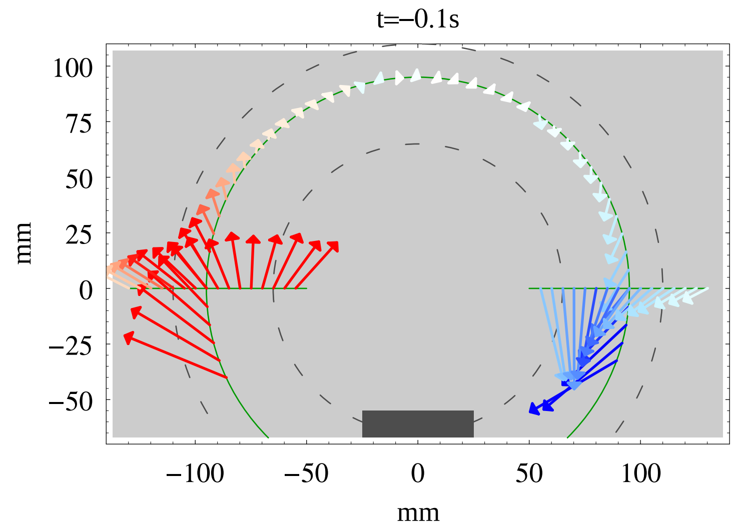
Induced field





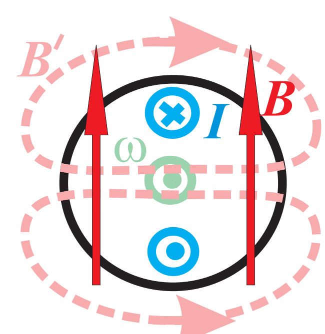
Induction mechanism



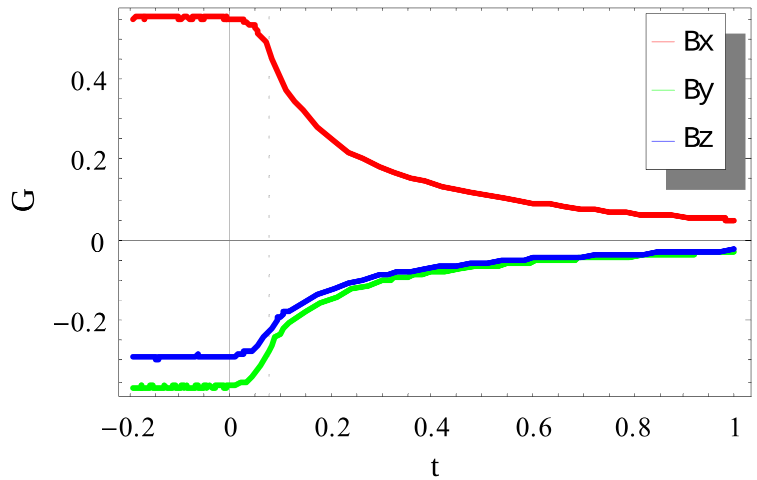


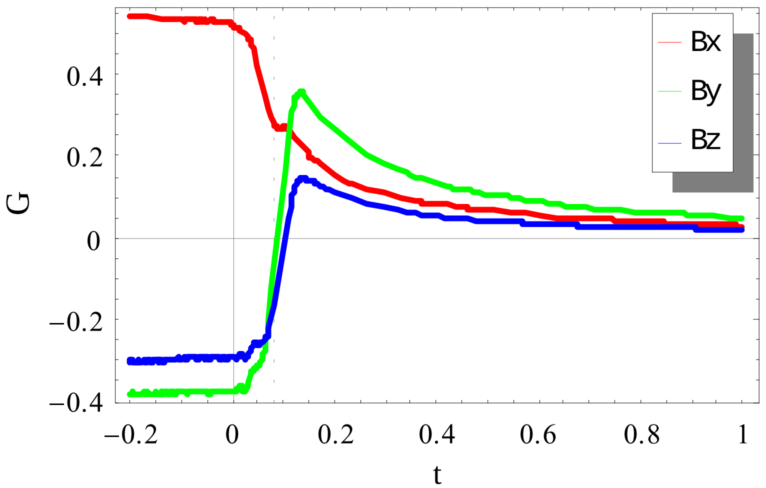
Solid-like rotation

Local rotation



Time evolution



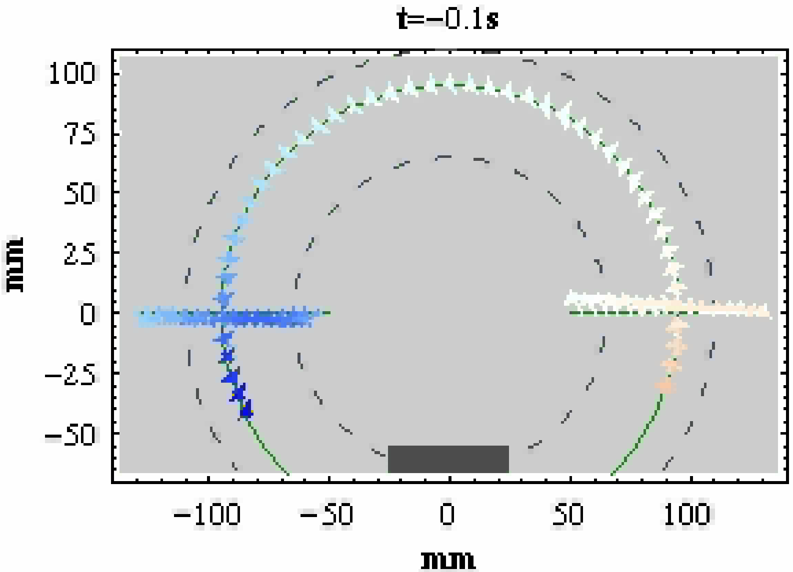


no diverters

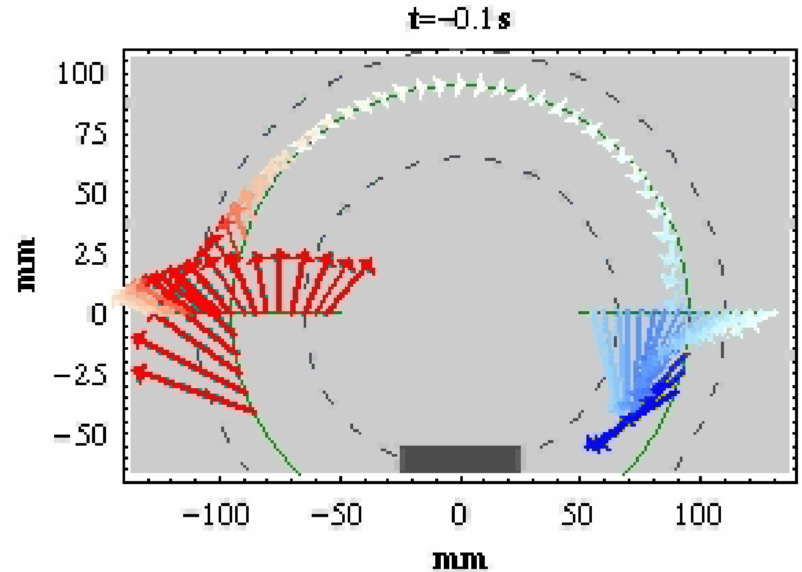
right diverters

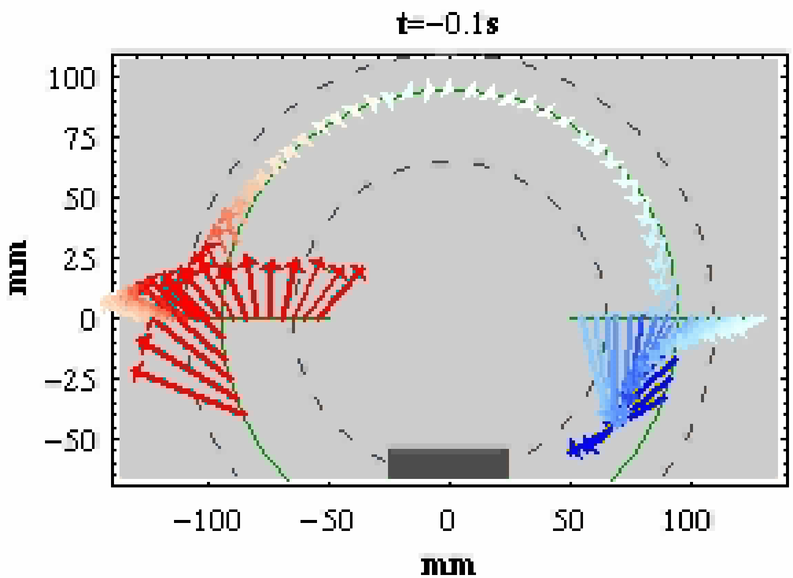
\phi=90 degr.

empty channel

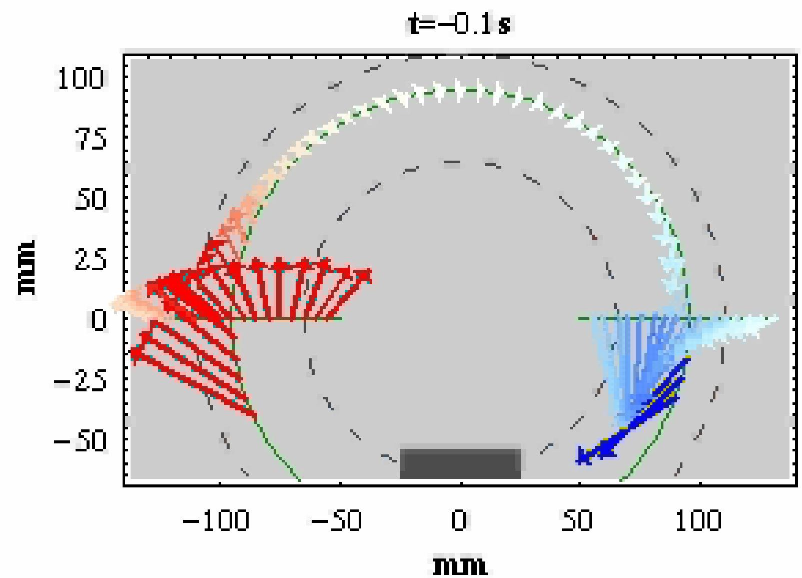


Ga without diverters

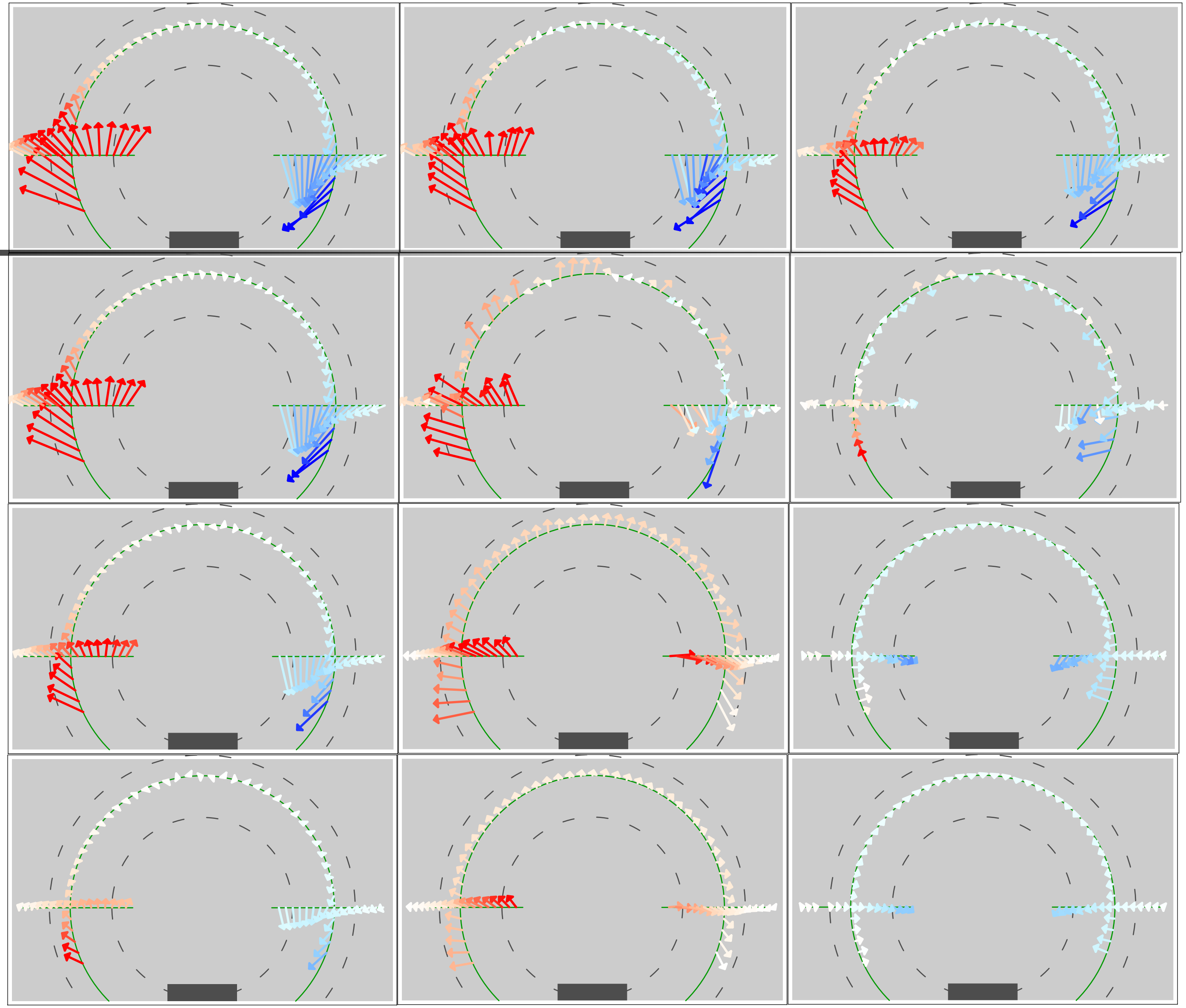




Right diverters



Left diverters



t=0.08s

t=0.15s

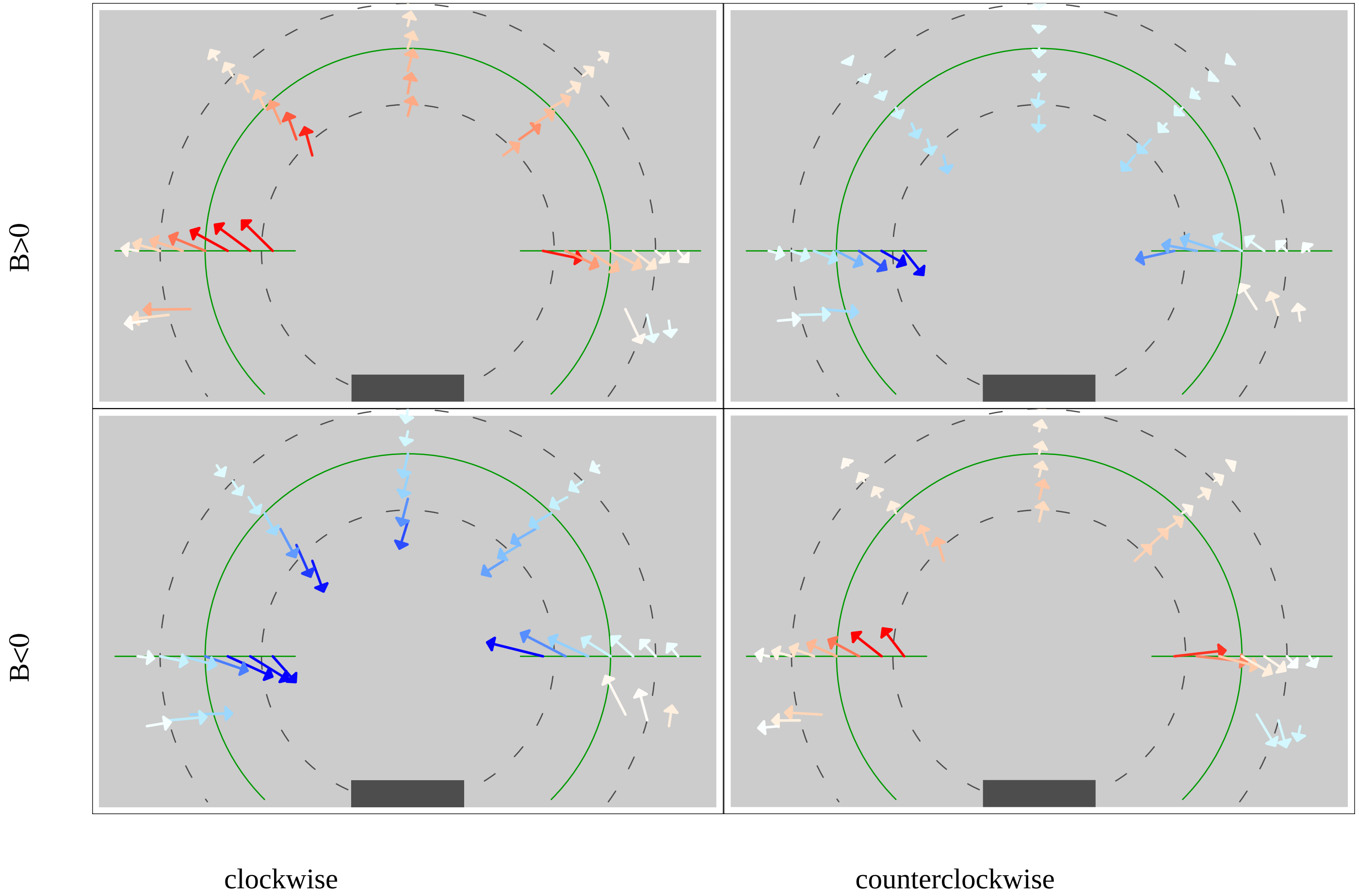
t=0.3s

no diverters

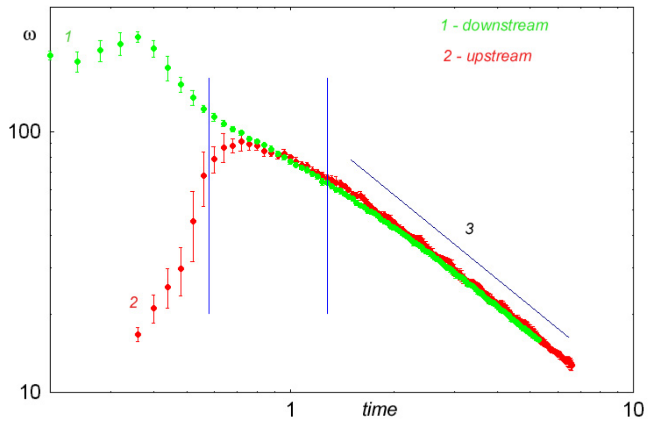
right diverters

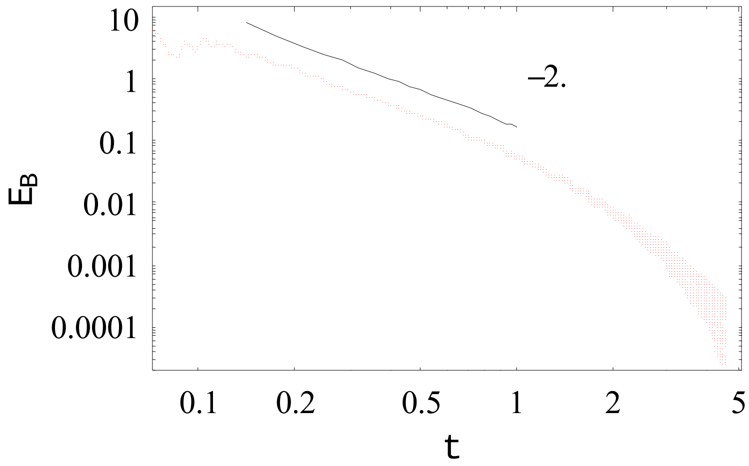
left diverters

Symmetries



Decay

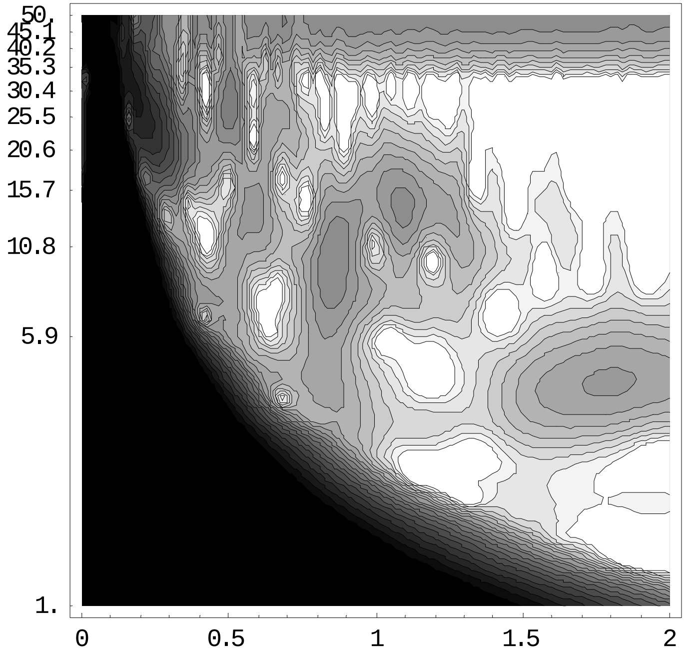




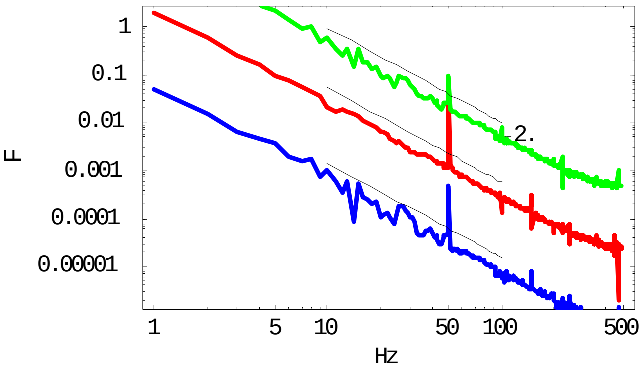
Kinetic energy
(water experiment)

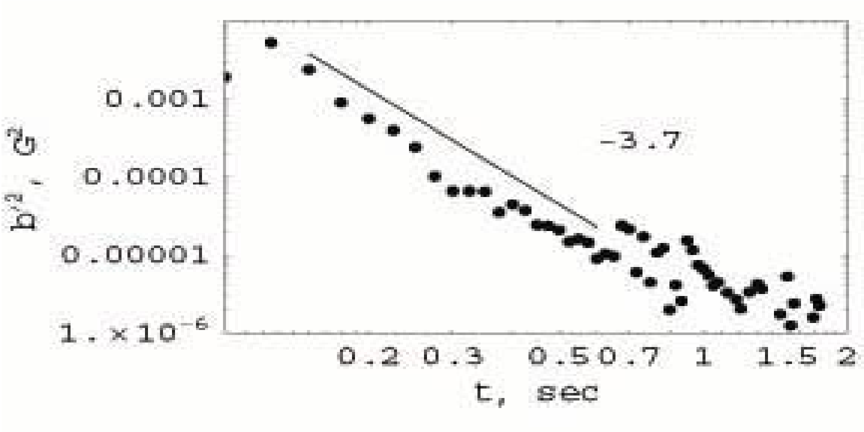
Magnetic energy
(gallium experiment)

Magnetic Field Pulsations



Wavelet plan





Pulsations energy in the band 10<f<40 Hz