COMPASS BEHAVIOUR IN A RIGA DYNAMO OUTSIDE FIELD

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Abstract: Riga Dynamo creates an AC (rotating round dynamo axis) magnetic field. A compass was put on floor near by and its needle started to rotate. The needle rotation appeared non-uniform and in direction opposite to overall field rotation. Why?
We present an actual video record and explain it by a simplified mathematical model where a real dynamo outside field is replaced by a rotating dipole field. When dipole rotates uniformly the all three field components at compass oscillate like sinus but with different amplitudes. Hence field direction there rotates non-uniformly. Depending on compass location the needle rotates either in direction of the dipole rotation or in opposite.

1. Introduction

Riga Dynamo experiment is designed to reproduce in laboratory a widespread natural phenomenon, when intense movement in huge volume of a fluid electrical conductor starts magnetic field. So creates magnetic field in Earth, the Sun, other planets, stars and even galaxies. In our experimental facility an externally powered (by 200 kW motors) spinning propeller sets 2 m^3 of molten Na in a pre-calculated flow, which generates the magnetic field [1,2]. Field pattern slowly rotates around the vertical axis of the device causing AC signals in the device inside sensors, which record and analysis is the primal experimental task (more on parent experiment in [3]). Part of the field penetrates outside the facility. As an ultimate monitor next to experiment is arranged a compass, which reading is the subject of this work.

2. The experiment

As shown in Fig.1 the compass is 40 cm away from the outer wall of the device, it is twice far from the axis of symmetry. Compass is read by a web-camera attached to PC located in the control room. Dynamo experiment is conducted in 15-30 min. long sessions. During the session Na in facility heats up and the experiment have to stop for cooling.

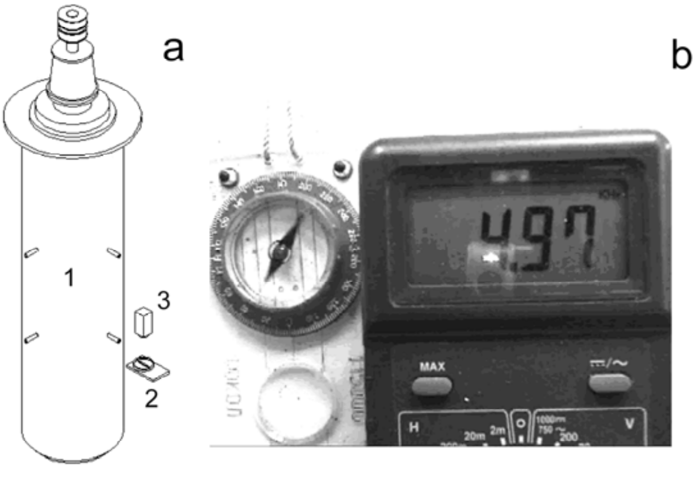

Figure 1: Experimental facility 1 with compass 2 and web-camera 3 (a), Video screen with compass and propeller rpm x 0.002 (b)

Compass readings were recorded in a number of sessions, this work deals with one explained on fig. 2. Starting session the compass is staying in a direction of an outside field (buildings deformed Earth magnetic field). While propeller accelerates to working speed the compass needle makes approx. 30° turn against propeller. Then it starts a growing oscillation and at last goes into rotation contrary to the propeller rotation (and overall field rotation as well, fig.

3). The oscillation and rotation frequencies both agree with frequency of internal field shown on fig. 2.

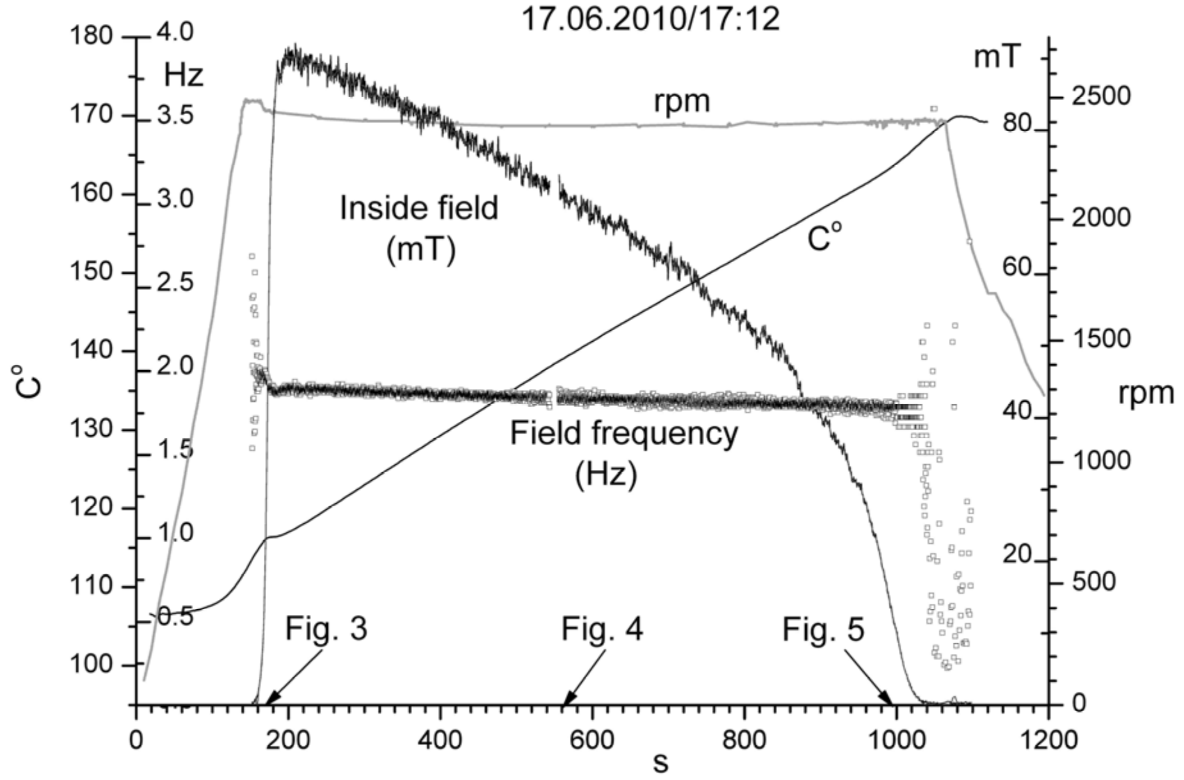

Figure 2: Basic information on parent experiment with time references to our figures.

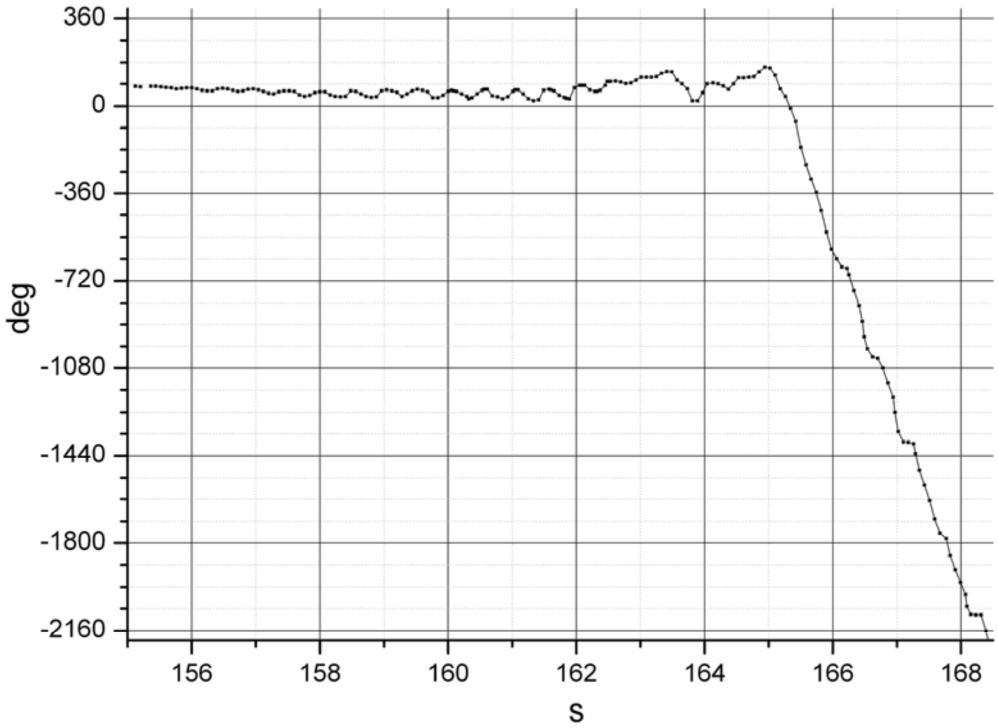

Figure 3: Compass readings at field start

The needle rotation is highly non-uniform - each full rotation stops for a while and then continues to rotate in the previous direction (Fig. 4 and steps on fig. 3).

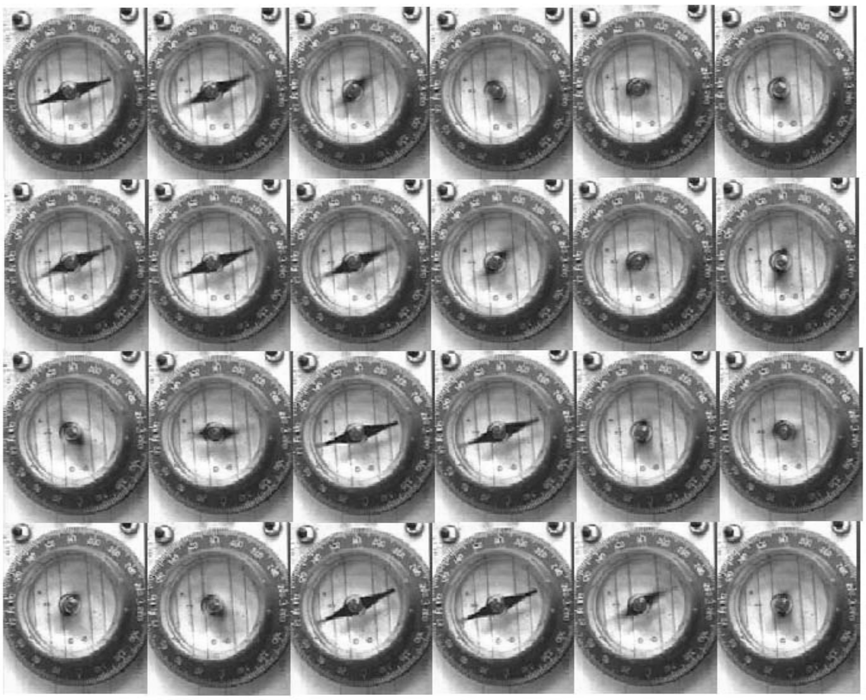

Fig. 4: Periodic non-uniform rotation at the middle of the session. Video rate: 12.5 frames per sec.

At some stops it turns even a few degrees back. It should be noted that in this and in all other sessions the white end of compass needle always stops at the same direction which is neither radial nor azimuthally to dynamo center and close to position where it started to oscillate. This means that the needle 'senses' direction of outside field even when it is superposed by overwhelming dynamo field. With operating temperature growing magnetic field decreases to disappear for all. At the same time, the compass goes from the non-uniform rotation to damped oscillation (Fig. 5). Oscillation ends at the very compass reading where it started.

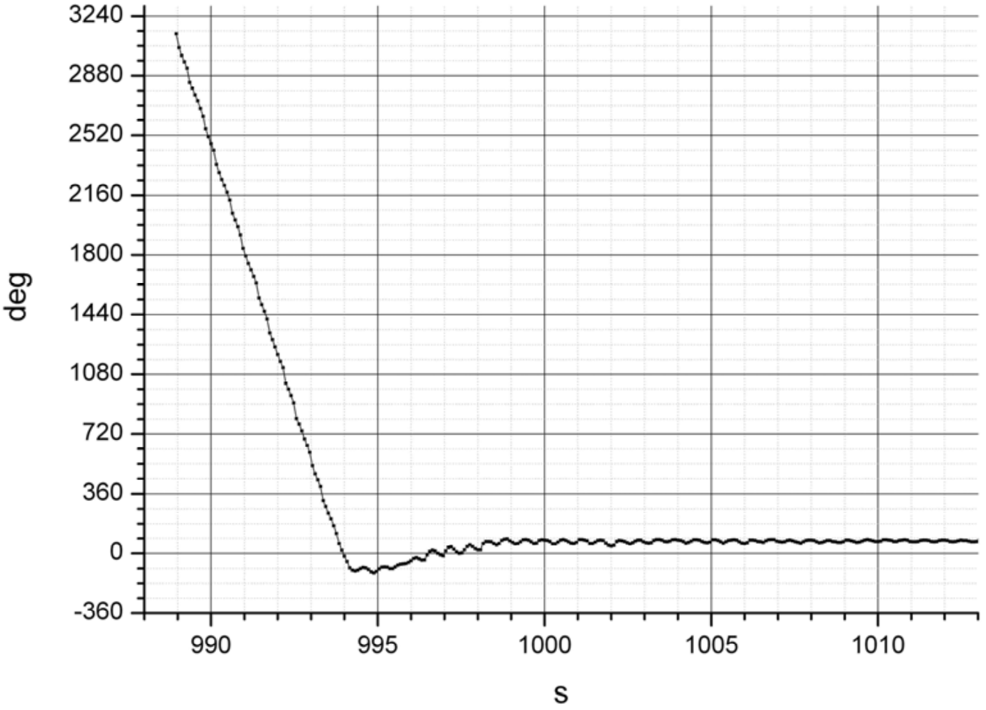

Fig. 5: Compass goes from the non-uniform rotation through oscillation perturbed retrograde half-turn into damped oscillation.

3. Simplified model

Compass motion raises several questions. Why compass rotates propeller contrary? Why rotation is considerably non-uniform? Are these properties unique for dynamo field or common features for compass next any solid magnet rotating around vertical axis (Fig. 6)? Outside the magnet its field is close to the dipole field:

$$\vec{B} = grad\varphi = grad\left(\vec{r}\vec{D}/r^3\right) = \vec{D}/r^3 - 3\vec{r}\left(\vec{D}\vec{r}\right)/r^5$$

Rotating dipole moment in laboratory frame is periodic in time:

$$D_x = D\sin\omega t$$

$$D_y = D\cos\omega t$$

In our experiment the compass was in only one location, aside from facility. Here we consider the whole lower hemisphere. In point (x=r*cosθ*, y=0, z=r*sinθ*) the compass senses only two magnetic field components B_x, B_y from three. The both varie periodically in time, but with different (θ dependent) amplitudes:

$$B_x = D\sin\omega t\left(1 - 3\cos^2\theta\right)/r^3$$

$$B_y = D\cos\omega t/r^3$$

Hence at compass location the field projection on B_x, B_y plane executes an ellipse with major axis either in x or y direction. As a result, magnetic field direction at the compass location rotates around the vertical axis, but unsteady in general. There are two locations (90° and 35.26°=$\arcsin\sqrt{1/3}$) where the ellipse is a circle hence compass rotate steady. At all other location angles compass rotates unsteady in location dependent direction. So:

1. $0° \le \theta < 35.26°$ - unsteady rotation opposite to magnet rotation;
2. $\theta = 35.26°$ - steady rotation in direction opposite to the rotation of the magnet;
3. $35.26° < \theta < 54.74°$ - unsteady rotation opposite to magnet rotation;
4. $\theta = 54.74° = \arcsin\sqrt{2/3}$ - the ellipse is deformed into straight line, magnetic field is AC field in y direction and rotation direction is un-definite.
5. $54.74° < \theta < 90°$ - unsteady rotation in direction of magnet rotation.
6. $\theta = 90°$ - steady rotation in the direction of the magnet rotation

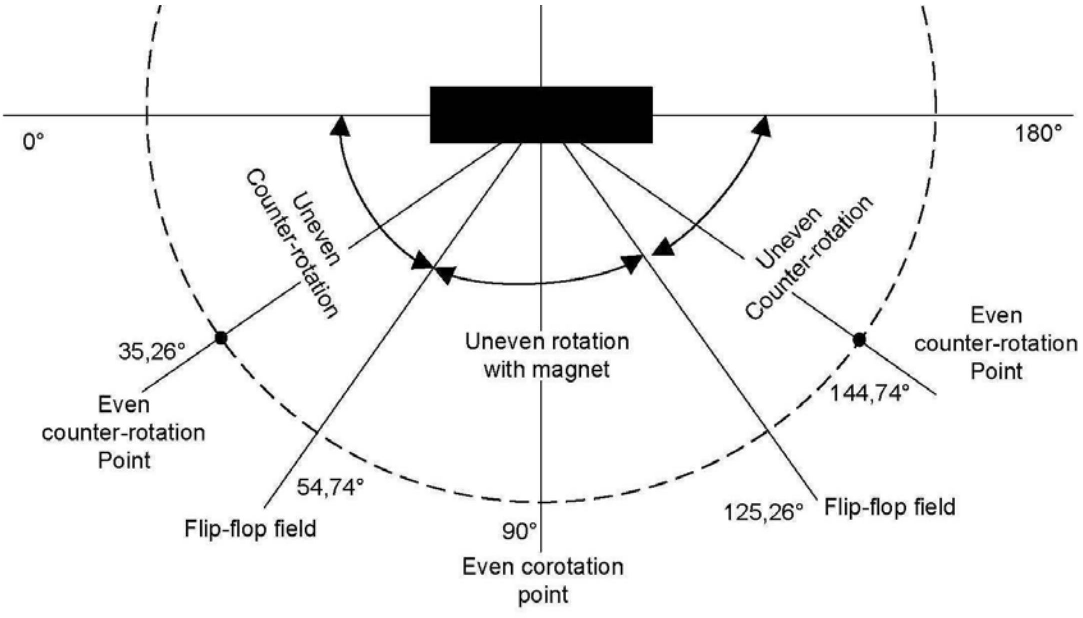

Figure 6: Angles of different compass behaviour.

The real dynamo field changes direction $\alpha_B(t)$ too rapidly to be exactly followed by compass used. Hence compass reading $\alpha(t)$ depends not only on the magnetic field, but also on such compass properties as the inertia and magnetic moments of the needle (I, d), and the damping factor γ:

$$(I/d)d^2\alpha/dt^2 = B(t)\sin(\alpha_B(t)-\alpha)-\gamma\, d\alpha/dt$$

Until PAMIR2011 we hope to learn more on compass behavior numerically solving this equation.

4. Conclusions

Compass is a useful device in parallel with other instruments to monitor magnetic field generation in Dynamo experiment. It underlines importance of dynamo effect as accessible not only with sophisticated instruments but also with an ancient compass.
Unlike the one-dimensional sensors compass clearly indicates the direction of the magnetic field rotation.
The simplified model sufficiently explains the experimental observation.

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5. References

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