MEASUREMENTS IN A DOWNSCALED WATER MOCKUP AND NUMERICAL SIMULATION FOR THE DRESDYN LARGE SCALE PRECESSION EXPERIMENT

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Abstract: Precession has long been discussed as a complementary energy source of homogeneous dynamo action. In the framework of DRESDYN (DREsden Sodium facility for DYNamo and thermohydraulic studies) a precession driven dynamo experiment is under construction. For proper dimensioning of the sodium experiment, measurements at the 1:6 down scaled water mockup are compared to numerical simulations. We present pressure, velocity, and motor power measurements for the water mockup. Furthermore, we provide an insight into mechanical engineering aspects of the real sodium experiment.

1. Introduction

Although most theories of the geodynamo rely on a flow driven by thermal and/or compositional buoyancy [1], precession has long been discussed as a complementary energy source [2,3,4]. This idea seems to be supported by paleomagnetic measurements showing a modulation of the geomagnetic field intensity by the 100 kyr Milankovic cycle of the Earth's orbit eccentricity and by the corresponding 41 kyr cycle of the Earth's axis obliquity [5]. Most interesting in this respect is the correlation of geomagnetic field variations with climate changes, as hypothesized for the sequence of ice ages [6]. Recently, precession driving has also been discussed in connection with the generation of the ancient lunar magnetic field [7], and with dynamos in asteroids [8].

Aside from geophysical questions, precession driven dynamo action is also interesting from the viewpoint of fundamental MHD. This applies, in particular, to the experimental study of dynamo action which has made great progress during the last 15 years [9]. In a sequence with the previous liquid metal experiments in Riga [10], Karlsruhe [11] and Cadarache [12], a precession driven dynamo experiment would represent a logical next step towards a real homogeneous dynamo. With just a fluid rotating around two axes, it would neither contain any propeller, as in Riga, nor any assembly of guiding tubes, as in Karlsruhe, nor any soft-iron material (which is crucial for the low critical magnetic Reynolds number and the nearly axisymmetric eigenmode) as in the Cadarache experiment [13]. The precession driven dynamo experiment that is planned to be set-up in the framework of the DREsden Sodium facility for DYNamo and thermohydraulic studies (DRESDYN) will be a cylindrical stainless-steel vessel of approximately 2 m diameter and length, rotating with up to 10 Hz around its symmetry axis, and with up to 1 Hz around the precession axis whose angle to the symmetry axis can be varied between 90° and 45°. With the indicated rotation and precession rates, this precessing vessel would exert a huge gyroscopic moment of around 8×10^6 Nm on the ground which requires the construction of a very solid basement.

Despite some numerical evidence for the possibility of dynamo action in precessing cylinders [14] and cubes [15], many aspects are still in need of further investigation. In order to figure out optimal design and process parameters for the later large-scale liquid sodium experiment, we have started a series of experiments at a smaller, 1:6 down-scaled, water precession experiment that is shown in Figure 1.

2. The water mock-up and the ultrasonic Doppler system

The 1:6 scaled water experiment is quite similar to the ATER experiment guided by J. Léorat [16], but allows additionally for choosing different angles between the rotation and the precession axes. The installed measurement equipment enables the determination of the torques and motor powers needed to drive the rotation of the cylinder and the turntable, and of the gyroscopic torques acting on the basement.

Concerning the flow field determination, we have installed a number of ultrasonic sensors for the determination of the axial velocity component. While the facility can run with rotation rates of 10 Hz and precession rates of 1 Hz, the well-known relation $d\ v_{max}=c^2/(8\ f)$ between signal depth d and maximal velocity v_{max}, for given sound velocity c and frequency f, restricts the UDV measurements to rather low rotation rates.

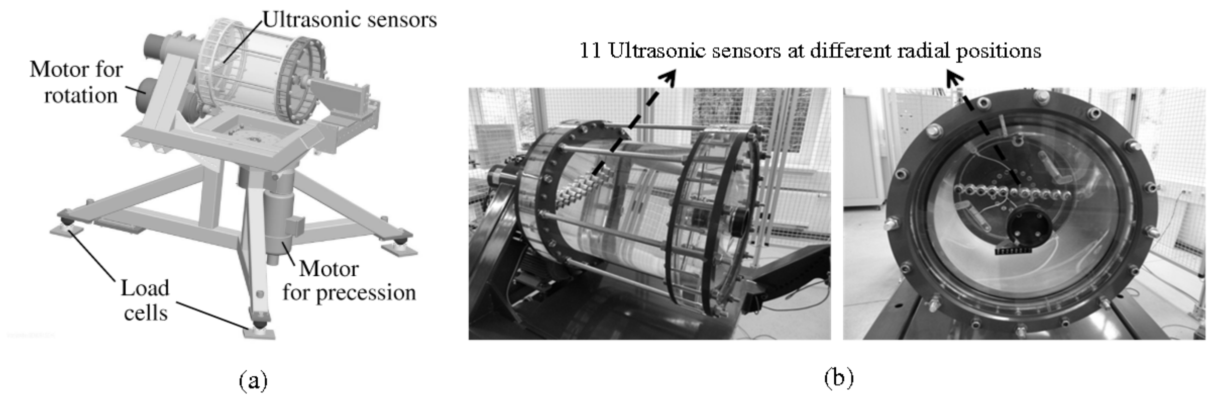
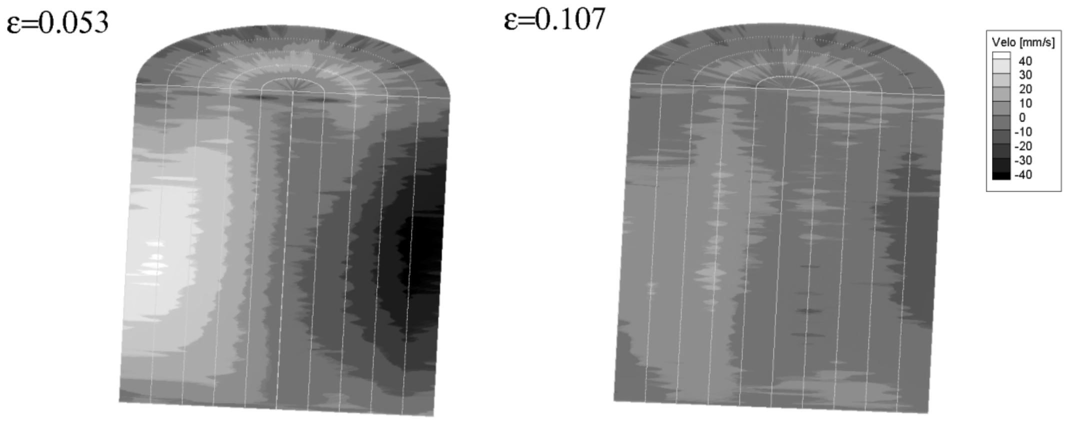


Figure 1: Drawing (a) and photography (b) of the 1:6 downscaled water precession experiment for the determination of velocity fields, motor powers, and torques on the basement for various driving conditions.

3. Results

For a rather low rotation rate of 0.2 Hz and two different precession ratios ε, Figure 2 shows the averaged results of the axial velocity measured by UDV for an angle between the two axes of 90°. The left-right asymmetry in Figure 2a (ε=0.053) is a typical indication for the dominant non-axisymmetric Kelvin mode with an azimuthal wave number m=1. When scaled to the planned 10 Hz rotation rate, and to the 6 times larger sodium facility, the observed velocity of 40 mm/s would correspond to a value of around 12 m/s. For a higher precession ratio, ε=0.107, this clear structure disappears and gives way to a turbulent flow regime.

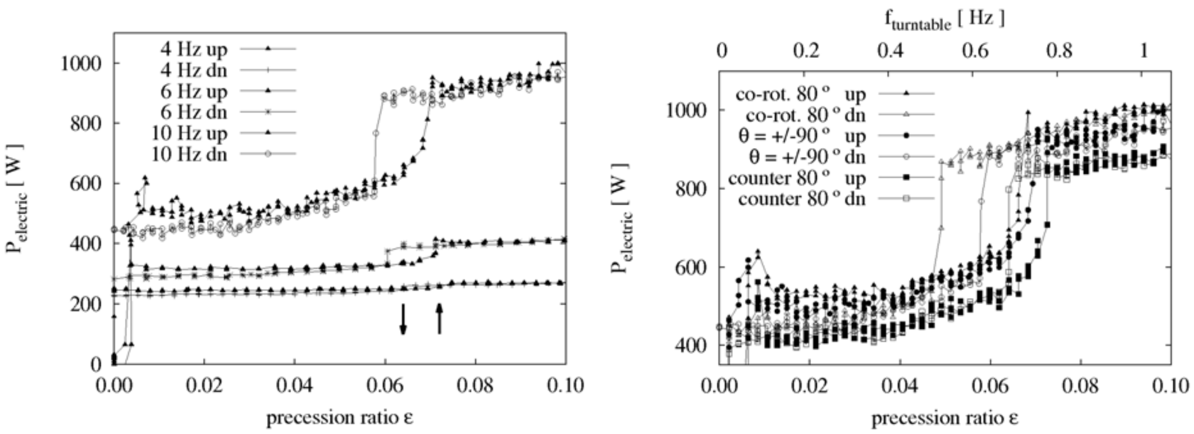
The difference between these two precession ratios illustrates a typical feature of precessing flows in cylinders. With the details depending slightly on the aspect ratio of height to diameter of the cylinder, we first observe a laminar flow with only a few non-axisymmetric modes which changes suddenly, at some critical value, to a turbulent flow. At this point the torque that is necessary for driving the rotation, and hence the motor power, jumps significantly.



(a) (b)

Figure 2: Averaged axial velocity component measured by the 6 UDV sensors for two different precession ratios in the laminar case (a) at ε=0.053, and in the turbulent case (b) at ε=0.107. The cylinder rotation rate was 0.2 Hz.

This behaviour is illustrated in Figure 3 which shows, now for a cylinder rotation rate of 10 Hz, sudden jumps of the electrical motor power with increasing ε. Figure 3 shows the comparison between 3 different cylinder rotation rates, which all exhibit a typical hysteresis of the transition between laminar and turbulent regime. It is interesting to note that the critical precession ratios for this transition depend only slightly on the rotation rate.



(a) (b)

Figure 3: Electrical power measured at the motor for the cylinder rotation. (a) Comparison between 3 different cylinder rotation rates, which all show a typical hysteresis of the transition between the laminar and the turbulent regime. Note that the critical precession ratios for this transition depend only slightly on the rotation rate. (b) Comparison between 3 different angles of the axes between rotation and precession and rotation axes.

In Figure 3b, we compare this transition behavior for 3 different angles between rotation and precession axes. For 90°, the upward jump occurs approximately at ε~0.065, while for decreasing precession ratio the downward jump occurs at ε~0.055. The critical precession ratio changes slightly when we modify the angle between the axes to 80°. Then we have to distinguish between the co-rotating case and the counter-rotating case. It seems that the hysteresis becomes broader for the co-rotating case, and narrower for the counter-rotating case, although this needs further confirmation.

4. Conclusions

This paper was motivated by the ongoing construction of a precession driven dynamo experiment. For the detailed characterization of the fluid flow in a precessing cylinder at different precession ratios and angles, we have carried out a variety of experiments at an 1:6 downscaled water mock-up. The power measurements have confirmed the existence of a critical value of the precession ratio at which a transition between a laminar and a turbulent flow regime occurs which seems to depend only weakly on the Reynolds number. Up to present, the UDV flow measurements were restricted to a rather small rotation rate of 0.2 Hz, due to the limitation of the maximum product of depth and velocity. An important goal for future measurements is the detailed characterization of the few large-scale helical eddies in the cyclonic regime, as they were identified by Particle Image Velocimetry (PIV) at the ATER experiment in Meudon [17]. For this purpose, we presently implement and test a 3D-PIV system for the simultaneous determination of all three velocity components in some finite volume of the cylinder.
The next step will then be to assemble the acquired information about the stationary and fluctuating parts of the velocity field into an appropriate form that can then be utilized in dynamo codes to determine in detail the conditions and optimal parameters for magnetic field self-excitations in the precession driven dynamo.

Acknowledgments.

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