Complementary Experiments at the Karlsruhe Dynamo Test facility

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Summary The Karlsruhe Dynamo Experiments have demonstrated that a permanent magnetic field of dipole character can be generated by sodium flow in a proper arrangement of helical and axial channels in a cylindrical container. Moreover, it has been shown that the dynamo state originates from the hydrodynamic turbulent state of channel flow as an imperfect bifurcation.(see Mueller, Stieglitz, Horanyi 2004). In a following series of experiments the critical conditions for dynamo action as well as the dynamo behaviour under supercritical conditions has been investigated with regard to the following aspects: **A)** The feedback of the dynamo magnetic field on the velocity of the forced flow in the guide channels of the test module; **B)** The dynamic response of the dynamo to an enforced periodic variation of the volumetric flow rates; **C)** The response of the dynamo magnetic field at supercritical conditions to a variation of electrical conductivity due to a change in the system's temperature.

A) The influence of the growing dynamo field on the velocity distribution in the axial channel of the test module is studied with the help of Compensated Permanent Magnetic Potential Probes (CPMPP) (Knebel, Krebs 1994). Based on Ohm's induction law the particular design of the used probe renders possible the measurement of the velocity in the axial channels located near to the centre of the module. A typical result of such a measurement is shown in figure 1.

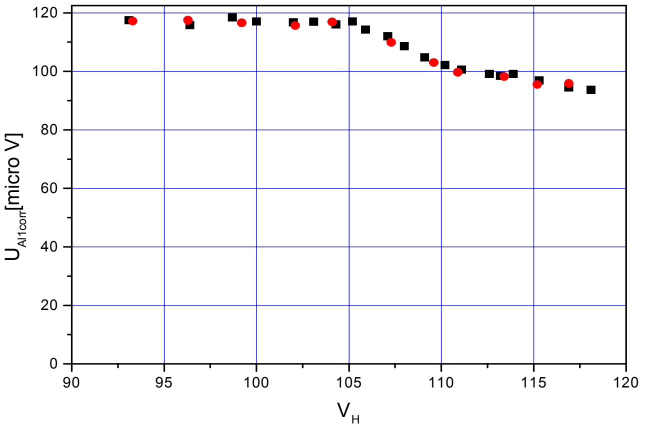

Figure 1:The measured compensated voltage at the Permanent Magnet Potential Probe located in an axial channel near the centre of the test module. One micro Volt (1 micro V) corresponds to a velocity of 0.04 m/s.

The result was obtained for a fixed central flow rate $\dot{V}_c$ = 105 m^2 /h (i.e. at a mean velocity 3.7 m/s) and for varying helical flow rates which were raised from sub-critical to super-critical conditions. The graph shows that the local axial velocity decreases from a plateau value for sub-critical flow rates at onset of dynamo action and saturates at another lower plateau value at higher super-critical flow conditions. This must be interpreted as a transition and redistribution of the turbulent velocity profile without magnetic field at Reynolds numbers 4,1 10^5 to a flat velocity profile at Hartmann number Ha $\approx$ 500. From this observation we conclude that the saturation of dynamo action at supercritical conditions is substantially governed by the formation of a MHD-core-flow with Hartmann boundary layers in the channel system of the test module.

B) It has been conjectured (Normand 2003, Petrelis & Fauve 2003) that a variation of the volumetric flow rates at time scales comparable to the magnetic diffusion time scale of the module's dimensions could lead to reduced critical flow rates for the onset of dynamo action. This conjecture has been tested by periodically varying the flow rate in the axial channels of the module at periods of 20 s and 7.5 s and an amplitude variation of 10 and 5% respectively to the mean value. The result is shown in figure 2.

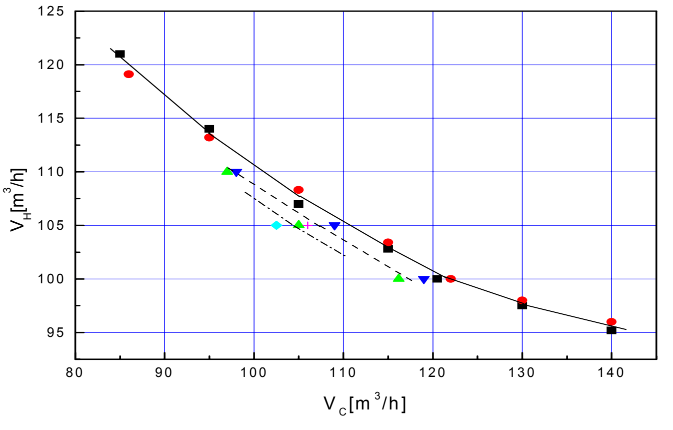

Figure 2: State diagram for dynamo action; steady state flow conditions (□ pressure loss criterion; • energy criterion, - fitting curve); periodic axial flow rates of period τ = 7.5 s and a 5% change in amplitude (▼ pressure loss criterion, ▲ energy criterion, --- fitting curve); periodic axial flow rates of period τ = 20 s and a 10% change in amplitude (+ pressure criterion, ♦ energy criterion, - • - • - conjectured fitted marginal line for dynamo action).

Using the local energy and the integral pressure criteria, developed in previous investigations (Mueller et al. 2004), the phase diagram for dynamo action demonstrates a shift of the critical flow rates towards lower values in the case of oscillatory flow rates, compared to the steady state ones. Moreover, the quantity of reduction seems to increase with the intensity of the fluctuations and with decreasing frequency.

C) The effect of a changing electrical conductivity of the fluid on the intensity of the dynamo magnetic field was studied by varying the system-temperature. We observed for instance at high supercritical flow rates of 115 m^3/h a drastic decrease of the field intensity from about 500 Gauss down to several Gauss when the system-temperature was increased from 125 °C to 145 °C. This can be explained by the enhancement of the critical Reynolds number Rm_c for onset dynamo action and, as a consequence, a reduction of the measure for the system's super criticality, i.e. $Rm - Rm_c$ (with Rm as the actual Reynolds number of the system).

As a result of the outlined experiments we summarize and conclude as follows: The dynamo magnetic field modifies the velocity distribution in the channels from its purely turbulent character to a MHD-core-flow with Hartmann boundary layers. A time periodic modulation of the volumetric flow rate may reduce the critical conditions for onset of dynamo action. The dynamo intensity is very sensitive to a variation of the electrical conductivity of the test fluid.

References:

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