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TOPICS

- Fundamental Problems of Magnetohydrodynamics
- Astrophysical and Geophysical Magnetohydrodynamics
- Applied Magnetohydrodynamics
- Magnetic Fluids and Their Applications
- Soft Magnetic Matter and its Application-Oriented Aspects
- Heat and Mass Transfer in Liquid Metals (with and without magnetic field)

CONTENTS

THE MAGNETIC HELICITY AND HIGHER HELICITY INVARIANTS AS CONSTRAINTS FOR DYNAMO ACTION

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It is known by the Arnold's Theorem that the magnetic helicity is not only an invariant in an ideal MHD, but also admits a gauge-invariant density [1], [2]. We will consider a question: «Is it possible to achieve an exponent -1.7 for a turbulent spectrum of the magnetic energy?» We get an affirmative answer, assuming that quasi-periodic magnetic fields are distributed free over the scale. Our answer uses asymptotic Hopf invariants [3], and the M-invariant [4] (a numerical measure of knottiness of magnetic lines).

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CONDITIONS FOR THE FORMATION OF THE MAGNETIC FIELD AT THE EARLY STAGES OF THE EARTH'S EVOLUTION

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One of the fundamental questions in Earth physics is the age of the existence of the magnetic field (geodynamo), which is important for understanding the evolution of the core, atmosphere, and life on Earth. Did it arise in the early stages of the formation of the Earth or later, in the process of its further evolution? According to paleomagnetic data, the existence of a stable magnetic field of about 3.5 billion years is reliably known [1]. The earlier evidence for a magnetic field is probably complicated by the presence of convection in the Earth's mantle. At the initial stage of accumulation, the main source of internal energy of the planet is considered to be the release of heat due to the decay of short-lived radioactive elements, primarily ^{26}Al and ^{60}Fe [2, 3]. Heating due to the decay of short-lived radioisotopes ensures the melting of the central regions in the first few million years. The presence of thermal convection in the central region can serve as a mechanism for the implementation of the MHD dynamo in the protoplanet, i.e., to have its own magnetic field. This assumption is supported by the fact that recently it has become increasingly obvious that some large (larger than 100 km) asteroids were able to generate their own magnetic fields at the early stages of their history [4, 5]. The period of core separation from various isotopic systems is estimated to range from 3×10^7 to 10^8 years [6]. By this time, the interplanetary magnetic field had already weakened sufficiently to become a "seed" for triggering the MHD dynamo mechanism in the core. During the growth period, a magmatic ocean is formed, where thermal convection is realized [7]. In addition, in the growing Earth, convection could also be realized in local regions (diapirs) formed when colliding with large planetesimals (macroimpacts).

In this paper, on the basis of numerical calculations, various scenarios of the Earth's growth are considered, which ensure the realization of the conditions for the formation of a magnetic field at the early stages of the Earth's growth.

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MAGNETOCONVECTION IN A HORIZONTAL DUCT FLOW AT VERY HIGH HARTMANN AND GRASHOF NUMBERS

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Direct numerical simulations and linear stability analysis are carried out to study mixed convection in a horizontal duct with constant-rate heating applied at the bottom and imposed transverse horizontal magnetic field. The two-dimensional approximation derived in the asymptotic limit of very strong magnetic field effect is validated and applied to investigate the flow's behavior in the previously unexplored range of control parameters corresponding to the typical conditions of a liquid metal blanket of a nuclear fusion reactor. It is found that the instability to quasi-two-dimensional rolls parallel to the magnetic field discovered at smaller Hartmann and Grashof numbers in earlier studies also occurs in this parameter range. Transport of the rolls by the mean flow leads to magnetoconvective temperature fluctuations of exceptionally high amplitudes.

MHD DRIVEN LOCALIZED SHORT CIRCUITS IN LIQUID METAL BATTERIES

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Liquid metal batteries (LMBs) are electrochemical devices, which operate as simple concentration cells at elevated temperature. Abundant raw materials and the totally liquid interior promise a very long life time, extreme current densities and a very competitive price of these storage devices. For this reason, LMBs are discussed as an ideal candidate for grid-scale energy storage.

The cathode of the cells (e.g. molten Bi, at the bottom) is typically contained in a metal vessel, while the anode (e.g. molten Li, at the top) is soaked into a FeNi-foam. Both electrodes are separated by a molten salt electrolyte. When discharging the cell, Li is oxidised, crosses the electrolyte layer and alloys into Bi; upon charge, the process is reversed. Due to corrosion or electrochemical reactions of the molten salt layer with the FeNi-foam, the Li-wetting of the foam might decrease during operation. In case of insufficient wetting of this current collector, it might happen that the Li does not penetrate the foam any more, when the cell is charged. Consequently, small Li-droplets will appear below of the foam, and will grow into the electrolyte layer, when charging the battery. As the conductivity of the electrolyte is four orders of magnitude smaller than that of the metals, the current will take the shortest way through the electrolyte, i.e. a large current will flow through the Li-droplets. This current might pinch the droplet locally, possibly deforming, or even cutting it off. Hence, small Li-spheres might be transferred into the electrolyte. This might lead to unwanted self-discharge, if Li reaches the Bi-layer.

In the presentation, the appearance and significance of such localised droplet-transfer and short-circuits will be discussed first. Then, some experimental evidence of similar effects will be presented. Finally, numerical simulations of the transfer of a single droplet will be shown. Moreover, the relevance of the results for practical applications and real cells will be explained.

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DISPERSION OF SLOW MAGNETOACOUSTIC WAVES CAUSED BY THERMAL MISBALANCE AND FINITE SIZE OF MAGNETIC FLUX TUBE

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Since coronal processes of radiation cooling and non-adiabatic heating may be dependent on plasma parameters, any disturbance of these parameters can lead to a misbalance between heating and cooling processes in the plasma. On the other hand, this misbalance can affect the disturbance that caused it. Thus, when a thermal misbalance occurs, there is a positive or negative feedback between the disturbance and the plasma. This feedback leads to amplification or attenuation of waves, as well as to dispersion of their phase velocity. At the same time, the dispersion of waves is caused by the presence of some characteristic dimensions of the problem, for example, the radius of a magnetic tube.

The second order thin flux tube approximation is used to obtain a linear equation describing the dynamics of magnetoacoustic disturbances of small amplitude in plasma with the thermal misbalance. The obtained equation allows us to derive the dispersion equation. This dispersion equation can be solved analytically for the case of traveling waves. This analytical solution sheds light on the dispersion properties of slow magnetoacoustic waves caused by thermal misbalance and finite size of magnetic flux tube under coronal conditions. For example, for the conditions of active region fan loops, it is shown that, in the low-frequency limit, the phase velocity of slow waves is determined by the effect of thermal misbalance, and in the high-frequency limit — by the finite width of the tube, while the wave decrement is mainly determined by the effect of thermal misbalance.

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SPECIFIC DEFORMATION OF DROPS OF MAGNETIC EMULSION IN A VARIABLE ELECTRIC FIELD

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At present, a large number of works are devoted to the study of the features of the interaction of microdroplets of magnetic fluids with magnetic and electric fields [1–11], in which both the features of deformation and the development of instability of their shape. Initially, the studies were carried out in magnetic fields [1–3, 9], and later the study of the features of deformation of microdroplets was carried out in electric fields, as well as under the combined action of electric and magnetic fields [4, 5–8, 11].

It was established in [4, 6] that in alternating electric fields, drops can either flatten or elongate along the direction of the field, while drops in a magnetic field always along its direction. This difference in the behavior of microdroplets in an electric field is associated with the development in the electric field of the movement of liquid phases along the boundaries of microdroplets, due to the accumulation of free charge at the interphase boundaries. Previously, this mechanism of deformation of droplets of a homogeneous liquid in a constant electric field was considered in [12]. According to its results, the nature of droplet deformation (flattening or elongation along the field) is determined by the ratio of the conductivities and dielectric permittivities of the droplet substance and the surrounding medium. However, in the course of the experiments, it was found that the nature of the deformation of drops in an alternating electric field depends on the temperature of the sample. In particular, if a magnetic emulsion, the dispersed phase of which is presented in the form of a magnetic fluid based on kerosene, and the dispersion medium is AMG-10 oil, then with an increase in the sample temperature (27–80°C), an increase in the deformation of the droplet (elongation along the field). For a sample of a magnetic emulsion, the dispersed phase of which is presented in the form of a magnetic fluid based on kerosene, containing spontaneously magnetized aggregates, the nature of the deformation is different. So, with an increase in temperature from −2°C to 25°C, an initially elongated drop along the field decreases its deformation, acquiring a spherical shape, then with a further increase in temperature (30–60°C) it becomes flattened, thus shape inversion is observed drops. This phenomenon is typical only for drops with spontaneously magnetized aggregates.

The theoretical substantiation of the experimental data requires additional research, which is currently being carried out.

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NUMERICAL SIMULATION OF MELTING AND STIRRING IN INDUCTION FURNACE WITH GRAPHITE CRUCIBLE

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Introduction In non-ferrous metallurgy, a special role is given to induction furnaces with a graphite crucible, which is not wetted by high-density metals, and also plays the role of a reducing agent [1]. However, being electrically conductive, it shields the metal from the external electromagnetic field, thereby reducing the force effect on it, which negatively affects the uniformity of the distribution of the chemical composition and temperature of the melt. This work is devoted to finding a solution to this problem.

Formulation of the Problem It has already been proposed to use a magnetohydrodynamic (MHD) stirrer in the hearth of the furnace. The conducted initial research showed that this method is acceptable [2]. However, the work was carried out for a simplified electromagnetic model, in which induction heating was not taken into account. And the conclusions were based on the magnitude of the electromechanical force in the metal. Therefore, at the next stage, a joint model will be investigated, which includes three tasks: electromagnetic, hydrodynamic and heat exchange. In addition, both processes will be described: heating and stirring.

Description of the Model As mentioned earlier, the model is described by electromagnetic, hydrodynamic and thermal problems and has the following assumptions:

- Dividing the installation into 2 separate tasks of heating and mixing, followed by combining the results into one model;
- The melt is in a liquid state and is considered completely homogeneous, free of impurities;
- Material properties are set nonlinearly with temperature;
- The metal is heated exclusively by heat transfer from the walls of the crucible.

Results Evaluation of efficiency was carried out by the distribution of the flow rate of the melt during the technological process, as well as by the time of temperature equalization in the volume of the melt for installations with and without an MHD stirrer. The obtained results are a significant improvement in both the mixing velocity due to the force effect on the side of the installation, and a more uniform temperature distribution.

Findings As can be seen from the results, the force action of the MHD stirrer is sufficient to set the entire volume of liquid metal in motion, and its use allows the temperature of the melt to be equalized much faster.

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MAGNETOCONVECTION WITH ANISOTROPIC DIFFUSION AS A TOOL TO INVESTIGATE THE DYNAMICS OF DYNAMO REGIONS

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The Dynamo Theory is an important branch of the Magnetohydrodynamics, which also studies the generation and evolution of cosmic magnetic fields, in particular planetary, stellar and galactic ones. Natural dynamos are dynamos which generate natural magnetic fields, e.g., cosmic magnetic fields. We focus especially on Geodynamo, which concerns the Earth's magnetic field.

The turbulent dynamo theory is important because describes many processes, like, e.g., α-effect and β-effect, which are very important to explain some basic problems concerning the dynamics of the magnetic fields (see, e.g., [1]). This turbulence occurs because the dynamo regions, like the Earth's outer core and the convective zone of the Sun, are driven into motion by forces so strong that the flow and field are turbulent, fluctuating on many length and time scales, as it is accepted by the most of geophysicists. There are forces with preferred directions (e.g., buoyancy, magnetic field, Coriolis, etc.) so the turbulence is probably anisotropic.

The Magnetoconvection is a crucial theme in Dynamo Theory and its importance is increased in the recent times. For example, in the studies concerning dynamo problems, instabilities (convective and magnetic) are also thoroughly investigated (see, e.g., [2]). That is, the origin of flows necessary for dynamo action, as studied in magnetoconvection with resulting instabilities, is important, as well as the problem of the origin of magnetic fields.

The probably anisotropic turbulence and the importance of the rotating magnetoconvection inspired us to develop several models of rotating magnetoconvection in the Earth's outer core with anisotropic diffusion. More specifically, we studied some rotating magnetoconvection problems where at least one of the diffusivity coefficients (viscosity, thermal and magnetic diffusivity) is anisotropic. By these models, it is possible to see, that some types of convection are facilitated in the Earth's outer core if there is anisotropy [3,4]. Then, we built other models and we discover that different types of anisotropy in the Earth's outer core, the Geodynamo region, imply important physical differences, especially about the balance of the forces (Magnetic, Archimedean and Coriolis) in the above mentioned region [5].

We present the state of art of these magnetoconvection models with anisotropy, some new models [6] and the links with other topics of the Magnetohydrodynamics. We also discuss how to apply such methodologies about anisotropic diffusion in magnetoconvection to other cosmic magnetic fields concerning stars and galaxies.

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LIMITS OF MAGNETO-CONVECTIVE FLUCTUATIONS IN LIQUIDMETAL DOWNFLOW IN VERTICAL CHANNELS AFFECTED BY A TRANSVERSE MAGNETIC FIELD

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It is known from experimental and numerical studies that in channel flows of liquid metals, strong buoyancy forces, provided by temperature gradients, generate in magnetic field specific structures, which manifest themselves in the form of large-scale magneto-convective fluctuations (MCFs), accompanied by temperature fluctuations of anomalously large amplitude. The specific structure of MCFs depends on the properties of the liquid metal, on the channel configuration and its orientation to gravity and to the magnetic field, and on the combination of governing parameters of the flow [1].

An experimental study of magneto-convective fluctuations (MCFs) in liquid metal downward flow in a vertical channel (pipes [2] and ducts) under a strong magnetic field has been performed. The considered configuration is typical for elements of fusion reactor blanket modules. The main goal is to specify existence area of regimes characterized by strong MCFs. After processing of hundreds of experiments, we defined the MCF area in parameter planes Stuart-to-Richardson and inverse Reynolds (defined through the Hartmann scale)-to-Richardson numbers.

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PLASMA-SURFACE INTERACTION IN FUSION DEVICES: REVIEW OF RECENT RESULTS

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The near-wall (edge) plasma in fusion devices with magnetic confinement is in a strong turbulent state [1, 2]. Drift-wave instabilities drive fluctuations of density and electric fields in edge plasma. Electrons, ions and impurities move over the material surface in turbulent electric fields generated by plasma turbulence. Universality of turbulence properties at the edge of magnetized plasmas is discussed [1,2]: edge turbulence properties like an intermittency, non-Gaussian statistics, multiscaling and multifractality, anomalous bursty transport and superdiffusion are typically observed in the fusion devices. The intermittency and the self-similarity properties are responsible for the memory effect and large-scale correlation in space and time leading to substantial particle, heat and momentum intermittent transport to the surface producing high-heat load.

Plasma-surface interaction in a fusion device leads to erosion, melting and melt motion over the surface, redeposition of eroded materials, stochastic clustering of the surface [3,4,5]. It leads to the change of the surface morphology. Cauliflower-like structures [3,6] and «fuzz»-like layers [7] were recently observed on the plasma-facing materials irradiated by plasma in fusion devices. Such new structures were never observed before. They are formed under high heat plasma load in fusion devices. The statistical characteristics of hierarchical granularity and scale invariance of such new materials were estimated revealing a link with statistics of edge plasma turbulence effected the surface morphology change.

The known approaches of fractal growth of the interface layers and agglomeration are used to analyse the plasma-surface interaction in fusion devices [3]. Due to strong plasma turbulence, the plasma particles over the surface can be involved in stochastic large-scale dynamics known as superdiffusion or Levy-type process with predominant «flights». In result, the dynamics of ions and clusters over the surface and on the surface deviates from normal diffusion (ordinary Brownian motion) influencing the agglomeration process on the surface and producing an inhomogeneous stochastic clustering of the surface with self-similarity properties of the granularity structure from nanoscale to macro scale [3,6]. Stochastic clustering of the plasma-facing material was observed in tokamaks and linear plasma facilities like PLM [6]. Recent results of plasma-surface interaction investigation and analysis of materials irradiated by plasma in fusion devices are reviewed.

The ASNI construction on the PLM was supported by the RF Megagrant No. 14.Z50.31.0042, the plasma tests on the PLM were supported by the RSF grant No. 17-19-01469, the material tests were supported by ROSATOM Project EOTP-223.

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INSTABILITY OF A FLAT SURFACE OF A MAGNETIC FLUID AT THE BOUNDARY WITH WATER IN AN ELECTRIC FIELD

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A magnetic fluid («magnetite in kerosene») was placed in a rectangular cell between two electrodes, one of which was water. The cell is placed in an orthogonal electric field. When the field strength reaches a certain critical value $\mathbf{E}_{cr2}\mathbf{E}_{cr1}\mathbf{E}_{cr1}$ on the interface, cone-shaped protrusions were observed — Taylor cones, from the tops of which a large number of small highly charged droplets were emitted. When the intensity increases to the value $\mathbf{E}_{cr2}\mathbf{E}_{cr2}\mathbf{E}_{cr2}$, an avalanche formation of ions occurs, a layer of particles is charged with the same name with the water surface (in the experiment — a negative electrode), is repelled from the electrode, which leads to deformation of the interface — surface waves appear [1].

It is known that in a magnetic fluid near the electrodes, thin near-electrode layers of micron size are formed, consisting of particles of the dispersed phase, in which surface processes (electrochemical reactions, complexation, etc.) play the main role. The interaction of oleic acid molecules surrounding the MF particle with the electrode (water) leads to the injection of ions that charge the near-electrode layer of the particles. The concentration of particles in the layer is $\sim 30\%$, the particles are close-packed, that is, the ions trapped in the layer are inactive, as a result of which the near-electrode layer is charged.

The behavior of the surface is largely determined by the conductivities of the contacting media [2]. The relaxation time of the space charge for the MF used in the experiment (conductivity $\sigma \sim 10^{-7}$ (Ohm·m)-1), $\tau_m \sim 510^{-5}$s. In the near-electrode layer, the conductivity increases, the relaxation time of the charge decreases [1]. The characteristic time of the observed disturbances is $\tau_0 \sim 10^{-3}$s. Since $\tau_m \geq \tau_0$, it is necessary to take into account not only bulk, but also surface conductivity [2].

A boundary value problem is formulated for two immiscible incompressible fluids (magnetic fluid and water) placed in an electric field perpendicular to the interface and boundary conditions are written taking into account the viscosity, conductivity of fluids, and physicochemical properties of the interface. A dispersion equation is written, a dimensionless stability criterion is introduced, and it is shown that at $\mathbf{E} = \mathbf{E}_{cr1}\mathbf{E} = \mathbf{E}_{cr1}$, the Tonks-Frenkel instability is observed.

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COMPARISON OF COMPUTATIONAL AND MEASUREMENT RESULTS FOR ELECTROVORTEX FLOW IN EXPERIMENTAL SETUP WITH LIQUID METAL AND POWER SUPPLY OVER TOP AND BOTTOM ELECTRODES

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The paper continues authors' researches cycle, which deal with comparison of numerical and experimental results for electrovortex flow (EVF) with different schemes of direct current (DC) power supply. For example, see [1], where bifilar power supply scheme is considered for cylindrical vessel with *galinstan* (*GaInSn*) melt and for rectangle vessel with *mercury* (*Hg*). Measured magnetic field is compared with quasi-2D analytical solution as well as with 3D numerical computations. Numerical study of velocity field in EVF toroidal vortex in cylindrical vessel is performed. Observed and computed flow patterns are compared at melt free surface.

The aim of the paper is the further in-depth study of EVF phenomena based on numerical approach validated by comparison with measurement results.

Experimental study. Measurement results for *mercury* EVF velocities have been obtained with *fibre-optic sensor* at experimental setup with cylindrical vessel (radius and height are 30 mm) with DC ($I_{el} = 0 \div 1500\ A$) power supply over top and bottom *cooper* electrodes (radii are 6 and 30 mm accordingly). Schematic of setup is shown in [2, fig. 1b].

Flow patterns [3, fig. 1] have been obtained at experimental setup with semi-cylindrical vessel (scheme is shown in [4, fig. 2]) by means of photography of melt free surface.

Numerical study. Computations of 3D electromagnetic (EM) field and *Lorentz* force have been performed with commercial *Ansys Maxwell* package based on *Maxwell* equations solution in electrodynamics approximation. Liquid metal flow in laminar and turbulent regimes has been computed with *Ansys Fluent* package. *Large Eddy Simulation (LES)* model of turbulence is used. Estimation of *Reynolds* number for *mercury* flow is $Re \sim 6.2 \cdot 10^4$ for DC $I_{el} = 1000$ A.

Comparison of results. The following computed and measured data have been compared for cylindrical experimental setup:

- axial component of melt velocity V_z as function of axial coordinate z at vessel axis-symmetry $(r = 0)$ – $V_z = V_z(z)$;
- melt jet velocity profiles in near axis area $V_z = V_z(r)$ for several cross-sections $z =$ const;
- dependence of melt axial velocity and melt jet velocity profiles on DC value – $V_z = V_z(I_{el})$.

For semi-cylindrical experimental setup the photographs of flow patterns at melt free surface have been compared with computed streamlines distributions. Good qualitative and quantitative agreement has been obtained.

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TRANSIENT AND PERMANENT CONVECTION OF COLLOID IN A HORIZONTAL CELL

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Convection in colloidal suspensions, specifically, magnetic fluids, has been intensively studied both theoretically and experimentally [1–4]. In particular, oscillatory transient and permanent convection as well as bistable heat transfer are observed in experiments [1–2].

We analyse the bifurcation phenomena and nonlinear evolution of spatiotemporal patterns that develop in non-isothermal colloids. A special attention is paid to the combined effect of thermal diffusion, gravity sedimentation, and convection. Thermal convection of colloidal suspensions [3-4] is characterized not only by the Rayleigh R, the Prandtl Pr, the Lewis Le numbers and separation ratio ψ but also by two additional parameters: the dimensionless length of sedimentation $l = l_{sed}/h$ and the Boltzmann number $B = g\beta\bar{C}h^4/\nu\xi l_{sed}$ (h is height of the cavity; β, ν, ξ are the coefficients of thermal expansion, kinematic viscosity and thermal diffusivity, respectively), $\bar{C}$ is mass concentration of the nanoparticles).

Oscillatory convection in colloidal suspensions is studied for the case of a closed horizontal cell of finite length. The cell has solid and impermeable boundaries and is heated from below. We determined the spatial structure of the concentration field and the character of the time evolution of the convective characteristics. The numerical analysis is carried out within the Boussinesq approximation.

The behaviour of the colloidal suspension strongly depends on the initial conditions. If you initially set a fully established thermodiffusion distribution of the concentration, all perturbations are damped. When the initial distribution of the concentration is homogeneous, permanent (stable) convective flows may exist. At the initial stage, convection is a flow of homogeneous liquid, which is determined only by the temperature gradient. After some time, the stationary flow loses its stability, and an oscillation regime could be formed. Permanent modulated traveling waves appear in the cell when the Rayleigh number exceeds a certain critical value, $R > R_S$, which depends on the length of the cell. For a set of parameters ($L = 8.14$, $Pr = 6$, $Le = 8.85 \cdot 10^{-5}$, $\psi = -7.5$, $l = 3.5$) the result of numerical research ($R_S = 3350$) is a good agreement with the experimental data ($R_S = 3400$ [2]).

If the Rayleigh number falls below the critical value R_S ($R < R_S$), long-term transient flows near the threshold of convection, including localized traveling waves and waves that change their direction, is simulated and elucidated. By analyzing the behavior of the world lines of the vortices and the concentration field, the mechanism of formation of defects in the form of vortex coalescence is clarified. Two vortices with the opposite direction of rotation are involved in the process of defect formation.

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MAGNETOACTIVE ELASTOMERS: MOLECULAR DYNAMICS SIMULATIONS OF MAGNETIC PROPERTIES

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Magnetic elastomers are the systems consisting of magnetic particles embedded in a nonmagnetic elastic matrix. We consider several models of magnetoactive elastomers. We use the soft package ESPResSo [1] to perform Molecular Dynamics Simulations. The main interparticle interaction in systems is dipole-dipole magnetic potential. Also we consider Weeks-Chandler-Andersen potential as a short-range repulsion, Zeeman energy to describe an interaction between magnetic particles and an homogeneous external magnetic field, classical harmonic interaction to include elastic interactions in systems. In order to introduce the elastic interactions to systems we consider fixed nonmagnetic particles which are connected with dipolar or non-magnetic ones by harmonic springs. As the simplest model, we consider spherical magnetic particles in an elastic matrix. Also we can take into account the shape anisotropy of magnetic particles and particle polydispersity. We can obtain the hysteresis loop of a magnetisation, radial distribution functions, etc. Also we can measure the First-Order Reversal Curves (FORCs) distribution, using a classical method developed by Ch. Pike [2]. The first order reversal curves (FORCs) method helps us to study the effect of the matrix on the internal magnetic interactions. We can use this method during study of the magnetic elastomers without known microstructure. When it is no data about a microstructure in experiments, the FORCs diagrams can provide some information about it. It is convenient to use the FORCs method in computer simulations because we can find the correspondence between obtained diagram and microstructure implicitly. This is impossible to do during experiment.

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INFLUENCE OF MHD-CHANNEL GEOMETRY ON PRESSURE DROP

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In this work, we study a method for creating a pressure drop between the inlet and outlet of a channel with a liquid metal using an electromagnetic force. The electromagnetic force is created when an electric current and a crossed magnetic field are existed in the channel. A conductive force generation mechanism is used. This mechanism is implemented when the electric current initially flows through the channel. Ferromagnetic C-shaped cores are placed on the channel. The magnetic field of the electric current, passing through the cores, generates magnetization in them. The magnetic induction arising in the gap of the poles of the cores is directed mainly across the channel. Its value significantly exceeds the magnetic field of the current, which is the main advantage of this implementation of the conduction mechanism. The use of C-shaped cores results in a flat channel shape, the thickness of which is significantly less than the length and width. This allows us to significantly increase the magnitude of the electromagnetic force, as well as control its direction. The direction of the force and, as a consequence, the value of the generated pressure drop is significantly influenced by the internal geometry of the channel. The paper considers a channel with a simple rectangular parallelepiped shape. One way to change the channel geometry is to add internal barriers. The barriers are located at an angle to the long side of the channel. They do not completely overlap the flow area of the channel, which allows the liquid metal to be completely drained from this channel. Such a channel is part of a conductive electromagnetic submersible pump for molten metal in metallurgical production. This pump is capable of operating at high temperatures, which is its main advantage over other types of electromagnetic pumps. The aim of the study is to clarify the influence of the size and inclination of the barriers, as well as the position of the cores, on the magnitude of the electromagnetic force and pressure drop.

Mathematical modeling of the electrodynamic part of the problem made it possible to study the process of generating the longitudinal component of the electromagnetic force for a solid metal. In this case, the electrical conductivity of the barriers was zero. The results showed a significant dependence of the magnitude of the electromagnetic force on the angle of inclination of the barriers, the length of the barriers, the size of the gap between the barrier and the channel wall, and the location of the core. An experimental study of the hydrodynamic part of the problem made it possible to study the dependence of the pressure drop on the channel geometry and physical parameters. The pump model was tested using the gallium circuit of the ICMM UB RAS. The flow-rate - pressure drop characteristics of the models are obtained for different values of the length of the barriers and their position relative to the narrow walls of the channel at several values of the current strength.

The developed electromagnetic conduction pump has a simple design and is not expensive to manufacture. It is designed for pumping low-melting metals and alloys. The pumped metal easily fills the channel and at the end of the pumping process is easily drained from the channel. The most attractive is the use of a submersible pump.

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METAL PAD ROTATION INSTABILITY EXPERIMENTAL MODEL

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In this paper, Metal Pad Rotation Instability (MPR) is experimentally investigated. It manifests itself in the rotation of the inclined free upper boundary of the liquid metal around the axis of the cylindrical cell.

The experimental setup is a cylindrical cell with a height of 150 mm, which is made of stainless steel. The bottom of the cell is made of organic glass and is tightly connected to the side wall. The inner part of the side wall of the cell is insulated from the bottom to a height of 80 mm. The cylindrical volume is filled 7 mm below the insulation level with gallium alloy GaZnSn. The plexiglass bottom has slots that take seats the sensors of an ultrasonic Doppler velocimeter, which measure the profile of the vertical component of velocity and echo along the beam. Around the outer side of the side wall of the cell, 8 induction level sensors are installed, which register the position of the liquid metal boundary. Cylindrical coaxial electrodes are located on the cell axis, which make it possible to compensate for the current lead own magnetic field. The central copper electrode is located so that its end is in contact with the liquid metal. The outer electrode is connected to the side wall through a contact system. The electrodes are connected to a current source. Outside the cell are Helmholtz coils that create a constant vertical magnetic field.

In the experiment, a mechanical disturbance is introduced to the surface of the liquid metal, as a result of which a certain volume of liquid comes into contact with the non-insulated part of the wall-electrode. As a result, an electric current begins to flow through the cell. The current interacts with an external magnetic field, which, in turn, leads to the emergence of an azimuthal component of the electromagnetic force. Under certain conditions, this force causes the metal to rotate around the cell axis in a skewed state, simulating the MPR instability. As a result of processing the experimental data, the velocity profiles, echo profiles, as well as the amplitudes and frequencies of oscillations of the free metal surface were obtained. The study of the MPR frequency was carried out depending on the magnitude of the external magnetic field, as well as on the current flowing through the cell.

SIMPLE APPROXIMATE FORMULA FOR SUSCEPTIBILITY OF CONCENTRATED FERROFLUID IN A DC AND AC MAGNETIC FIELDS

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In this work, simple analytical expressions are obtained for the real and imaginary parts of the dynamic susceptibility of a concentrated ferrofluid in a dc and ac magnetic fields.

The ferrofluid is modelled as a suspension of spherical, uniformly magnetized particles. It is assumed that the relaxation of the magnetic moments of the ferroparticles occurs according to the Brownian mechanism. The dc and ac magnetic fields are applied along the z axis. The rotational motion of a particle magnetic moment is described by the probability density which is the solution of the Fokker-Planck equation. The interparticle dipolar interactions are taking into account with the help of additional term into the Fokker-Plank equation. This term is determined on the base of the first-order modified mean-field theory [1] in a systematic way, based on classical statistical mechanics. The numerical solution of the Fokker-Planck equation is provided using the finite difference scheme with weights for convection-diffusion problem [2]. The probability density is used for the calculation of the real and imaginary parts of the susceptibility. The dependence of the susceptibility spectrum on the amplitude of the ac field, ferroparticle concentration, intensity of the dc field and interparticle dipole-dipole interaction is analyzed.

On the basis of the numerical calculations of the dynamic susceptibility, following the procedure suggested in [3], the simple analytical formulas were obtained for the real and imaginary parts of the susceptibility as the functions of the amplitude of the ac field, intensity of the dc field and the Langevin susceptibility.

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EVOLUTION OF STRONG ELECTROVORTEX FLOW UNDER EXTERNAL MAGNETIC FIELD IN CYLINDRICAL CELL

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The mechanism of the rearrangement of an electro-vortex flow (EVF) under the action of an external magnetic field is studied in liquid metal experiments and numerical simulations. The liquid metal is contained in a vertical cylindrical cell. The electric current is applied in a localized area at the bottom and is collected on the entire side wall of the cell. The cell is subject to a vertical homogeneous external magnetic field. In this configuration, two types of electromagnetic force arise. The first one appears due to the interaction of the electric current and its own magnetic field. This leads to the development of a poloidal electro-vortex flow [1]. The second force arises from an interaction of the electric current and the external axial magnetic field. This leads to the development of an azimuthal vortex flow. Then, an additional secondary poloidal flow is formed. The interaction of both flows leads to different scenarios of evolution, depending on the governing parameters [2]. We present results of numerical and experimental studies of the peculiarities of the evolution of the flow from a zero-velocity state to the formation of a stationary state, which is characterized by the stability of the mean values of the poloidal and azimuthal energies. The relevance of the study is due to the presence of such flows in the developed liquid metal batteries for storing electrical energy [3]. The study of the instabilities arising in them and the search for methods to overcome them will make it possible to reach industrial scale dimensions of liquid metal batteries.

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COULD EARTH'S SOLID CORE BE A MAGNET?

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At present, when modeling the Earth's magnetic field (EMF), its solid core is considered as a certain paramagnetic region. This is due to the thermodynamic conditions characteristic of this region.

However, as follows from experimental data and theoretical models, the solid iron core of the Earth is in a rather unusual state. As follows from numerous experiments, the crystal structure of iron is bcc state in the solid core of the Earth, which is typical for normal conditions. In addition, model calculations of the behavior of the Curie temperature for iron show its strong increase in this region, and it becomes possible that the solid core (or part of it) can be in a ferromagnetic state. Consequently, it becomes necessary, take into account the occurrence of hysteresis in it, which affects the stabilization and polarity reversal of the EMF. It should be noted that if the temperature of the solid core is slightly higher than the Curie temperature, then the generation of an effective magnetic field associated with fluctuations of the magnetic moment near the critical point is possible. Thus, the modern study of the magnetic and crystalline properties of iron for the conditions of the inner core makes it possible to take a fresh look at its role in describing the EMF.

DYNAMO ACTION OF THE LARGE SCALE FLOW IN A PRECESSING CYLINDER

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Precession is a well known phenomenon that (in a very general sense) paraphrases the temporal change of the orientation of the spin axis of rotating objects. In rotating celestial bodies with liquid interior precession causes a volume force that directly drives a non-axisymmetric fluid flow [1]. A paradigmatic example is the liquid core of the Earth [2], for which the forcing is considerably strong due to the rather large angle between rotation axis and precession axes. An even stronger forcing is assumed for the ancient moon three to four billion years ago [3]. Precessional forcing of the fluid interior of planets or moons is of interest because the resulting internal flows in terms of inertial modes or turbulence back-react on the rotation of the whole body, which may become evident for example in length-of-day variations or periodic changes of the nutation angle. Furthermore a precession-driven flow of an electrically conductive fluid is capable of generating a large scale magnetic field [4]. From an energetic point of view, the directly driven non-axisymmetric flow is not sufficient to generate a magnetic field [5], however, multifaceted instabilities of the primary flow provide the possibility to extract kinetic energy from the rotational fluid motions into a flow with a structure that may be more suitable of generating a magnetic field via electromagnetic induction [6].

In order to investigate to what extent a precession-driven flow can power a dynamo, and what properties the related magnetic field would have, an experiment is currently being constructed at HZDR, in which 6 tons of liquid sodium will precess in a cylinder with 2 meters height and 2 meters in diameter [7]. The design of the experiment is attended by comprehensive numerical simulations, which showed that at the edge of the transition between a complex but still laminar flow to a fully developed turbulent state, onset of dynamo action can be expected [8]. This state of flow is characterized by an almost complete transformation of the original rotation into large-scale inertial waves and small-scale turbulent flow. The dynamo effect found in the simulations is mainly due to an evolving axially symmetric flow component and the strong shear layer near the outer walls due to the massive extraction of rotational energy [9]. Free inertial waves in the form of triadic resonances as the first instability, which describe the transition from the stationary to the time-dependent state, do not seem to play any special role for the dynamo-effect. Open questions concern the role of this triadic instability as a trigger for the transition to turbulence, the character of the turbulence itself (is it three-dimensional or quasi-geostrophic?) and the very mechanism that causes the redistribution of the internal angular momentum that goes along with the significant modification of the large scale pattern of the velocity field.

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THE MAGNETIZED SPHERICAL COUETTE SYSTEM: FROM NUMERICS TO EXPERIMENTS

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The study of magnetohydrodynamic (MHD) instabilities occurring in liquid metals, with imposed differential rotation and magnetic field, is of fundamental importance in the astrophysical context. MHD instabilities are especially relevant in planets or stars, where electrically conducting flows are confined within their interiors. Such environments could be modeled by solving the Navier-Stokes and induction equations with appropriate conditions in a spherical shell composed of two concentric spheres. In particular, we consider the case where the liquid metal (GaInSn in our case), bounded by a stationary outer sphere and a uniformly rotating inner sphere, is subjected to an axial magnetic field. When the aspect ratio of the radii of the two spheres is fixed, only two parameters, namely, the Reynolds number (associated with the differential rotation) and the Hartmann number (associated with the applied magnetic field strength), govern the dynamics of the system (see [1,2] for full details).

For the magnetized spherical Couette system, three different types of instabilities have so far been identified and characterized by means of numerical simulations (e.g. [1,3]), and also in experiments (e.g. [2,4]). These instabilities can each be described as a hydrodynamic radial jet instability, a return flow instability, and a Kelvin-Helmholtz-like Shercliff layer instability. We provide an overview of these instabilities with a focus on the description and analysis of the different spatio-temporal symmetries of the MHD flow. In particular, numerical and experimental bifurcation diagrams of nonlinear waves in the quasi-laminar regime (with moderate differential rotation) are presented and some numerical tools, related to nonlinear dynamics and chaos theory [5], are outlined. These tools include the numerical continuation of periodic solutions and their stability assessment, time series analysis such as the computation of the fundamental frequencies in one or several spatial dimensions, time dependent frequency spectra, and Poincaré sections.

Our results show how periodic and quasiperiodic MHD flows with two, three and even four incommensurable frequencies, as well as MHD chaotic flows, are developed following a sequence of bifurcations from the base state. The knowledge of the different routes to chaos is of fundamental importance in turbulence theory. In addition, by taking into account the symmetries of the solutions several regions of multistability (and also hysteretic behavior) are identified in the parameter space with a good agreement between simulations and experiments, both in their temporal and spatial structures. Although unstable MHD flows are not experimentally realized, their numerical computation as in [1,6] provides a more complete picture of the dynamics and aids the understanding of transient and hysteretic behaviors in experiments.

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CONVECTION OF A MAGNETIC FLUID IN VERTICAL CONNECTED CHANNELS IN A PERMANENT MAGNETIC FIELD

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The results of experiments on convection of magnetic fluid based on undecane in vertical, connected and heated from below channels in gravitational and magnetic fields are analyzed in this work.

The change in the period of convective oscillations and other effects observed with changes in the external field are associated with inhomogeneities of the magnetic field inside the ferrofluid. The contribution of various mechanisms to the formation of the internal gradient of the field strength is estimated. Field inhomogeneities arise due to the refraction of lines of force at the boundary of the liquid and the wall, or are associated with the dependence of the magnetization on temperature $M = M(T)$, which leads to the appearance of a thermomagnetic force. Experiments with channels of square and circular cross-section and with a transverse dimension of 3 mm and a height of 50 mm were carried out.

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ELECTROMAGNETIC STIRRING IN CONTINUOUS CASTING OF STEEL

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The technology of continuous casting of steel has been actively used since 1930s of the XX century. Casting is always accompanied by a number of defects in castings, which cannot be eliminated by nowa days. The main defects are discontinuity of the axial zone, central porosity, axial liquation and others. Variable electromagnetic fields are applied at different solidification steps, this eliminates some problems, such as axial porosity.

The work examines the influence of electromagnetic fields on the properties and characteristics of the resulting castings. Complex magnetohydrodynamic problem is solved with selection of optimal parameters of field, as well as place of its impact. In practice, it is of high interest to use two EM agitators, which results in for high quality castings. The first effect is carried out on the mould to reduce the concentration of non-metallic inclusions in the solid layer. This is due to the fact that their speed is lower than that of liquid steel. The second effect is already exerted at the final stage of solidification in order to crush the structure and eliminate axial porosity [1].

The mathematical model includes a system of differential Navier-Stokes equations for motion of a viscous incompressible liquid taking into account the occurrence of turbulent flows and solidification. The heat transfer in the solid, liquid and mushy zone regions is determined from the law of conservation of energy. Thermal and hydrodynamic flow parameters are functions of temperature and the ratio of solid and the liquid phase fractions [2]. Maxwell's equations in quasi-stationary approximation are used to describe electric and magnetic fields [3].

In the process of mathematical modeling, various modes of electromagnetic fields are studied and their effect on the properties of the resulting steel castings. A series of calculations is carried out with various parameters of the magnetic field and the location of the stirrer. Graphs of temperature, alloy phase, and density change are obtained.

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MAGNETIC AND STRUCTURAL PROPERTIES OF MAGNETIC ELASTOMERS

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Magnetic elastomers are hybrid materials composed of a rubber-like carrier with magnetic particles embedded into it. These particles have different sizes and magnetic characteristics. They can be either permanent magnets or magnetisable in an external magnetic field. Magnetic elastomers can actively react to an external magnetic field, changing their shape, mechanical and magnetic properties. This kind of susceptibility to magnetic fields makes these materials very attractive for numerous technological applications [1, 2].

In the present study, we focused on self-assemble of magnetic raspberry type particles in shear flow. Each particle has point dipole in its center. In our simulations, we first reach the steady state with exclusively steric interactions and constant viscosity, after that, we turn on the magnetic interaction, switch off the shear and quickly increase the viscosity based on linear law. This procedure aims at observing off-equilibrium kinetically trapped self-assembled structures.

To perform molecular dynamics computer simulations combined with Lattice-Boltzmann hydrodynamic solver, we use the simulation package ESPResSo [3]. To get full information about structural properties of the elastomer we analyze structure factor and radial distribution function. Also we performed cluster analysis using graph theory and the magnetic moment.

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MAGNETOSPHERE RESPONSE TO SOLAR WIND FORCING: 2D MHD SIMULATION RESULTS AT VARIOUS SOLAR WIND PARAMETERS

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The magnetosphere response to the stationary solar wind forcing at various values of the main solar wind parameters (plasma resistivity η_p, velocity u_0 and the interplanetary magnetic field (IMF) induction B_{z0}) is reviewed. The simulation was performed in the magnetosphere meridional plane within the framework of the 2D resistive MHD model (the flowing over the bar carrying magnetic dipole). The solar wind parameters are stationary, their values are various in individual calculations ($\eta_p = \{10^6, 10^4\}\ \Omega \cdot \mathrm{m}$, $u_0 = -\{200, 400, 800\}$ km/s and B_{z0} in the range from $+2$ nT to -10 nT). The reference set of the parameters was $\eta_p = 10^4\ \Omega \cdot \mathrm{m}$, $u_0 = -400$ km/s, $B_{z0} = 1$ nT, one of third parameters was varied at fixed two others. In all computations, the solar wind plasma density and pressure were equal to 10^7 m^{-3} and 10^{-10} Pa, correspondingly.

In this formulation, solar wind resistivity controls the magnetospheric response modes: the steady magnetospheric convection (SMC) or the periodic magnetic reconnection occurring in the geomagnetic tail (the sawtooth event). It is shown that regardless of the resistivity value, the dayside magnetic reconnection occurs with formation of the elongated magnetic island oriented normally to the longitudinal axis (x-axis) with two X-points symmetrically located at its top and bottom peaks. Between the magnetic island aforementioned and the body, the double vortex with oppositely rotating parts is generated. The presence of the magnetic island leads to the deceleration of the plasma flow and its deflection around the magnetosphere, generating attached vortices near north and south cusps.

At higher plasma resistivity, the SMC event takes place; the solution is symmetric relative to the x-axis. At lower resistivity, the solution is quasi-periodic and asymmetric. In the latter case, a magnetic island (plasmoid) is periodically formed in the dipole magnetic field nightside; then it is separated from the dipole and drifts downstream into the IMF. The sequence of the sawtooth cycle phases presented by the temporal profile of the open magnetic field flux per body unit length, as well as the evolution of magnetic lines of force and the flow streamlines, are analyzed. The vortices attached to the cusp regions split up by the total body force (i.e., the sum of the pressure gradient and the ponderomotive force). The separated vortices drift downstream in a staggered manner (like the Karman vortex street) and dissipate in the wake of the body. A thin current layer between two sequentially traveling plasmoids oscillates (the flapping current sheet) with formation of additional plasmoids. The oscillation period and the wavelength correlate with the corresponding Alfven wave's values.

For all considered solar wind velocities, the sawtooth event is observed with the standard tooth cycles consisting of the growth, expansion and recovery phases. With the solar wind velocity increase, the cycle period, the standoff distance of the bow shock as well as the vortex-shedding period, decrease. The solution in the dayside region is the same, as described above.

The variation of the IMF induction gave rather diverse results. The simulation versions with northward IMF demonstrate the standard SMC event with magnetic reconnection occurring over the cusps. At B_{z0} near -1 nT the solutions are similar to described above the sawtooth event. A further decrease in the induction of the southward IMF (for $B_{z0} = -2$ and -4 nT) leads to the flapping of the current sheet in the near wake without generation of magnetic islands. At $B_{z0} < -5$ nT the SMC regime is realized. In these solutions, a pair of narrow layers of increased current density divergent from the stationary nightside X-point is arising. On these layers, the magnetic lines of force have the kink. Between the current bands, the magnetic field is almost one-dimensional.

In the future, the authors suggest to check and to revise the presented results in 3D advanced model.

FINITE MEMORY TIME AND ANISOTROPY EFFECTS FOR THE INITIAL STAGE OF DYNAMO PROCESS

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Dynamo is a process of magnetic field self-excitation in a moving electrically conducting fluid. Most interesting for astrophysical application is the case of random motion. For the very first stage of the process the governing dynamo equation can be reduced to a system of first order ordinary differential equations. For this case we suggest a regular method to calculate the growth rate of magnetic energy. Based on this method we calculate the growth rate for random flow with finite memory time and (or) anisotropic statistical distribution of the stretching matrix and compare the results with corresponding ones for isotropic case and (or) short-correlated approximation. We find that for moderate Strouhal numbers and moderate anisotropy the analytical results reproduce the numerically estimated growth rates reasonably well, while for larger governing parameters the quantitative difference becomes substantial. In particular, analytical approximation is applicable for the Strouhal numbers $\mathrm{St} < 0.6$ and we find some numerical models and observational examples for which this region might be relevant. Rather unexpected, we find that the mirror asymmetry does not contribute to the growth rates obtained, while mirror asymmetry effects are known to be crucial for later stages of dynamo action.

FLOATING OF NON-MAGNETIC AND SUPERPARAMAGNETIC SOLIDS IN FERROFLUIDS: INDUCTIVE APPROACH

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Floating of grain solid bodies (typical size $0.01 \div 10$ mm) in non-magnetic containers filled with ferrofluids (FFs) can be used in useful technical and medical applications. This problem was studied since 1960s [1] when first FFs were synthesized. At that time almost all promising applications were technical [1,2], thus the magnetic ponderomotive buoyancy force was studied for such special cases as levitating permanent magnets in sensors, magnetic fluid separators of non-magnetic grain materials, etc. All these problems were studied in the framework of the so called non-inductive approach, which assumes that the demagnetizing fields h generated by the container with FF are negligibly small compared to the applied field of electro- and permanent magnets $H_0 \sim 10^5 \div 10^6$ A/m (FF is saturated, its magnetization $M \ll H_0$ and its susceptibility $\chi(H_0) \approx 0$). This approach simplifies ferrohydrodynamic problems, because the field inside FFs is assumed to be equal to H_0 and only demagnetizing fields of the solid bodies are taken into account. Nevertheless, the non-inductive approach has known limitations [2] in small and moderate fields ($H_0 \sim 10^4$ A/m) typical for biomedical applications.

The present work contains a comprehensive (experimental, numerical and theoretical) analysis of the problem in the framework of the inductive approach (FF container demagnetizing fields are taken into account). All investigation approaches are based on the common test object: a solid (magnetic or non-magnetic) sphere immersed in a cylindrical container, magnetized by a homogeneous magnetic field. The analytical and numerical results were verified by experimental measurements. All methods showed the same non-standard force behavior with two extrema for the case of non-magnetic bodies and a typical (monotonous) behavior of a magnetic body in FF. The numerical simulation was performed using Finite Element Method Magnetics (FEMM) [3]. The non-monotonic force (in case of a non-magnetic body) is explained by the competition between two mechanisms: the attraction of the non-magnetic body to the top and bottom of the narrow cylindrical container caused by the inhomogeneous demagnetizing factor of the narrow container; and the repulsion of the non-magnetic body from the walls of the container caused by the interaction of the body's magnetic moment with its own mirror image (it was shown in theoretical analysis). The results of numerical simulations are in quantitative agreement with the experimental data, and the analytical results are in qualitative agreement with the experimental data because of the non-linear magnetization law of real FFs used in experiments.

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MATHEMATICAL MODELLING OF THE COLLECTIVE MAGNETIZATION RELAXATION DYNAMICS OF BROWNIAN MAGNETIC NANOPARTICLES

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Relaxation timescales in the magnetization dynamics of Brownian magnetic nanoparticles are studied using a combination of Brownian dynamics simulations and analytical theory, paying particular attention to the collective effect of the interparticle dipole-dipole interactions. The particles are modeled as dipolar soft spheres, and single-particle magnetic relaxation occurs only through Brownian rotation with a timescale τ_B. The collective time dependence is predicted analytically by solving the Fokker-Planck equation for the one-particle orientational distribution function. Interactions between particles are included by introducing an effective magnetic field acting on a given particle and arising from all of the other particles. Computer simulations are performed for monodisperse and bidisperse systems, and two different cases are studied. In the first case, the dynamic magnetic response of a ferrofluid to a weak AC magnetic field [1,2], and the frequency spectrum of the initial magnetic susceptibility, are calculated for various particle volume fractions and dipolar coupling constants. In the second case, the magnetization time decay under zero-field conditions, from an initially saturated state to zero magnetization at equilibrium, is investigated [3].

The main conclusion is that the effects of interactions are very significant. In each of the cases studied, the collective relaxation time of a moderately concentrated, weakly-interacting, monodisperse dipolar fluid is well described by the expression $\tau_{eff} = \tau_B\,[1 + \chi_L/3]$, where χ_L stands for the ferrofluid Langevin susceptibility. Moreover, the effect of particle-size polydispersity is more pronounced for interacting particles, and the susceptibility spectra can be changed significantly by the influence of the collective interactions.

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EXPERIMENTALLY SYNCHRONIZING THE LARGE-SCALE CIRCULATION IN A CYLINDRICAL RAYLEIGH-BENARD CELL BY TIDE-LIKE ELECTROMAGNETIC FORCING

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In a set of recent papers [1–4], a possible synchronization mechanism behind the 11.07-year solar Schwabe cycle [5] was addressed. Due to the weakness of the forces exerted by the tidally dominant planets Venus, Earth, and Jupiter, the underlying synchronization mechanism must be very susceptible to small disturbances. The kink-type Tayler Instability (TI) of flux tubes in the solar tachocline was proposed to be at the root of this mechanism. Specifically, oscillations of the helical component of this instability (with azimuthal wavenumber m = 1) were shown to be resonantly excitable by an m = 2 tide-like forcing [1]. In the present work, we investigate if this type of helicity synchronization can also be realized in the similar case of Rayleigh-Bénard Convection (RBC).

Our setup consists of an cylindrical RBC cell with aspect ratio one, filled with the eutectic liquid metal GaInSn. The Large Scale Circulation (LSC) emerging in this setup has a distinct $m = 1$ flow mode, onto which we apply a modulated m = 2 excitation using electromagnets. This experimental setup was proposed in [6] and is described in detail in [7].

In order to mildly influence the RBC flow by an m=2 excitation, a current I with time dependence

$$I(t) = A \cdot |\sin(2\pi f_E \cdot t)| \cdot \sin(2\pi f_{AC} \cdot t)$$

with $f_{AC} \gg f_E$ is applied to the coils. Here, A is the amplitude, f_E is the envelope frequency, and $f_A C$ is the base frequency. This results in a force proportional to $sin(4\pi f_E \cdot t)$. Depending on the parameter set, the force excites an m = 2 flow with a maximum velocity of a few mm/s, approximately 10% of the LSC velocities. Using this configuration, we model the paradigmatic helicity synchronization mechanism by m=2 forces which we believe to be responsible for the tidal synchronization of the solar cycle.

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VERTICAL HEAT TRANSFER IN A CYLINDRICAL VESSEL WITH LIQUID METAL UNDER ALTERNATING EXPOSURE TO TRAVELING AND ROTATING MAGNETIC FIELDS

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The paper describes an experimental study of the effect on the process of heat transfer in a cylindrical crucible with a liquid metal by alternately switching running and rotating magnetic fields. In the experiment, a process of bidirectional MHD-stirring of liquid metal was created, similar to the process of stirring in the hot top of the mold of a machine for continuous casting of round ingots from aluminum and its alloys. To control the directional solidification front of the ingot, the flow must be symmetrical about the longitudinal axis. With the simultaneous action of a running and rotating magnetic field on a liquid metal, additional forces arise in it due to the cross interaction of these fields. These forces generate additional modes of motion in the metal, breaking the symmetry of the metal flow in the cylindrical volume. The experiment implements the alternating action of a running and rotating magnetic field, which excludes cross-field interaction and ensures the symmetry of the generated flow. Heat was transferred from the heater on the surface of the alloy to the thermostated bottom of the vessel. In experiments on the basis of thermal measurements, the heat transfer in the container in the direction of its vertical axis was investigated, and the mixing time of the introduced impurity was also estimated under various modes of MHD-stirring of the liquid metal. It has been found that the effect of heat transfer is best achieved by poloidal flow, but creating additional azimuthal flow significantly reduces this effect. It was found that when alternately acting on a liquid metal with traveling and rotating magnetic fields, the effect of heat transfer occurs similar to when the traveling and rotating magnetic fields act on the metal simultaneously and continuously.

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METHOD FOR CALCULATING THE COMPLEX AMPLITUDES OF THE ELECTROMAGNETIC FIELD IN A CYLINDRICAL CHANNEL OF AN INDUCTION PLASMATRON

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In numerical simulations [1-8] of plasma flow through the channel of an induction plasmatron, one uses a cylindrical coordinate system. A boundary value problem is considered for a second-order ordinary differential equation with respect to the complex amplitude of the azimuthal electric field, which depends on the radial coordinate r. The complex amplitude is used to express the Lorentz force and Joule heat. These time-averaged terms appear in the Navier-Stokes equations for plasma in the channel of an induction plasmatron.

The boundary condition on the channel lateral side used in [1-8] contradicts the boundary condition on the interface between media. The latter one is imposed on the tangential component of the electric field by the electrodynamics laws. Magnetic field is not considered in these studies.

In this paper, we consider a model problem of calculating the complex amplitudes of the electromagnetic field. The flow of a viscous liquid with high conductivity through a dielectric tube, caused by a pressure difference at the ends of the tube, is investigated. The tube sits inside a long coaxial solenoid powered by a very weak RF AC current.

At high frequencies of the supply current, the penetration depth b of the magnetic field into the liquid is negligible compared to the radius of the liquid cylinder. The force and energy effect of an electromagnetic field on a liquid in a surface layer of thickness b causes a small perturbation of the Poiseuille flow. Thus, the influence of the electromagnetic field can be neglected. The alternating current summed over all the turns is considered as a surface current localized on the outer surface of the tube. It depends on time according to the law of harmonic oscillations.

From the boundary condition for the magnetic field on this surface, a spatial coordinate-independent magnetic field strength inside the tube wall is found. The found value is used to express the boundary condition in the boundary value problem for the complex amplitude of a magnetic field in a liquid. The solution to this problem is the zero-order Bessel function of the first kind of a complex argument proportional to r. The complex amplitude of the electric field in the liquid is obtained using the Faraday law of induction by differentiating the found complex amplitude of the magnetic field in the liquid with respect to r.

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INFLUENCE OF NONLINEARITY OF MAGNETIZATION LAW ON KELVIN-HELMHOLTZ INSTABILITY FOR HORIZONTAL RELATIVE MOTION OF FERROFLUID AND GAS FLOWS IN A LONGITUDINAL MAGNETIC FIELD

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A study of the Kelvin-Helmholtz instability for the relative motion of ferrofluids with different magnetic susceptibilities in a longitudinal magnetic field was carried out in [1]. One assumes that two ferrofluids occupy the lower and upper half-spaces, respectively. The case of layers of a given thickness was considered in [2]. In [1, 2], it is assumed that the magnetic susceptibilities are constants and thus the linear law of magnetization is used. This approach is justified only in case of weak fields. In reality, magnetization curves obtained for strong fields show a nonlinear dependence of the magnetization of the ferrofluid on the magnitude of the applied magnetic field.

In this paper, the influence of magnetic forces on the Kelvin-Helmholtz instability is investigated for uniform longitudinal magnetic field intensities from a range technically achievable in experiments.

In order to cover the widest possible range of the applied magnetic field strength, the experimental curve of the magnetization of the ferrofluid is approximated by the Langevin function [3] from the modified argument. The modified argument [4] is expressed in terms of three parameters: a) magnetic field strength; b) saturation magnetization of the considered ferrofluid obtained from experiment; c) magnetic susceptibility corresponding to the linear law of magnetization.

Analysis of the Kelvin-Helmholtz instability at the interface separating layers of ferrofluids [2] shows that the stabilizing effect of an external magnetic field manifests most efficiently when magnetic field lines are parallel to velocity vectors of the layers. In such a situation, the most rapidly growing magnetic field perturbation caused by a change in the shape of the interface due to the presence of waves makes its maximum possible contribution to the balance of surface forces that appear in the dynamic condition at the interface.

Numerical values of the physical properties of a ferrofluid are taken from the experimental study [5] of turbulence caused by waves on the surface of a ferrofluid bordering on air in the presence of a uniform horizontal magnetic field. An equation for the neutral stability curve is obtained in the parameter plane: magnetic field strength – relative velocity of considered media. Due to nonlinearity of magnetization law the neutral stability curve has an inflection point outside the region of applicability of the linear magnetization model.

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PECULIARITIES OF ELECTROVORTEX FLOWS IN A MULTI-ELECTRODE ARC FURNACE AT DC AND LOW FREQUENCY AC POWER SUPPLY

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One of the main directions in the designing of ultra-high power arc furnaces with multi-electrode power supply is the choice of a rational arrangement of electrodes and parameters of electromagnetic effects. In this case, it is necessary to take into account the processes of temperature and chemical homogenization of the melt, as well as the electrovortex flows, which are formed as a result of the interaction of the electric current with its own magnetic field. The Tokyo Steel plant operates a 256 MVA six-electrode furnace [1]. This furnace has two top and four bottom electrodes and is powered by DC power supplies.

In our publications for ultra-high power electrometallurgical complexes, a six-electrode furnace with three top and three bottom electrodes is proposed and investigated [2, 3]. In this furnace, the angle between the adjacent axes of the top and bottom electrodes is 60°. In addition, the power supply of the furnace is proposed to be carried out from special converters that provide power supply with both DC and low-frequency AC current (0.01–1 Hz) with adjustable parameters of amplitude, shape, phase, and frequency. According to [2], these parameters can be regulated independently for each electrode. Such regulation will provide effective correction of the electromagnetic field in the furnace melt and will thus allow the electrovortex flows and heat fluxes in the melt to be effectively controlled during the technological process.

Numerical calculations for the proposed six-electrode furnace made it possible to investigate the characteristics of vertical and azimuthal flows of the melt when the furnace at DC and low frequency AC power supply. When simulating the furnace, the melt bath capacity was 180 tons, and the effective values of the electrode currents were 80 kA. The values of the pitch circle diameter of electrodes varied in the range from 0.2 to 0.5 relative to the bath diameter [4].

When DC power supply an increase in the azimuthal flows of the melt is detected in the case when the pitch circle diameter of the top electrodes is not equal to the pitch circle diameter of the bottom electrodes.

When the furnace is powered by a three-phase sinusoidal current with a frequency of 0.1 Hz, the volume of stagnant zones in the melt is approximately 2 times less than with a direct current power supply. The possibility of dynamically changing the parameters of vortex flows by changing the sequence of the current vectors in the electrodes has been substantiated.

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DYNAMIC MODE DECOMPOSITION OF MHD BUBBLE CHAIN FLOW

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Bubble flow in liquid metal occurs in industrial processes such as metal stirring, purification, continuous casting, etc. These processes can potentially be controlled and stabilized via applied magnetic field (MF). However, bubble flow exhibits complex collective dynamics which make it difficult to predict even without applied MF. Some aspects of magnetohydrodynamic (MHD) bubble flow are still not fully understood, preventing accurate modelling with effective Euler-Euler and Lagrangian models. Experimental and numerical data from explicit simulations, such as volume of fluid, are required to understand how MF orientation/intensity and gas flow rate affect system dynamics. To this end, downscaled systems with model liquid metals and gases, such as gallium and argon, are used [1]. It is known that bubble trajectories are mostly controlled by wake flow dynamics and are influenced by bubble shape oscillations [1,2]. This also determines bubble chain flow characteristics. Bubble chain flow is a simplified representation of industrially relevant processes, but despite the seeming simplicity exhibits complex quasi periodic patterns and entails a wide range of time scales. It is therefore of interest to perform a combination of dimensionality reduction and flow mode analysis to see exactly how MF affects wake flow patterns and shape oscillation wavelengths, as well as liquid metal flow surrounding the bubble chain.

To analyse the model system wherein bubbles are injected at the bottom of a rectangular vessel and ascend to the top through liquid gallium, dynamic mode decomposition (DMD) is applied. We have developed an algorithm in Python based on the higher order DMD scheme combined with the MOSES algorithm for streaming singular value decomposition [3], [4]. This makes the code resilient to noise in simulation/experimental data and also very computationally (memory) efficient, enabling one to quickly process high resolution data on a desktop PC. Vertical bubble chain flow in a rectangular vessel filled with liquid gallium is studied without and with applied static horizontal magnetic field (MF) and DMD is applied to the results of OpenFOAM volume of fluid simulations. Flow patterns are investigated in vessel and bubble reference frames. We demonstrate the effect of applied MF by comparing velocity and volume fraction field modes with and without MF which elucidates how MF affects bubble wake flow and surface shape and oscillations, all of which determine bubble trajectories and collective dynamics within the chain, as well as large scale structures within the vessel. Mode dynamics are also compared.

Our DMD implementation was applied to the velocity field to compute the first 20 modes for the gallium vessel. With this method, one can immediately quantify the effects of applied MF: changes in the mode frequency spectrum can be identified and it can be determined which modes are damped by the induced Lorentz force. Combining this with volumetric mode representations, an in-depth quantitative analysis of the effects of MF orientation/intensity and gas flow rate can be performed for the parameter space (Reynolds/Eötvös/Stuart numbers) of the model system. This in turn can help derive effective parameters for approximate numerical models of bubble flow in industrial installations.

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INDUCTIVE SYSTEM FOR MAGNESIUM LEVEL DETECTION IN A TITANIUM REDUCTION REACTOR

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The determination of the magnesium level in a titanium reduction retort by inductive methods is often hampered by the formation of titanium sponge rings which disturb the propagation of electromagnetic signals between excitation and receiver coils. We present a new method for the reliable identification of the magnesium level which explicitly takes into account the presence of sponge rings with unknown geometry and conductivity. The resulting inverse problem is solved by a look-up-table method, based on the solution of the electromagnetic forward problem for several tens of thousands parameter combinations. The feasibility of that method is demonstrated by performing numerical simulations and measurements on a model experiment.

We consider a simplified model of a titanium (Ti) reduction retort with a geometry as it is typical for the VSMPO-AVISMA company in Berezniki, Russia. The retort is a cylindrical vessel with a radius of 0.75 m and a total height up to 4 m, filled initially with liquid magnesium (Mg) at a temperature of 850°C. A total of nine circular electric heaters are wound around the retort at different heights, of which our method will use only the upper four heaters which are utilized also as excitation coils. While they are usually fed with a 50 Hz heater current of some 200 to 300 A, we will apply multiple frequencies, which are needed for the reliable identification of the Mg level. As sensor we assume one dedicated coil with high sensitivity to be installed just above the upper lid of the retort. A simplified numerical model of this setup was used to calculate a look-up-table (LuT) which contains the numerical results of the induced voltages in the sensor coil for many different parameter combinations of the Mg level, as well as the radius, location and electrical conductivity of the Ti sponge ring [1]. By comparing measurements to the numerical results, the most likely parameter combination at the real setup can be identified by calculating the mean square error (MSE) of the measured voltages to all voltages in the LuT. Assuming that the numerical model depicts the real setup with reasonable accuracy, the parameter combination of the LuT with the lowest MSE has the highest probability to be the unknown parameter combination at the real setup.

Since there exists no experimental data for the real reactor, a model experiment was constructed where measurements can be performed and compared to the LuT of a new numerical model which is based on the model experiment. Using the experimental data, we have demonstrated that the Mg level can be identified with reasonable accuracy by using a LuT approach [2].

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INFLUENCE OF THE PRECESSION ANGLE ON THE FLOW INSIDE A PRECESSING CYLINDER

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Precession driven flows are potential drivers for dynamo action in the Earth [1], the ancient moon, and some asteroids. As part of the DRESDYN project at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) a precession-driven dynamo experiment is presently under construction, which consists of a liquid sodium filled cylinder with a radius of 1 m and a height of 2 m respectively. The cylinder rotates with a frequency of up to 10 Hz and precess around the second axis with a frequency of up to 1 Hz [2].

To understand the hydrodynamics in a precessing cylinder a downscaled 1:6 water mockup was built with the same aspect ratio and rotation frequencies. The typical non-axisymmetric Kelvin mode that grows as the precession ratio rises is alone not suitable for dynamo action in the experiment. However, a secondary axisymmetric mode that emerges in a small region of the precession ratio was shown to be very promising for dynamo action in the sodium experiment [3].

The ability to predict dynamo behaviour for different precession ratios and precession angles requires a thorough understanding of the flow structure in the precessing cylindrical vessel. Consequently, we have performed series of precession measurements with Ultrasonic flow velocimetry (UDV) on the downscaled water experiment with various precession angles α at 60°, 75°, 90° [4]. In this paper, we present the effect of precession angle and rotation direction (i.e. prograde or retrograde) on the dominant flow modes, and quantify this behaviour in dependence of the rotation rate parameterized by the Reynolds number $Re = \Omega_c R^2/\nu$ and the precession ratio $Po = \Omega_p/\Omega_c$, with ν the viscosity and $\Omega_p = 2\pi f_p$ the angular frequency of the precession. We have not taken into account the effect of the precession angle, which changes the definition of Reynolds number. The experimental results are supported by numerical simulations.

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SEPARATION OF ACTIVE-DIPOLAR CUBES IN APPLIED FIELDS

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The term «active matter» describes a class of out-of-equilibrium systems, whose ability to transform environmental energy to kinetic energy is sought after in multiple fields of science. A challenge that still remains is the creation of nanometer sized active particles, whose motion can be effectively directed by externally applied stimuli. Adding a magnetic component and therefore being able to direct the motion of active nanoparticles with an applied magnetic field proofed promising and effective in previous experimental and theoretical studies[1,2]. However, magnetic, steric and active interactions in suspension of those particles lead to unexpected properties of the systems that have yet to be discussed before developing reliable applications. In the present study, we employ molecular dynamics simulations to shed light on the internal mechanisms taking place in suspension of magneto-active nanometer sized particles in an applied constant magnetic field. We show that the orientation of the dipole compared to the active force acting on the particles determines the direction of the swimming motion while a magnetic field is applied. Particles with different orientations therefore separate under the influence of a magnetic field. However, this is only the case in dilute systems where interparticle interactions are mitigated by the low concentrations of particles. In dense systems, those interactions overpower the sorting effect and the bulk of particles perform a swimming motion in the same direction. We elucidate the underlying internal mechanisms of this effect by directing the separate components of the interparticle interactions and their influence on this behaviour.

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TRANSFORMATION OF A SUBMERGED JET UNDER STRONG TRANSVERSE MAGNETIC FIELD

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Wall bounded shear flows of electrically conducting fluids subjected to static magnetic fields are found in many technological applications. The magnetic field transforms the flow in a way, which depends on the field's strength and orientation and may include complete restructuring of the mean velocity and modification of turbulence properties. The transformation is particularly radical when the magnetic field crosses the mean flow in the direction of its shear. An interesting type of such a situation is a submerged jet injected into a wall-bounded domain. The flow is also practically relevant. Such jets appear in molds of continuous steel casters or in elements of liquid metal blankets of nuclear fusion reactors.

A duct flow generated by a planar jet at the inlet and affected by a magnetic field perpendicular to the jet's plane is analyzed in high-resolution numerical simulations. The case of high Reynolds and Hartmann numbers is considered. It is found that the flow structure is drastically modified in the inlet area. It becomes determined by three new planar jets oriented along the magnetic field lines: two near the walls and one in the middle of the duct. The down-stream evolution of the flow includes the Kelvin-Helmholtz instability of the jets and slow decay of the resulting quasi-two-dimensional turbulence.

WAVES ON A FREE SURFACE OF A MAGNETIC FLUID IN ALTERNATING VERTICAL MAGNETIC FIELD

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Magnetic fluids are colloidal suspensions of magnetic nanoparticles in a nonmagnetic carrier liquid that have unique properties to move and change its shape under the influence of a magnetic field [1]. The free surface of a magnetic fluid (MF) can be disturbed by an applied mechanical action or by an external electromagnetic field, or by both mechanisms at the same time. While the mechanical perturbations of any amplitude causes waves on the MF surface, its excitement is possible in the applied magnetic field of a specific parameters only [2]. When the amplitude of surface deformation is comparable to the thickness of the MF layer, instability of the system arises. The instability of the initially flat horizontal MF layer is expressed in its disintegration along with the formation of a structure in the form of individual drops [3]. The critical value of the wave number of the layer instability is determined from the minimum of the neutral curve obtained from the dispersion relation [4]. For the MF layer located on a solid substrate one minimum of the neutral curve is observed. In a more complex multiphase system, i. e. «liquid substrate – magnetic fluid – gaseous medium or liquid» type, two minima are observed for both of the layer surfaces [3]. Fluids in such systems should be immiscible and stratified in density to avoid the occurrence of Rayleigh-Taylor instability [5]. The process of wave generation at the interface in the «magnetic – nonmagnetic» liquid system under the action of an external uniform, oscillating, running or rotating magnetic fields is of a particular interest [6]. Under the influence of an alternating magnetic field, two types of waves can be formed on the magnetic fluid surface: a standing wave of the same frequency as the alternating magnetic field, and a standing wave, independent of the field frequency. Experiments show that viscosity has a significant effect on the waves of the first type, and practically does not affect the waves of the second one [7].

In this work waves on the free surface of the MF layer on a liquid substrate were obtained under the influence of a vertically oscillating spatially uniform magnetic field. The results of the study are based upon the data obtained in the stability investigation of the two-layered liquid system [8, 9]. The wave process exerted on the free ferrofluid surface was captured with the high-speed video and processed with an algorithm, written specially for defining the wavelength. The dependences of the wavelength on the frequency and amplitude of alternating magnetic field and on the thickness of the MF layer, oscillating in the vessels of various diameters, are presented in this work.

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INJECTION OF NANOPARTICLES OF BORON NITRIDE IN LIQUID ALUMINUM DURING ITS MHD-STIRRING

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Modern industry is impossible without the use of new structural materials with higher strength, low weight, long lifetime, and other useful physical properties. Such properties are inherent in aluminum composite materials produced by introducing reinforcing micro or nanoparticles into a liquid aluminum matrix and subsequent crystallization of the melt. In this work, we investigated the method of introducing tableted reinforcing nanoparticles into aluminum melt during its MHD stirring and subsequent directional crystallization of the melt in the crucible. The electrical and mechanical properties of the obtained material at different concentrations of reinforcing particles were analyzed.

To gain a better understanding of the propagation of reinforcing particles released from the injected and dissolved pellets into the stirred aluminum melt we performed numerical computation, which consisted of two stages. In the first stage, the field of electromagnetic forces in the crucible with the stirred metal was determined and in the second stage, the hydrodynamic problem was solved. An exact geometric model of the MHD stirrer with a crucible used in the experiment was developed. The computational domain includes the MHD-stirrer and crucible containing stirred metal, as well as some exterior content, the size of which was selected according to the accuracy of the stated problem. At the outer boundary of the computational domain, the normal component of the vector potential was set equal to zero. The geometrical dimensions of the stirrer and crucible with aluminum, as well as the value of the inductor current were the same as those in the experiment. ANSYS MAXWELL 3D package was used to compute the field of Lorentz forces in the liquid metal, which was then transferred to the hydrodynamic problem solver.

A three-dimensional boundary value problem of the liquid flow was solved using the ANSYS CFX package within a multiphase model represented by three phases: liquid aluminum, pellets with an admixture of microparticles - a phase of large solid particles dissolving in the melt, and a dispersed phase consisting of microparticles formed by dissolution of pellets. The following conditions were imposed on the model boundaries: the adhesion and impermeability of the liquid on the lower and lateral solid faces of the crucible, and impermeability and slippage on the upper solid face. The evolution of the multiphase liquid suggested the introduction of melt surface pellets and their gradual dissolution, which results in the formation of a dispersed phase from microparticles. The computational grid contained more than 10^5 nodes, and was refined in the vicinity of the walls, where the concentrated Lorentz force field was observed due to the skin effect. The effect of stirring on the dispersed phase distribution was determined

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EXPERIMENTAL STUDY OF THE MAGNETIC FLUID SURFACE TENSION VARIATION IN THE UNIFORM MAGNETIC FIELD

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Magnetic fluids are widely applied in science and technology, and their usage is mainly based on the fact that magnetic field have strong effect on the interface between the magnetic and non-magnetic media. In most studies, the magnetic fluid surface tension is considered to be independent of the applied magnetic field and is determined by the properties of the base fluid. However, it was theoretically shown that there is a jump in magnetization at the magnetic-nonmagnetic liquid interface. The source of the jump is the force acting on magnetic particles in the transition layer where the magnetic field is nonuniform [1]. The variation of the magnetic fluid surface tension in the external magnetic field is important for both fundamental and applied science.

The exact measurements of magnetic fluid surface tension, viscosity and surface elasticity under the action of external forces are difficult to carry out. In our work we develop the experimental method for studying the surface tension of a magnetic fluid in an external uniform magnetic field taking into account the orientation of a magnetic field relative to the liquid-gas interface [2]. A modified version of the capillary wave method [3] with the new data processing algorithm based on solitary wave definition [4] was used. In the case of a longitudinal field we used the ring detachment method. The interfacial properties of the magnetic fluids of various base liquids and the stabilizers in magnetic fields have been experimentally investigated.

It was obtained that the surface tension of a ferrofluid decreases with the growth of intensity of the magnetic field orthogonal relative to the interface and with increasing frequency of acoustic vibrations. However, an increase in the field strength longitudinally directed to the interface provokes an increase in the surface tension of a magnetic fluid. The experimental results are in good qualitative agreement with the theoretical predictions of [5]: the eigenvalues of the surface tension tensor monotonically increase with the tangential magnetic field component and monotonically decrease with an increase in its normal component.

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THE SPECIFIC LOSS POWER OF A SYSTEM OF SINGLE-DOMAIN INTERACTING SUPERPARAMAGNETIC PARTICLES

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The specific loss power (SLP) is an indicator of the effectiveness of the magnetic hyperthermia method. In this work SLP of interacting dipolar particles are studied.

The monodisperse ensemble of spherical, uniformly magnetized superparamagnetic particles immobilized in a nonmagnetic matrix is considered. The easy magnetization axes of the particles are aligned parallel to the AC magnetic field. The rotational motion of a magnetic moment is described by the probability density function which is the solution of the Fokker-Planck equation. Interactions are included within the framework of the first order modified mean-field theory [1]. Analytical and numerical predictions are given for probability distribution function which is used for calculation of SLP. The dependence of SLP on the intensity and frequency of the magnetic field is discussed as well as on diameters and concentration of ferroparticles, intensity of the interparticle interactions.

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MODELLING OF LIQUID MAGNESIUM CONVECTION IN A TITANIUM REDUCTION APPARATUS

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The turbulent convection of liquid magnesium in a titanium sponge reduction reactor is investigated. Titanium production is a complex physical and chemical multi-step process in which titanium tetrachloride is fed from above, resulting in an exothermic reaction at the magnesium surface. Controlling the processes inside the apparatus is one of the metallurgical problems due to the fact that the convective flow has a significant influence on the formation front of the titanium block.

As the process runs for two days, simulating the whole time evolution is computationally demanding and it is not possible to use DNS (direct numerical simulation) and LES (large vortex simulation). This is one of the reasons for carrying out a numerical study using the RANS (Reynolds-averaged, Navier-Stokes) approach, as it is less demanding on computational resources.

For liquid magnesium the thermal convection equation in the Oberbeck-Boussinesq approximation is solved. The problem was considered for different heating configurations that occur at different stages of the actual production process.

The calculations were performed using the OpenFOAM 4.1 package. The model built gives results that are qualitatively consistent with those obtained using LES on a more detailed computational grid. Depending on the heating configuration inside the apparatus, a binary flow or a large-scale circulation similar in structure and dynamics to the classical Rayleigh-Benard problem appears. The fields of temperature, velocity, transition mode dynamics, turbulent pulsation energy and energy dissipation rate for k-ω SST model are analyzed [1,2].

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NUMERICAL SIMULATION OF THE FREE SURFACE MAGNETOHYDRODYNAMIC WAVE TURBULENCE

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It is known that under the influence of external mechanical force (in the absence of an external magnetic field), turbulence of surface capillary waves can develop on the free boundary of a liquid. The theory of such turbulence was first proposed by V.E. Zakharov in the late 1960s, and since then has been well confirmed numerically and experimentally. In our work, we first investigated the effect of an external horizontal magnetic field on the development of wave turbulence of the free surface of a liquid. Direct numerical simulation of three-dimensional fluid motion shows that an external field is capable of stabilizing the growth of the amplitude of surface perturbations directed along the field. In the direction perpendicular to the external field, on the contrary, there is a tendency towards the formation of high energy densities. The simulation results show that in the limit of a strong external field at the fluid boundary, a new type of wave magnetohydrodynamic turbulence with its own unique spectrum is realized, see [1-3] for details. In the future, the study of the mechanisms of the development of wave turbulence on the surface of a liquid in an external field can be useful for creating new materials with a given surface microrelief and level of roughness. This work is supported by RFBR project No. 20-38-70022.

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ELECTROVORTEX FLOWS IN CYLINDRICAL CELL AND EXTERNAL MAGNETIC FIELD

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We study the electro-vortex flow of liquid metal in a cylindical cell with a solid or free upper boundary. Direct electric current is supplied at a localized circular area (electrode) in the center of the cylinder bottom end face. The top end face of the cylinder acts as a second electrode. The inhomogeneous distribution of the electric current and its interaction with own magnetic field gives rise to electromagnetic (em) force. This leads to the formation of electro-vortex flow (EVF).

In this configuration, in the absence of an external magnetic field, the EVF has the shape of a large-scale vortex. That is, the velocity field has only poloidal component. There is a threshold value of the electric current, upon exceeding which the EVF oscillations begin. It looks like the oscillating deformation of the toroidal shape of the vortex. In this case, pulsations of the toroidal component of the velocity field appear to have mean value close to zero.

If an external axial homogeneous magnetic field is applied, a toroidal component of the em-force appears. This component of the force is also localized in the area of the bottom electrode. This component leads to a rise of rotating flow. The toroidal component of the velocity field is initially inhomogeneous along the axial cross-section, which is due to the inhomogeneity of the toroidal component of the em-force. We have found that there is a range of the value of the external magnetic field induction, in which the energy of the poloidal flow is significantly reduced. What is the reason for this phenomenon?

To clarify all the features of the system behavior in this regimes, several subtasks were studied numerically and experimentally. We investigate the behavior of the poloidal component of the velocity field in the cases of the absence and presence of its toroidal component. The spectra of turbulent velocity pulsations and the dependence of the azimuthal component on the magnitude of the induction of the external magnetic field are obtained. The behavior of the flow in configuration when the bottom cylindrical electrode is fully protruded into the cell is studied. In this case, it is possible to completely eliminate the EVF only when there is a very large difference between the electrical conductivity of the liquid and the rod. The behavior of the flow in cases of gradually increasing poloidal or toroidal components of the em-force, as well as the effect of a magnetic field from supply cables are studied. Finally, observation of the EVF evolution at parameters providing a non-oscillatory flow regime helped to find the reason of reduction in the energy of poloidal flow. The obtained results have theoretical and practical value for the development of devices with EVF.

TRAVELLING MAGNETIC FIELD PUMPS FOR LIQUID METALS: NUMERICAL AND EXPERIMENTAL STUDIES

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Electromagnetic pumps for liquid metals are widely used in the metallurgical and nuclear industries [1]. In metallurgy the pumps are used for casting the molten metals [2,3]. In the nuclear industry, they are used for transport the coolant in the main and auxiliary circuits of fast neutron reactors. The main advantage of such a pumps is the absence of moving parts, because the pressure is generated by electromagnetic force in a non-contact manner. The work studies the processes in a coaxial channel under the influence of a traveling magnetic field. The magnitude of the electromagnetic force essentially depends on the frequency of the field, the ratio of the drift velocity of the field and the average velocity of the flow. The parameters of the MHD channel are significantly affect the characteristics of the devices.

At the ICMM UB RAS the pumps are developed and studied numerically and experimentally [2-5]. The processes occurring in the magnetohydrodynamic (MHD) channels of the pumps are studied using mathematical modelling and special experiments. Mathematical modelling is performed in full three-dimensional statement. The model takes into account such non-linear effects as ferromagnetic parts saturation and the magnetic field transfer by a moving electrically conductive medium. In experiments, the effect of various parameters of MHD channels on the pump capacity is studied in cases where the liquid metal is modelled by a solid conductive body. The results of such studies are used for better understanding the processes, as well as for verifying and developing the mathematical models.

Capacity of the designed pumps is measured on the gallium and sodium circuits available at ICMM UB RAS on full-sized models. Sodium tests were carried out in a wide temperature range (from 150°C to 450°C). The results have shown the achievement of the required characteristics and good agreement between the mathematical modelling and the experiments on key working parameters of current, voltage, developed pressure and flow rate.

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LIQUID METAL FLOW GENERATION IN CYLINDRICAL CELL BY SMART INDUCTOR

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Generation of a molten metal flow in a cylindrical cell using an alternating magnetic field is widely used in metallurgical production. The flow has to be created before the solidification process. This makes it possible to significantly improve the properties of the resulting ingot, namely, to achieve a uniform distribution of impurities and grain size. This is achieved, among other things, by homogenizing the temperature of the liquid metal in the cell. In this case, the cylindrical ingot can be crystallized either in a stationary crucible or in a crucible of a continuous casting machine. For a cylindrical ingot, it is most convenient to use a alternating rotating magnetic field. The main problem in this case is the weak intensity of the poloidal flow and, as a consequence, the inhomogeneity of mixing and temperature distribution. One way to overcome this problem is to add a traveling magnetic field that creates a strong poloidal flow in a cylindrical cell. This essentially improves mixing. However, it allows one to realize only two types of flow with limited possibilities for controlling their topology. Also, this circuit increases the size and weight of the inductor and limits the ability to make the inductor collapsible in sections. Another way to overcome the problem is the non-stationary power supply of the inductor, which is achieved by modulation, changing the direction of the field movement, or switching power supply on and off. This also essentially improves mixing. However, by the methods described above, only a classical traveling or rotating magnetic field can be generated. The question arises - are there other ways to complicate the topology of the alternating magnetic field and, as a consequence, the flow, in order to obtain even more efficient mixing?

In our work, we develop a method for finding such a mixing method using a "smart" inductor. It is a set of windings placed in space on a complex shaped ferromagnetic core. A key feature of our inductor is that each winding is connected to a computer controlled power supply. This allows us to control the voltage, phase shifts and supply frequencies of each winding or group of windings. This makes it possible to implement a complex spatio-temporal configuration of an alternating magnetic field in the cell. Another advantage of this design is that it is more compact than traditional devices of this type and consists of sections. This allows us to integrate our inductor into existing production processes and devices without the need for modernization or even shutdown.

This work presents the results of a numerical and experimental study of processes in a smart inductor using the example of its simplest mode. In this mode, rotating magnetic fields are realized, creating an electromagnetic force, the azimuthal component of which changes its direction along the cell axis. This leads to a torsional action on the liquid metal in the cell. A numerical study of magnetohydrodynamic processes was carried out in Ansys Emag and Fluent. The experimental study was carried out on a gallium alloy using an ultrasonic Doppler velocimeter. It is shown that even this regime significantly complicates the form of both azimuthal and poloidal flow over the cell region. The resulting flow is accompanied by the oscillatory motion of vortex structures over the region and the interaction between them. This leads to efficient mixing of the liquid metal.

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LIQUID METAL LEVEL MEASUREMENT

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For the safety of technological processes, they must be equipped with measuring instruments capable of providing reliable and accurate level measurement. The main task of level measurement is to determine the position of the surface of the medium inside a storage facility, reactor or tank. More precisely, level measurement consists in determining the vertical linear distance between the reference point (which usually coincides with the bottom of the container) and the surface of a liquid, a bulk medium, or the interface between two liquids. Accurate measurement of the liquid level in a vessel, reactor or other vessel is of great importance for many technological processes.

In processes where liquid metals are used, direct level measurement is often difficult. High temperature, required tightness of volumes, high pressure, aggressive environment often lead to the use of non-contact measurement methods. One of these is the inductive level measurement method. A prerequisite for using this method is the electrical conductivity of the medium.

The work investigates the interaction of an alternating magnetic field and a stationary conducting medium. The magnetic field is generated by a cylindrical coil. The conductive medium is a liquid metal placed in a cylindrical volume. The magnetic field of the coil will generate eddy currents in the cylindrical conductive body, which will create a secondary magnetic field. The superposition of the initial and secondary magnetic fields is the resulting magnetic field. Thus, the presence of a conductive cylindrical body leads to a distortion of the magnetic field of the coil. This method is used in a number of induction electromagnetic devices, one of which is a level gauge.

A method for determining the interface of a conducting body is studied numerically and experimentally. The measurement method is based on the effect of an alternating magnetic field on a conductive body. Distortions of the magnetic field are recorded by coils (either measuring or generating itself). Distributions of magnetic fields and their distortions near a conducting body are calculated numerically. A laboratory experimental setup has been developed and created, which confirms the numerical calculations.

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NON-AXISYMMETRIC FLOWS IN THE SOLAR INTERIOR AND QUASI-BIENNIAL VARIATIONS OF SOLAR ACTIVITY

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Nonaxisymmetric flows in the form of Rossby waves [1] are manifested everywhere in both atmospheric and oceanic hydrodynamic flows, and possibly also in magnetohydrodynamic flows in the convective envelopes of the Sun and stars. For stars, an important property of this phenomenon is that Rossby waves can exist both in the convective zone and in the radiation core.

Hereby, we study the properties of Rossby waves in the convective envelope and the radiation core, modified by the average (large-scale) magnetic field of the solar convective envelope. The effects associated with Rossby waves may underlie the nature of quasi-biennial fluctuations [2] of various indicators of solar activity and solar-terrestrial phenomena. We carried out a wavelet analysis of the known observational data of solar activity in order to determine the phase of the solar cycle in which these fluctuations are most pronounced. Using the theory of Rossby waves modified by a large-scale magnetic field, we have shown that at zero magnetic field there are several modes (about 38) of Rossby waves which are capable of providing two-year oscillations. Among them, we distinguished the mode with l = 7, m = 1. It is this mode, even at presence of a sufficiently strong magnetic field (about 1000 G at the base of the convective zone), that can exist (without noticeable distortion of the quasi-biennial periodicity) simultaneously both in the convective and radiation zones of the Sun, simultaneously affecting both solar activity and, possibly influencing on a neutrino flux, modulating nuclear reactions in the central part of the radiation zone due to changes in temperature and pressure.

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ELECTROMAGNETIC MEASUREMENTS OF NON-FERROUS METALS CONDUCTIVITY

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Metallurgical production is the basis of many types of economic activities, including the production of weapons, vehicles, mechanical engineering and everyday goods.

In turn the production of ultrapure metals is one of the most urgent tasks facing the modern metallurgical industry. Ultrapure materials have increased strength characteristics and have tremendous potential for application in the aerospace and military fields. However, at present there are no cheap methods of operational control of the non-ferrous metals purity. Chemical analysis requires the consumption of reagents, spectroscopy and radiography require complex and expensive equipment. All of the above methods are also difficult to adapt for operational control which is just as important in the conditions of nuclear power plants. Therefore, non-contact and high-speed analysis of the metals purity is an important and urgent task.

Operational control of the purity of metals during the production process will significantly reduce the level of rejects and eliminate the influence of the human factor due to the automation of quality control systems.

Within the framework of this work, we investigate the possibility of electromagnetic measurement of electrical conductivity of samples with strictly specified geometric shape made of non-ferrous metals. Due to the rather strong connection between the conductivity of metals and the number of chemical impurities in them measurements of conductivity will also make it possible to determine the level of contamination of a metal or alloy regardless of the specific chemical nature of impurities.

Conductivity analysis is carried out using an induction circuit for generating eddy currents in the analyzed sample and measuring the intensity of the magnetic fields generated by these currents. This scheme avoids the problems associated with the presence of contact resistance and contamination of the surface of the sample due to the volumetric mechanism for generating currents.

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ELECTROMAGNETIC FIELD IN THE FLOWMETER CHANNEL FOR LIQUID METALS

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The physical formulation of the problem is reduced to the following: a conducting liquid with known physical parameters flows in a channel in which an external field is created (i.e, the field that exists if the liquid is stopped); it is required to find the induced electromagnetic field and, in particular, to relate the potential difference between two or more points with some quantitative characteristics of the flow, for example, with the average velocity . This formulation of the problem presupposes finding the distributions of the velocity and the induced magnetic field and, therefore, reduces to the joint solution of the system of Maxwell's equations and equations of hydrodynamics [1].

There are several circumstances that facilitate the solution of this.

1) A change in the magnetic field occurs only at sufficiently large magnetic Reynolds numbers. The value reaches about 10 and more only in pipes of large diameter d. In this case, the hydraulic Reynolds number is of the order of $10^5 \div 10^6$, which corresponds to a developed turbulent flow. Such a flow is characterized by an almost constant velocity value everywhere, except for the boundary layer, in which there is a sharp change in velocity to zero. The boundary layer thickness is of the order of $\delta/d \approx 1/\sqrt{Re} \approx 0.1 \div 0.3\%$. Examining the effect of changing the magnetic field by induced Re currents, one can neglect the boundary layer and consider the fluid velocity constant throughout the channel.

2) For an accurate calculation of the deformation of the magnetic field, it is necessary, generally speaking, to know the distribution of sources that create an external magnetic field. In this work, it is assumed that the sources of the external field are located at a sufficient distance from the pipeline axis . Due to the strong attenuation of the induced magnetic field outside the pipeline, this assumption actually has little effect on the results obtained.

Under these assumptions, all components of the induced electromagnetic field are expressed through the electric potential and the axial component of the induced magnetic field.

An exact analytical expression is obtained for the induced electromagnetic field as a functional of the external magnetic field. The dependence of the induced electromagnetic field on the magnetic Reynolds number, the length and inhomogeneity of the magnetic field of the inductor, the ratio of the wall and liquid conductivities, and the thickness of the pipeline is investigated.

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EIGENFUNCTIONS IN DIFFERENT GALACTIC DYNAMO MODELS

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Now it is no doubt that a lot of galaxies have magnetic fields of several microgauss. From the observational point of view, they are studied by measurements of Faraday rotation and characteristics of synchrotron emission. Theoretically their generation is usually studied by so-called dynamo theory [1].

The large-scale magnetic field is described by Steenbeck-Krause-Raedler equation, which is quite difficult to be solved. It is necessary to have large computational resources to model the magnetic field numerically. Analytical methods for three-dimensional equations are complicated, too.

However, the magnetic field can be described by two-dimensional models which take into account specific features of the galactic disc. One of the most important approaches is connected with no-z model which takes into account that the galaxy disc is quite thin, so it is possible to solve the equations only for two components of the field [2]. Most of the research in this field was done numerically, but basic results can be obtained using spectral decompositions. Also eigenfunctions of the differential operators of no-z model can describe some special characteristics of the magnetic fields, for example ones connected with its symmetry [3].

Nowadays it is also important to use models which take into account vertical structure of the field, such as torus dynamo for outer rings of galaxies of rz-model for main part of the galaxy [4]. Their solutions can be analyzed using eigenfunctions of corresponding differential operators, too.

Here we present the spectral decomposition of solutions for the magnetic field for different models, and compare them. Also we give the main astrophysics conclusions connected with features of eigenfunctions.

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A NEW TYPE OF DOUBLE-DIFFUSIVE HELICAL MAGNETOROTATIONAL INSTABILITY IN ROTATING FLOWS WITH POSITIVE SHEAR

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The magnetorotational instability (MRI) can destabilize various natural and laboratory rotating flows with radially increasing specific angular momentum but radially decreasing angular velocity, which are otherwise linearly stable according to Rayleigh's criterion. One of the notable classes of such flows is Keplerian rotation of astrophysical disks, where MRI plays a central role, mediating outward transport of angular momentum and inward mass transport. The standard version of MRI (SMRI) with a purely axial magnetic field as well as the azimuthal MRI (AMRI), with a purely azimuthal field, and the helical MRI (HMRI), with combined axial and azimuthal fields, were extensively studied theoretically (e.g., [1–3]). AMRI and HMRI, were also obtained in liquid metal experiments [4,5], while the SMRI remains still elusive in laboratory.

In contrast to Keplerian-like rotation with decreasing angular velocity, much less attention is devoted to flows with radially increasing angular velocity, i.e., *positive shear*. Until now, it was believed that such flows are very stable, even under magnetic fields. However, it has been recently shown that at high enough Reynolds numbers, $Re \sim 10^6$, they can in fact yield non-axisymmetric linear instabilities [6]. Besides, in the presence of magnetic fields, there exists a special type of AMRI for much lower Reynolds number but very strong positive shear [7].

This restriction to very strong shear makes this so-called Super-AMRI unlikely to be astrophysically significant. One of the few positive shear regions is a region of the tachocline in the Sun extending $\pm 30°$ about the solar equator. However, even there, the shear measured in terms of the Rossby number, Ro, is only around 0.5, much less than the upper Liu limit (ULL) $Ro_{ULL} \approx 4.83$ required for Super-AMRI to operate [7]. Given the general similarity between AMRI and HMRI, one might expect a similar threshold to hold for Super-HMRI too [8].

In this study, using the short-wavelength WKB approach combined with 1D linear stability analysis in a Taylor-Couette flow, we have discovered and analyzed a new type of axisymmetric double diffusive HMRI, which operates in dissipative, magnetized rotating flows with arbitrary positive shear, including $0 < Ro < Ro_{ULL}$ where MRI-s have been previously unknown (details are presented in Ref. [9]).

The only prerequisites are that (i) the magnetic Prandtl number is neither zero (the inductionless limit) nor too close to unity, $Pm \neq 1$, and (ii) the imposed magnetic field consists of both axial and azimuthal components. Both these conditions are satisfied in the near-equatorial parts of the solar tachocline, which are characterized by the positive shear of rotation, and, therefore, as we demonstrated, this new type of HMRI can in principle take place in those regions. This can have important consequences for the stability and dynamo action in this region of the tachocline. In particular, due to its axisymmetric nature, this instability could also revive the idea of a subcritical solar dynamo.

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STATISTICAL THEORY OF MAGNETIC FIELD INDUCED PHASE TRANSITIONS IN FERRONEMATICS

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Based on the molecular-field theory [1] we have studied the influence of the external magnetic field on the orientational structure of a ferronematic, i.e., suspension of monodomain magnetic particles in nematic liquid crystal. In contrast to the previous work [2] we take into account the interaction of the liquid crystal matrix with the magnetic field, which leads to additional ordering of the suspension. The dependences of the order parameters of the liquid crystal and the magnetic admixture as functions of temperature for different values of material parameters and magnetic field have been studied. We have investigated the transition temperature from the ordered nematic state to the paranematic one, and the jumps of the order parameters at phase transition points as functions of the coupling energy of subsystems.

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CONVECTIVE, ABSOLUTE AND GLOBAL AZIMUTHAL MAGNETOROTATIONAL INSTABILITY

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Magnetorotational instability (MRI) is the primordial mechanism that allows outward transport of angular momentum in accretion disks and mass concentration onto compact/central objects [1]. In light of the importance of MRI to astrophysics, in spite of many commendable efforts [2, 3], MRI in the laboratory experiments has not been successfully detected. However, the helical and azimuthal variants of MRI were observed in the PROMISE experiment [4, 5]. Although these experiments were studied in the setting of convective instability, interesting connections were discussed between the convective, absolute and global instabilities [6]. Convective instability propagates in the flow as a traveling wave and tends to spatially decay at large times while the absolute instability grows unlimited at every point in the flow. Hence, it is the absolute instability that stays in the device for long time, displaying a sustained growth which is more relevant experimentally.

Azimuthal magnetorotational instability (AMRI, [8]) is a non-axisymmetric instability, with dominant azimuthal wavenumbers $m = \pm 1$, arising in a (hydrodynamically stable) differentially rotating flow in the presence of a purely azimuthal magnetic field. In this paper, we study AMRI in terms of convective, absolute and global instabilities in a Taylor-Couette (TC) flow. We perform WKB and 1D linear stability analysis and show that the absolute variant of AMRI compliment the findings of PROMISE experiment [5] i.e., the emerging «butterfly-type structure» -a spatio – temporal variation in the form of the upward and downward traveling waves-, which hitherto was illusive to the effect of endcaps. We also show that the domain of the convective AMRI is wider than that of absolute AMRI. We also study the global AMRI in a TC flow of finite height using DNS and find that the emerging «butterfly-type structure» is in a very good agreement with the linear stability analysis, which indicates the presence of two dominant absolute AMRI modes in the flow giving rise to this global butterfly pattern.

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RHEOLOGY OF NANOSCALE POLYMER-LIKE CHAINS WITH FERROMAGNETIC NANOPARTICLES

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Construction of smart materials with sophisticated magnetic response by incorporating magnetic nanoparticles (MNPs) within permanently cross-linked structures, opens up the possibility for synthesis of complex, highly magneto-responsive systems [1]. Nanoscopic magnetic filaments (MFs) are polymer-like linear chains with magnetic, nano-sized colloids. They are a promising platform for engineering new magnetically controlled filtering and flow control elements in micro-fluidic devices. Recently reported assembly of linear polymer-like structures using DNA origami frames, where the structure building instructions are encoded via DNA sequencing, provides a new perspective on construction of filaments with MNPs [2–4]. Using programable DNA origami assembly, one can create scaffolds that serve as a blueprints for chain-like conformations of MNPs. Using MD simulations we previously studied how possible crosslinking scenarios and magnetic nature of monomers (ferromagnetic or super-paramagnetic) influence equilibrium properties of MFs [5]. In this contribution, we elucidate the effect of monomer shape on the dynamics of polymer-like linear chains and MFs with ferromagnetic MNPs, in shear flow and/or rotating magnetic field. We use explicit solvent representations using the Lattice Boltzmann method.

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NONSTATIONARY ELECTROVORTEX FLOW IN HEMISPHERICAL BOWL WITH EXTERNAL MAGNETIC FIELD: ANALYTICAL STOKES SOLUTION

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Electrovortex flow (EVF) is formed as a result of interaction between the non-uniform electric current passing through the liquid metal and the own magnetic field of this current [1]. We consider nonstationary flow in a hemispherical bowl under influence of the vertical magnetic field (see Fig. 1). In the linear approximation, the azimuthal swirl velocity U_φ evolves independently of the velocity of the main two-dimensional (toroidal) EVF. The meridional flow is described by the azimuthal projection of the vector potential ψ.

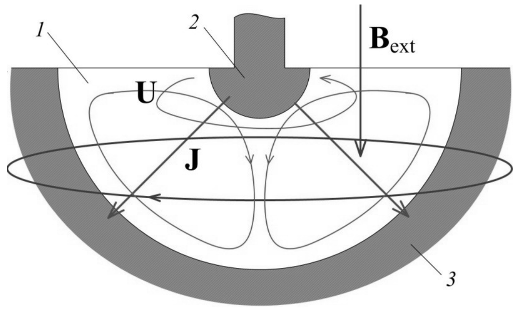

Figure 1. *Electrovortex flow in the hemispherical bowl under influence of the vertical magnetic field. 1 - liquid metal, 2 - small electrode, 3 - big electrode.*

The initial boundary value problem for U_φ has the form:

$$\frac{\partial U_\varphi}{\partial t} = \frac{1}{\sqrt{S}} L U_\varphi + \alpha \frac{\sin\theta}{r^2}, \quad t > 0, \quad a < r < 1; \quad 0 < \theta < \frac{\pi}{2},$$

$$U_\varphi|_{r=a} = U_\varphi|_{r=1} = 0, \quad \frac{\partial U_\varphi}{\partial \theta}|_{\theta=\frac{\pi}{2}} = 0, \quad U_\varphi|_{t=0} = 0.$$

The initial boundary value problem for ψ:

$$\frac{\partial L\Psi}{\partial t} = \frac{1}{\sqrt{S}} LL\Psi + \frac{\cos\theta - 1}{4\pi^2 r^4 \sin\theta}, \quad t > 0, \quad a < r < 1; \quad 0 < \theta < \pi/2$$

$$\Psi|_{r=a} = \Psi|_{r=1} = \frac{\partial \Psi}{\partial r}|_{r=a} = \frac{\partial \Psi}{\partial r}|_{r=1} = 0, \Psi|_{\theta=\frac{\pi}{2}} = L\Psi|_{\theta=\frac{\pi}{2}} = 0, \Psi|_{t=0} = 0$$

Here we use the following operator:

$$L = \frac{1}{r^2}\frac{\partial}{\partial r} r^2 \frac{\partial}{\partial r} + \frac{1}{r^2}\left(\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\sin\theta\frac{\partial}{\partial\theta} - \frac{1}{(\sin\theta)^2}\right)$$

Boundary conditions: on the electrodes — adhesion, on the free surface — slip condition. Here $\alpha = N/S$, $N = B_{\text{ext}} IR/(\rho\nu^2)$, $S = \mu_0 I^2/(\rho\nu^2)$ - electrovortex parameter, ρ is the density of the liquid, ν is the kinematic viscosity coefficient, p is the pressure, μ_0 - magnetic constant, R — radius of the big electrode, B_{ext} — external axial magnetic field. The paper presents analytical solutions to both problems.

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SIMULATION OF VORTEX AND MAGNETIC FIELDS IN THREE-DIMENSIONAL FLOWS OF CONDUCTIVE MEDIA

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The solution of problems of vortex dynamics in order to use the useful properties of complex vortex and swirl flows in technical applications, as well as for the diagnosis of catastrophic geophysical processes (hurricanes, tornadoes, changes in the direction of ocean currents, tsunamis, etc.), can be attributed to the fundamental problems of thermophysics associated with conducting complex theoretical and experimental studies of the mechanisms of the relationship of hydrodynamic, heat and mass transfer, electro- and magnetodynamic processes in complex vortex flows of natural and working environments.

The problems of vortex dynamics in the thermophysics of complex technical systems, such as nuclear liquid-metal reactors, should include theoretical and experimental studies aimed at identifying the relationship between the conditions for the formation of large-scale spiral-vortex structures in the flow of liquid-metal coolant with the emergence of a crisis of hydrodynamic stability caused by thermoelectric and magneto-hydrodynamic (MHD) effects. It was shown in [1,2] that magneto-hydrodynamic effects occur in fast reactors due to the generation of an axial magnetic field in the central part of the reactor and a complex pattern of thermoelectric currents recorded in the core, in the places where intermediate heat exchangers and main circulation pumps are located. All of that which leads, in particular, to self-excitation of the magnetic field in the lower pressure chamber of the collector.

With the adopted integrated layout scheme for the arrangement of the structural elements of the core and the collector system of fast reactors, large vortices with a helical-helical movement of the liquid metal coolant can occur in certain areas of the thermal-hydraulic path of the primary circuit. In this case, the non-zero helicity of the velocity field H ($H = \mathbf{u} \cdot \omega \neq 0$, where $\omega = \mathrm{rot}\,\mathbf{u}$ is the vortex vector of the total local flow velocity $\mathbf{u}$) is a factor that leads to the appearance of an «anomalous» electromotive force (EMF) or the so-called hydrodynamic α effect.

The results of theoretical studies obtained in the monograph [3] allow us to predict the nature of changes of helicity in complex vortex flows. In this paper, the objects of research were three-dimensional flows of liquid sodium flowing in the presence of an external transverse magnetic field in curved and rectilinear cylindrical channels with obstacles of various geometries placed in them, generating large-scale vortex motion. The calculation was performed using ANSYS Fluent. For the equations of hydromechanics the model of turbulence k-ω SST was also used.

The presented results show that the presence of large-scale vortex formations leads to the generation of fluctuations in the induced magnetic field at the same scales. In this case, the configuration of the induced vortex magnetic field in a moving conducting medium depends on the mutual orientation of the spiral-vortex motion and the direction of the external magnetic field.

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GENERATION MECHANISMS OF VORTEX-WAVE PROCESSES IN CONDUCTIVE MEDIA

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The study of the effects caused by the interdependence of the electric, magnetic and vortex fields of electrically conductive media is very relevant not only in terms of technical use, but also in connection with the tendency that has been clearly traced in recent decades towards an increase in the frequency of catastrophic natural phenomena that are combined into the problem of climate change. In this case, research aimed at identifying the mechanisms of vortex generation and accumulation of energy in large-scale natural vortex formations in the atmosphere and oceans is of particular importance.

As it was shown in publications [1, 2] the presence of large-scale vortices with a spiral-helical motion of conductive media in combination with magnetoelectric effects can lead to the emergence of a hydrodynamic alpha effect, which promotes self-generation of a magnetic field and prevents the movement of medium.

To study the mechanism of generation of vortex motion in electrically conductive media in a constant magnetic field, an experimental setup was created, the main elements of which were: a transparent vessel filled with electrolyte, into which two electrodes connected to a power source are lowered, a spherical magnet creating a constant magnetic field and being one of the electrodes, and recording equipment for photo and video surveillance. A movable cylindrical rod made of copper was used as the second electrode. The supply voltage was adjusted and the current flowing in the electrolyte solution was measured using a power supply unit. For the experiments, solutions of copper sulfate and acetic acid were selected.

Several electrolytes were considered as a model liquid: solutions of sodium chloride NaCl, copper sulfate CuSO4, iron sulfate FeSO4, glacial acetic acid CH3COOH, and as electrode materials: copper, graphite of nuclear grade, various iron alloys. The onset of an organized liquid movement observed for all solutions when an electric current is passed was accompanied by various chemical reactions that have different effects on vortex formation and visualization of flow patterns. For the experiments, solutions of copper sulfate and acetic acid were selected. The study of the vortex formation mechanisms when using these electrolytes gives a certain analogy with the processes taking place in liquid metals: acetic acid has a large difference in the mass of unlike ions (the mass of the negative acetate ion CH3COO- is 59 times greater than the mass of the positively charged hydrogen ion H+), and In copper sulfate (copper pentahydrate CuSO4 · 5H2O), the directed movement of positive complex copper ions together with attached water molecules [Cu · 5H2O] 2+ determines the direction of flow swirling, corresponding to the effects of vortex formation during the movement of liquid metal coolants in a magnetic field.

In the experiments, well reproducible and visualizable patterns of spiral-vortex flow, leading to large-scale swirling of the flow, were obtained. The intensities of vortices and their energy were estimated, and the velocity fields were measured depending on the mutual orientation of the magnetic and electric fields.

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FOUR-PARAMETER MODEL OF MAGNETIZABLE ELASTOMERS VISCOELASTIC BEHAVIOR

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A significant number of scientific works are devoted to the study of magnetizable elastomers rheological properties. In [1] the torsional oscillations of ferrogel samples are studied experimentally, and it is shown that these oscillations are more intensely damped in the presence of a transverse magnetic field. The viscoelastic properties and residual deformations of cylindrical samples with magnetizable elastomers in a longitudinal magnetic field are studied in [2].

In this work, in contrast to [1] and [2], torsional deformations of cylindrical bodies with magnetizable elastomers are investigated taking into account stress relaxation in a magnetic field. The viscoelastic properties of magnetizable elastomers in a uniform magnetic field have been studied in static and dynamic experiments. It is shown that the pure silicone sample deformations are described by the Kelvin–Voigt model. However, to describe the deformations of samples with ferromagnetic particles (for which stress relaxation is found) the four-parameter model is used. Stress relaxation of samples with ferroparticles in a magnetic field is found in the static experiment. Dependences of the viscosity coefficients and shear moduli on the magnetic field strength for the four-parameter model are determined by the static and dynamic experiments.

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THE SPIN-UP PROCESS OF THE ELECTROVORTEX FLOW SUBJECT TO THE EXTERNAL MAGNETIC FIELD

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It is well-known that application of the external axial magnetic field to the poloidal electrovortex flow (EVF) [1] results in suppression of the latter and rise of the azimuthal flow [2]. That effect takes place if some critical magnetic field is exceeded. Our previous study [2] has shown that the poloidal-azimuthal transient regime structure depends on the external magnetic field.

In laboratory experiments and real-world scenarios the electric current is not constant and changes over time. The highest variation in its value takes place when the setup is powered on and off, which is typical for the case of liquid metal batteries (LMB) [3].

In this work, transient regimes of the EVF of a liquid metal in a cylindrical container subject to the external magnetic field are studied numerically. The radius of the stainless steel container is equal to its height being 100 mm. A cylindrical copper electrode with 15 mm radius is localized at the center. The entire sidewall of the cell acts as a second electrode. All computations start from the zero-velocity state of the system, in the absence of the electric current. Then, the direct electric current is increasing gradually to its maximum value in range from 0 to 1000 amperes. The external vertical magnetic field is homogeneous and constant in time.

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FEATURES OF THE LARGE-SCALE CIRCULATION BEHAVIOR DURING RAYLEIGH-BENARD CONVECTION IN A SQUARE CYLINDER FILLED WITH LIQUID SODIUM

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Rayleigh-Benard convection in closed cylindrical cavities with a diameter equal to the height is a classical fundamental problem of hydrodynamics, which has enjoyed constant popularity since the 60s to the present [1]. The high scientific interest is due to the fact that convective motion caused by inhomogeneous heating is one of the most common types of liquid and gas flows in nature and technology. The relevance of the work is determined by the acute lack of experimental data on turbulent convection and turbulent convective heat transfer in liquids characterized by low Prandtl numbers (liquid metals). An important and insufficiently studied question is the structure and behavior of large-scale circulation (LSC) developing in the volume of a cavity against the background of small-scale turbulence. The paper presents the results of an experimental and numerical study of liquid sodium convection in a cylinder with a unit aspect ratio in different positions from vertical to horizontal.

The experimental setup consists of a closed cylindrical convective cell bounded by hot and cold heat exchangers. The cell and heat exchangers are made of stainless-steel pipe (inner diameter $D = 212$ mm, wall thickness 3.5 mm) and filled with liquid sodium. Convective cell length $L = 216$ mm. A feature of heat exchangers is that instead of traditional thick copper plates, thin (2 mm) plates are used, intensively washed with liquid sodium [2].

From the obtained temperature evolutions on 28 thermocouples immersed into the sodium in convective cell, the LSC sloshing mode was detected – a plane-parallel periodic displacement of the LSC plane from the cylinder axis. Sloshing is present not only in a vertical cylinder, but is also preserved when it is tilted at angles up to 30 degrees from the vertical. It is shown that the period of sloshing oscillations is consistent with the period of LSC circulation and depends on the Rayleigh number. The temperature correlation method for determining the velocity also made it possible to register the sloshing mode.

In the vertical position, sloshing was accompanied by rotations of the LSC plane along the cylinder axis at different angles (wandering process). The wandering process has a non-periodic character and consists in irregular rotations of the LSC plane, mainly at angles of the order of 40-50 degrees on time scales from a few to tens of minutes, and, rarely, at angles of the order of 90 and even 180 degrees at large and medium scale. Such rare events were recorded on wavelet diagrams in the form of bursts of the spectral energy density of temperature fluctuations.

Numerical calculations made it possible to study the flow structure in convective cell more thoroughly and understand the mechanism of the sloshing mode better.

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TEMPERATURE CORRELATION METHOD APPLICATION TO THE PROBLEM OF MEASURING THE FLOW RATE OF LIQUID SODIUM

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One of the ways to measure the flow rate of liquid metal is the correlation method based on the analysis of random fluctuations in the flow, in particular temperature. In this case, various types of thermal converters are used as a primary sensor. Their advantage is the small size and the possibility of using in specific conditions, for example, when measuring the flow rate in nuclear reactors with a liquid metal coolant. The advantage of the temperature correlation (TC) method is that it is assumed to be absolute and only needs to be calibrated to convert the average velocity into the flow rate taking into account the velocity profile. However, it is based on Taylor's hypothesis that temperature perturbations are «frozen in» into the flow of a liquid medium at a small but sufficient level of turbulence [1]. Pulsation levels of temperature and velocity should also be within certain limits. This means that the method has some limitations, which are the subject of research. This also means that for the existence of temperature fluctuations in the flow, there must be some source. In [2], a 90-degree bend of the pipeline was used as such a source. However, this is not always acceptable for flowmeters mounted on real cooling circuits. Therefore, it seems promising to use the so-called magnetic obstacle to create temperature perturbations.

If the flow of liquid metal in the investigated cylindrical channel is permeated by a localized DC magnetic field perpendicular to the flow, then this will lead to the generation of an electric current in this localized area. Interaction of this induced current and the external magnetic field generates an electromagnetic force directed against the flow. This leads to a situation that is similar to flowing around a solid obstacle in a channel.

The combined liquid sodium flow measurement system comprising three independent flowmeters has been designed and calibrated. The Reynolds number varies from $5.7 \cdot 10^3$ to $3.4 \cdot 10^4$ for velocities $5 \div 30$ cm/s. Magnetic obstacle has proven to be effective source of temperature pulsations required for the TC method.

The numerical calculations revealed the structure of the flow behind the magnetic obstacle and explained the mechanism of the appearance of temperature and velocity pulsations. They also helped to determine the location of the mixing zone and to draw conclusions about the best location of thermocouples in the experiment.

The correct choice of the temperature sensor's location is of a great importance. Calculations have shown that at high flow rates there are areas in flow where the temperature pulsations lag behind the flow so the Taylor's hypothesis works bad. In order to be able to measure the velocity by the TC method at high flow rates, the thermocouples must be located at a great distance from the magnet or the additional calibration is required.

At the beginning of mixing zone there is a strongly non-uniform distribution of velocities in the vertical section, which leads to the strong oscillations closer to the pipe axis. Large-amplitude velocity fluctuations negatively affect the TC method accuracy.

The velocity values obtained by the TC method in the experiment are in good agreement with the numerical velocity profiles, however, the location of thermocouples was chosen unsuccessfully, since in this region the velocity profile is strongly nonuniform.

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NUMERICAL SIMULATION OF HEAT AND MASS TRANSFER IN A METAL MELT AND DEFORMATIONS IN A DIELECTRIC FILM DURING INDUCTION MELTING

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A metal melt coated with a thin dielectric film in a cylindrical crucible placed in an inhomogeneous alternating magnetic field in a technical vacuum is considered. This field excites Lorentz force and eddy currents in the melt volume, which heat the melt. Thus, the melt convection is caused by two mechanisms, the first one is an electromagnetic mixing and the second is the thermal convection.

The melt motion is described in an axisymmetric formulation, and the contributions of the Lorentz force and thermal convection in the Boussinesq approximation are taken into account in the Navier-Stokes's equation. The heat transfer equation takes into account the Joule heat sources that heat the metal up to 1500°C. On the bottom and walls of the ceramic crucible the boundary conditions were the no-slip for the melt velocity and the thermal insulation for heat transfer, respectively. On the melt surface, where the quasi-solid film is present, there is a radiation heat exchange, the intensity of which is determined by the local emissivity of the surface, which is different for the melt and the film. For the velocity along the film-covered boundary, the no-slip condition is set, and the vertical component of the radial velocity gradient is set on the open surface, taking into account the contribution of the thermocapillary effect on the motion.

The dielectric film is assumed to be thin (in experiments about 0.5 microns) enough to assume that the temperature and mechanical stresses over the film thickness are the same, while it can already be considered as a continuous medium for which Hooke's law is valid. The only mechanism for formation of mechanical stresses in the film and its tension is the viscous force acting from the melt moving under the film. Thus, the equation of state of the film is Hooke's law, written in terms of the displacement in the film, taking into account the volume force, that acts in the film and it is proportional to the viscous stresses in the melt. The following boundary conditions are used to solve the displacement equation: on the symmetry axis and the wall of the crucible, the displacement is zero; if the edge of the film does not touch the wall, then the condition of the balance of elastic and viscous stresses is valid.

The steady flows in the melt under the film during induction melting are considered. Its effect on the elastic stresses and tension of the film are numerically investigated in the range of the magnetic field diffusion parameter $D_H \in [0 \ldots 1000]$. Various geometries of melt surface covering by the film are examined: a full covering, the film is a disk in the center of the crucible and the film is a ring touching the crucible. The dependence of displacements and deformations on the parameter DH and the Hartmann number Ha, both characterizing the frequency and intensity of the magnetic field, respectively, are revealed. The most stable film configurations that are harmful from practical point of view are found. Thus, the technological regimes for $D_H \in [20 \ldots 50]$ are most prone to forming of the film when the two-toroidal flow is gradually transforms into the four-toroidal flow. It makes clear some area at the periphery of the surface in which the flow, directed to the center, supports the film.

In addition, the results of the physical model verification are presented.

MAGNETIC NANOGEL IN SHEAR FLOW

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One of the prominent examples of potentially very useful in medicine smart nanomaterials, are so called magnetic nanogels (MNGs): built out of various polymers with embedded in them magnetic nanoparticles (MNPs). Recently, MNGs were successfully probed in cancer treatment experiments [1].

The key idea of using this substance is the encapsulation of toxic anti-cancer drugs within these gels alongside magnetic nanoparticles. One then could inject the suspension of nanogels into the human body, target the MNGs to the tumor by means of a gradient magnetic field, and then by applying an alternating magnetic field, the gels could be stimulated to release the medication. The important feature of the whole procedure concludes in the fact, that magnetic fields at values of several mT not interfere with any critical bio-processes.

In 2018, a numerical coarse-grained model of the magnetic microgel was developed [2]. This model was later employed to investigate the equilibrium structural properties of single microgel [3], suspension of MNGs in zero-field case [4] and in an applied external constant magnetic field [5], where we have found that the polymer matrix of nanogels enhances the magnetization of free magnetic nanoparticles.

Here, we investigate the effects of hydrodynamics within the Lattice-Boltzmann (LB) scheme [6] on an individual MNG in a shear flow, aiming to simulate the gel in circulatory system. We have discovered, that the shear leads to the oscillatory motion of the nanogel: it tumbles, rotates, wobbles and translates at the same time with a frequency defined by the value of the shear rate.

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THE ELECTROCONVECTIVE FLOWS OF A LOW CONDUCTING LIQUID IN A STEADY AND MODULATED ELECTRIC FIELD

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Nonlinear evolution of the electroconvective flows in a horizontal capacitor filled with low conductive liquid in the presence of autonomous injection from cathode, heating from above and steady or modulated electric field are analyzed. To examine the complex evolution of the system, numerical simulations are carried out using the finite difference method. In addition to hydrodynamic dimensionless parameters, such as the Rayleigh number Ra and the Prandtl number Pr, equation system and boundary conditions for electroconvective flows contain respectively dimensionless electric parameter T, charge injection parameter C and the mobility of injected charges M. The periodic conditions for vertical boundaries are used. The problem is solved without the non-induction approximation [1,2]: The Poisson equation for the electric potential is solved at every moment of time. The calculations are made at a set of parameters that characterize a typical low conducting liquid: $Pr = 10$, $C = -0.224$, $M = 14.14$ and $Ra = -2500$.

It is shown that the traveling wave (TW) is generated at $T = T_{c1} = 6819$. Oscillations with a characteristic frequency ν_0 are observed at a fixed point in the convective cell. With an increase of the electrical parameter (at $T = T_{c2} = 7035$), the traveling waves lose their stability and the modulated traveling wave (MTW) mode is being formed. Further growth of the parameter ($T > T_{c3} = 7062$) leads to the appearance of a stationary overturning convection (SOC), which intensity is ten times higher than in the TW mode. The properties of the regime of stationary electroconvection differ slightly from electroconvection in an isothermal liquid [1]. Similar electroconvection modes were observed in the case where the injection depends on the field at the cathode [2].

The influence of harmonic modulation of electric field with amplitude α and frequency ν on the electroconvection is studied. Stable solutions in the form of modulated traveling waves with modulated amplitude and phase velocity or synchronously modulated patterns are found in this case. The synchronously modulated patterns oscillate around the SOC solution and have zero phase velocity and are abbreviated as MC (modulated convection).

It is shown that the destroying of the MTW solution and the transition to the MC regime occurs when the modulation amplitude exceeds the critical value $\alpha*$ which depends on the electric field frequency. For instance, the critical amplitude $\alpha * (2\nu_0)$ at external frequency $2\nu_0$ are five times less than the amplitudes $\alpha * (\nu_0)$.

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TUNING THE MAGNETOELECTRIC EFFECT IN POLYMER-BASED NANOCOMPOSITES

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Polymer-based nanocomposites (NCs) with magnetoelectric (ME) effect — materials consisting of magnetic/magnetostrictive filler (e.g. magnetic nanoparticles (NPs)) and piezopolymer matrix or polymer-bonded composites of ferroelectric and magnetic particles [1]. They have merge attributes and advantages from both families (multiferroics and magnetorheological materials) and have attracted a lot of attention due to their high potential in various types of applications as magnetic field sensors, energy harvesting and biomedical devices [2–4].The magnitude of the ME effect for these materials could be regulated through strain interactions (elastic coupling) of magnetic filler and piezoelectric particles or matrix [1, 5]. The goal of this project is to keep the relatively high biocompatibility of composites based on a piezoelectric polymeric matrix, to decrease the amount of inorganic inclusions and to achieve a high value of ME effect at the same time.

In this work the NCs based on two types of polymers, poly(vinylidene fluoride) (PVDF) and its copolymers with trifluoroethylene (PVDF-TrFE) have been prepared. NCs based on PVDF-TrFE demonstrated a higher magnetoelectric performance and thus were chosen for further experiments. The highly crystalline CoFe2O4 NPs were prepared via a sol-gel auto-combustion method and they were used for the preparation of rheological magnetoelectric materials. The structural characterization of NCs was made via XRD and TEM techniques. The magnetic properties were studied using vibrating sample magnetometer (VSM), the FORC (First Order Reversal Curve) – analysis via VSM have been used to trace the magnetic interactions inside the composite. The ME studies were carried out using a custom-designed setup for measuring the magnetoelectric voltage ΔV with a lock-in amplifier. Magnetic and piezoresponse force microscopy have been used for deeper understanding of local properties of individual parts of cNCs. Further, new strategies of increasing magnetoelectric response were used. The strategies were involved in following steps: i) application of magnetic field during crystallization of polymer to align clusters of magnetic NPs and ii) creation of 3-component composite with ferroe-lectric BaTiO3 particles. Developed strategies allowed us to increase the αME value from $\sim$ 5 mV/cm·Oe for the composite of randomly distributed CoFe2O4 nanoparticles in PVDF matrix to $\sim$ 18.5 mV/cm·Oe for a composite of magnetic particles in PVDF-TrFE matrix with 5%wt of piezoelectric particles. The applicability of such materials as bioactive surface have been demonstrated on neural crest stem cell cultures.

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DEVELOPMENT OF ELECTROMAGNETIC PUMP FOR THE SECOND LOOP OF THE MBIR REACTOR

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Development results of an electromagnetic pump (EMP) on liquid sodium for the second loop of the MBIR reactor are presented.

Main EMP parameters: pressure head 0.5 MPa, nominal flow rate 1268 m^3/hr, sodium temperature 298°C. Required EMP service life time is 341 640 hours during 50 years.

Annular linear induction pump (ALIP) was chosen as the optimum variant. The pump identification — ALIP 5/1300, where the numerator is pressure head in bars and the denominator is flow rate in m^3/hr. To ensure the EMP service life time it was equipped with forced air cooling system. A non-standard frequency 31 Hz was chosen to improve the pump efficiency. Special system of power supply, data acquisition and control is under design to provide electrical supply including regime with loss of external power.

The technical design of the pump has been developed with electromagnetic, thermal, strength and reliability calculations as well as working design documentation for manufacturing.

New high-temperature winding wire is being developed to provide the required service life time of the pump. The wire uses a bimetallic core and fiberglass insulation made of quartz fibers.

ELECTROMAGNETIC FORCES ACTING IN A REPRESENTATIVE VOLUME OF LIQUID METAL WITH INCLUSIONS OF VARIOUS SHAPES

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The use of methods of electromagnetic separation allows you to clean the metal from impurities, thereby increasing its operational characteristics. Electromagnetic separation has a number of unique advantages: the ability to organize the simultaneous evacuation of impurities and flow mode, as well as high efficiency for small particles. These requirements are key to today's industry.

The work is devoted to the numerical study of the features of the effect of electromagnetic forces on inclusions in an electrically conductive medium [1, 2]. In this work, a mathematical model of the effect of electromagnetic forces on a representative volume of particles (inclusions) in a liquid metal (in the general case, in an electrically conductive medium) is constructed.

The magnitude of the electromagnetic force acting on a particle depends on the orientation of the particle and on its shape. In this regard, various distributions of particles by orientation angles in space are considered. The distribution of particles over the orientation angles is found, which provides the highest (and lowest) average electromagnetic force acting on the particles.

In addition, the influence of the particle size distribution on the average electromagnetic force is analyzed. It was found that the effect of the electromagnetic force on the elongated particles is the greatest. Thus, the maximum average electromagnetic force is provided by the distributions with the largest number of elongated particles.

Calculations with different concentrations of impurity particles (inclusions) in the volume of liquid metal have been carried out. The representative volume of metal with impurity particles (inclusions), sufficient for statistical averaging of the properties of the system, has been determined. In addition, calculations were performed with real values of the concentration of impurities (inclusions).

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IMPACT THE INHOMOGENEITY OF ELECTRIC CONDUCTIVITY ON MHD PROCESSES

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Magnetohydrodynamic processes are significant for many industries, such as metallurgy and nuclear power. As the metal flows through the channel, the crystallization process can begin. The electrical conductivity of the liquid phase and the solid phase can differ several times. The appearance of inhomogeneity of electrical conductivity can lead to a change in the flow regime. Thus, the estimation of the impact the inhomogeneities becomes an important task.

In this work, we propose the mathematical model of biphasic media within a continual approach. The first phase is an incompressible liquid metal. The second phase is solid particles, which have the electric conductivity that differs from the electric conductivity of the first phase. We suppose that the particles have a spherical form, and they are don't interact with each other. We don't consider the processes of phase transformations, creation, crushing, and coagulation of particles. The effective electric conductivity of the media depends on the temperature and the concentration of the particles.

To estimate the forces acting on the conductive media, we propose a simplification. We suppose that there is an effective electromagnetic force that acts on the biphasic media representative volume. This force has the same direction as the force acting on a medium without the inclusions. The magnitude of the effective force depends on the relation between the electric conductivities of phases.

The mathematical simulations of biphasic medium MHD flow were carried out. We've considered the impact of the inducer setup type that produces the electromagnetic force. The results of simulations were compared with the results obtained with more complex models [1].

The reported study was funded by RFBR and Perm Territory, project number 20-48-596015.

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STABILITY OF MHD FLOW IN A 90-DEGREE BEND

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Authors consider stability of a flow of viscous electrically conducting liquid in a bent channel in the presence of the vertical magnetic field. The problem statement and the basic patterns of the main steady-state two-dimensional flow are described in [1,2]. The system of magnetic hydrodynamics equations in the approach of small magnetic Reynolds numbers is considered using the electric potential notation. The stability of the flow is investigated by the linear method. For this purpose, the spectral-element method and a computer program described in [3] are used. The stability of two-dimensional and three-dimensional perturbations is studied, and the critical Reynolds numbers for three-dimensional perturbations are calculated.

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ON THE ISOTROPIC-NEMATIC LIQUID CRYSTAL PHASE TRANSITIONS IN A SOLUTION OF POLYDISPERSE MAGNETIC DISKS

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Based on Onsager's model of isotropic-nematic phase transitions [1] the system of hard disks with arbitrary polydispersity in diameter is investigated. It is considered that colloidal disks carry magnetic moments directed perpendicularly to their plane. Along with the excluded volume effects the influence of an external magnetic field on the orientational order of the statistical ensemble of polydisperse single-domain particles are taken into account.

To obtain an orientational distribution function (ODF) of the particles the excluded volumes are represented as a series expansion in terms of spherical harmonics. Most often this series truncate after the first term (the so-called L2 model [2]), which is only reliable for very weakly aligned nematic phases. In the present approach the ODF was obtained for an arbitrary number of harmonics, which makes it possible to carry out calculations for highly ordered nematic phases. The proposed model avoids using trial ODFs with a predescribed form as was used by Onsager in the original approach [1]. The trial ODF may be accommodated by several (or only one) variational parameters (see, for example [3]), which allows one to keep a model analytically tractable but the success of this method largely depends on the chosen form of ODF.

As was pointed out by Onsager, the second virial term in the free energy is not enough for correct describing of disklike particles orientational order. Since even for infinitely thin disks there is a nonzero probability of particles intersection, so that the finite excluded volume exists. Therefore, there is a serious trouble how to take into account the effect of many-body interactions. There is an approach which allows one to indirectly include higher virial terms into the free energy using the Carnahan-Starling excess free energy for hard spheres. In the framework of this approach, known as Parsons' theory [4], it is sufficient to consider only two particles interactions which ultimately leads to a renormalization of the second virial term of the free energy. The Onsager-Parsons' theory agreed very well with the simulation results for both short hard spherocylinders and prolate ellipsoids [5, 6]. Thus, a generalization of the Onsager-Parsons' theory to the case of a suspension of polydisperse hard disks is proposed.

Finally, the considered model can be used not only to study the orientational order and isotropic-nematic phase transitions in a solution of polydisperse disks with an arbitrary continuous distribution over diameters, but it also allows one to describe orientational order of the polydisperse magnetic disks induced by an external magnetic field [7].

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EFFECTIVE FIELD METHOD IN THE PHYSICS OF FERROMAGNETIC LIQUID CRYSTAL SUSPENSIONS

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The mean field-theory belongs to the exactly solvable models, but it is rather complicated, since this approach requires the numerical solution of a system of nonlinear integral self-consistency equations. In this work, the corresponding Landau potential is constructed based on the recently proposed molecular-field theory for ferromagnetic liquid crystal suspensions [1], which allows one to obtain analytical expressions for the suspension order parameters as a function of temperature. The so-called effective field method [2] is used to obtain the Landau expansion coefficients in terms of molecular-field constants and material parameters of the suspension. A comparison of the resulting expansion with the phenomenological Landau theories proposed for liquid crystal suspensions of carbon nanotubes, ferromagnetic and ferroelectric particles is introduced.

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COMPOSITIONAL CONVECTION IN LIQUID METAL ELECTRODES

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Liquid metal electrodes are a crucial element of innovative electrochemical cells such as liquid metal batteries (LMBs) and solutal - alkali metal thermal electric converters (S-AMTECs). The liquid phase is a key to guarantee scalability, extended life time and high cyclability; at the same time fluid mechanics plays a pivotal role in terms of cell capacity and efficiency [1]. The geometry of these electrodes is simple: a liquid metal alloy is confined by an electrochemically active interface and inert walls. The active interface can be fluid (molten salt electrolyte) or solid (fast ionic conductor). During operation of the cell a mass flux is established across the interface. The liquid metal alloy experiences an enrichment or depletion of the electroactive species. This changes the local density distribution and either induces or suppresses convective flows [2–4]. Here, we focus on the positive electrode of a liquid metal battery during the charging step. The electroactive species (e.g. Li) is extracted from the alloy (e.g. Li(in Bi)), and the heavy alloy generated at the top interface sinks down leading to strong compositional convection. The evolution of the concentration and velocity fields are studied with numerical methods; the results of a finite volume code (OpenFOAM) are compared with the ones of a spectral element code (SEMTEX). The effects of Schmidt number, current density magnitude and distribution and electrode geometry are investigated. Furthermore, the impact of a non-uniform temperature distribution and the mechanical coupling with a molten salt layer are discussed.

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NESTING MAGNETIC ACTIVITY ON THE FAST ROTATING SOLAR ANALOGS

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Mean-field dynamo models of the fast rotating solar analogs, [2], show the increasing complexity of the large-scale magnetic field distribution with the increase of the stellar rotation rate. In particular, for the stellar rotation period of fewer than 10 days, the dynamo model predicts the highly overlapping latitudinal distributions of the large-scale toroidal magnetic field. Also, the model shows the increased concentration of the toroidal magnetic field belts toward the surface. Following Parker, [1], we assume that the large-scale toroidal field can be the main source of the spot activity in the solar-type stars. Using the 3d mean-field dynamo model, which was suggested recently in [3], we show that the strong overlap between the subsequent magnetic cycles in the fast rotating solar analogs can result in the formation of the quadrupole active regions with the typical amplitude of the magnetic flux around 10^{24} Mx. Such regions provide the natural source for the nesting the spots activity on the fast rotating and magnetically active stars. The results of the model show the increased role of the surface magnetic activity for the whole dynamo process in the fast rotating solar analogs in comparison to the dynamo on the present Sun.

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RELAXATION SPECTRUM OF A SUPERPARAMAGNETIC NANOPARTICLE, SUSPENDED IN A LIQUID: THE EFFECT OF AN APPLIED FIELD

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Magnetic nanoparticles have great prospects for use in medicine. Far from complete list of their possible applications includes target drug delivery, immunoassay, magneto-induction hyperthermia, magnetic resonance imaging and magnetic particle imaging [1]. Evidently, an effective implementation of these techniques is hardly possible without a detailed understanding of magnetic response of nanoparticles. In the last two decades a theory of remagnetization of ensembles of nanosized ferromagnets, dispersed in various (solid, liquid and viscoelastic) media has been significantly extended and improved. However, some important problems still do not have an exhaustive solution. One of them is an accurate description of combined rotational diffusion of the «skeleton» of a superparamagnetic particle and its magnetic moment.

The two unit vectors form the configuration space of such a particle. The first one $\mathbf{e}$ is directed along the particle's magnetic moment (the magnitude of the magnetization is assumed to be constant) and the second $\mathbf{n}$ — along its anisotropy axis. Both of these vectors undergo orientation thermal fluctuations and due to that, magnetic state of the particle should be described by a joint distribution function $W(t, \mathbf{e}, \mathbf{n})$. Time evolution of this function obeys a kinetic continuity-type equation, first derived in [2]. Recently, in the paper [3] a consistent approach to solve the equation was proposed. The method presented there involves the introduction of a kinetic operator that generates the time evolution of the distribution function, and the usage of a quantum–mechanical formalism. In particular, in [3] a representation is specified in which the evolution equation transforms to a set of linear recurrence–differential relations for statistical moments of the distribution function.

In this work, such a methodology is used to describe features of the relaxation spectrum of a superparamagnetic particle, taking into account its mechanical and magnetic degrees of freedom. The study provides a foundation for understanding both linear and non-linear response of the particle to an applied field. The problem reduces to calculation of eigenvalues of the specified kinetic operator. The latter has two contributions: the first one (Brownian) corresponds to rotations of the «skeleton» of the particle, and the second (Neel) – to rotations of the magnetic moment inside it. In accordance with that, it is convenient to use the representation, where the basis is formed by the so-called bipolar harmonics, which are irreducible tensor product of two spherical harmonics of different arguments [4]. In this representation matrix of the kinetic operator is close to diagonal, and its eigenvalues can be calculated by one of the standard methods. Numerical calculations show that at weak applied field (parameter ξ equal to the ratio of Zeeman energy of the particle to thermal energy is much less than one) the only relaxation mode dominates. The corresponding relaxation rate can be calculated just as a sum of inverse Brownian and Neel reference times. An increase of the applied field results in enhancement of weights of the other modes, and at the values of $\xi \sim 1$ or greater the relaxation process is essentially multi-mode. At the same time, relaxation times, as expected, go down with the field growth. By usage of perturbation theory expressions for relaxation rates of weakly anisotropic particles are obtained and crosschecked with numerical results. Also, the scope of applicability of the so-called hard-dipole approximation, which neglects rotations of the magnetic moment inside the particle, is discussed.

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SELF-ASSEMBLY SUPRAMOLECULAR MAGNETIC POLYMERS WITH DIFFERENT MONOMERS

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Currently, much attention is paid to the physics of soft materials and nanomaterials. This paper is devoted to studying the effect of polydispersity and particle's shape on the self-assembly of supramolecular magnetic polymers (magnetic filaments). Such magnetic filaments are widely used to create new magnetically controlled materials [1] and represent an analogue of polymer chains, where polymer molecules serve as crosslinks, and magnetic particles replace monomers.

We propose to consider the bidisperse model, which takes into account only two fractions of particles in size, which is enough to track the main influence of polydispersity on the self-organization of a magnetic polymer. Also we investigate magnetic filaments with monomers for different shape: from almost spherical to the elongated one. Using the method of computer simulation of Langevin's dynamics, we study various structural parameters of an individual magnetic polymer of various configurations: a chain, a closed ring, an X-shaped and Y-shaped magnetic filament. Such types of polymer are the main states of the systems of magnetic particles, as was previously shown in [2, 3].

In this paper, an analysis of the qualitative change in equilibrium properties with temperature, at different lengths of the polymer and the parameters of the dipole-dipole interaction was carried out. As comparative characteristics were used: the radius of gyration, magnetic moment, form factor and anisotropy of the shape of the polymer. It turned out that the considered new types of polymer configuration compared with the monodisperse model significantly affect the equilibrium properties. Therefore, it can be concluded that it is necessary to take into account polydispersity in the synthesis and analysis of the behavior of magnetic filaments.

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ELECTROMAGNETIC FLOWMETER FOR LIQUID METALS: CALCULATION, DESIGN AND CALIBRATION

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The paper describes the features of development and calibration of the conduction electromagnetic flowmeter for liquid metals. When liquid metal flows through a region with a localized magnetic field, the Garthman's profile of mean flow is significantly complicated at high velocities and an inhomogeneous field [1]. The magnetic field also affects the spectral characteristics of turbulent velocity pulsations. And vice-versa, the induction currents generated in a high-speed electrically conductive medium produce a secondary magnetic field, observed as the transfer of the primary field.

The electromagnetic force resulting from the influence of magnetic field on a moving conductive medium depends on flow intensity and size of magnetic field action area. The channel geometry and the characteristics of magnetic field should provide sufficient accuracy of measuring the volume flow rate. The definition of these parameters in particular is the goal of this work.

A numerical study of the process was carried out: the effect of a localized magnetic field of different magnitudes on the flow of liquid metal was studied, and the distribution of the magnetic field was obtained at different flow rates. This made it possible to optimize the construction of an inductor generating magnetic field by reducing its mass and ensuring sufficient measurement accuracy.

The flowmeter calibration is carried out by volumetric-time method on ICMM UB RAS sodium facility [2]. Liquid metal flow through the channel of the flowmeter is provided by pressure difference between two tanks. One of the tanks is filled with sodium and overpressured by argon, the other one is empty and vacuumed. Each tank has a system of contact level gauges, whose signals are recorded by a high-speed data acquisition system and used to determine the reference flowrate value. Calibration experiments were performed at different reference values of flowrate and temperatures and showed high accuracy of measurements with low sensitivity to external electromagnetic noise.

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THE JOINT COOLING MODEL OF THE CORE AND MANTLE

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After accretion, formation of the iron liquid core and silicate melted mantle about 4.5 billions years ago, two main process controlled the Earth's thermal history: the heat flux into the outer space QS and the radioactive heating in the core and mantle. It is supposed that originally temperature in the Earth's center was of order 6000-7000K. Cooling of the core resulted in emergence of the inner core and probably the stagnation zone near the core-mantle boundary (CMB), where the thermal stratification took place. The last decades revealed prominent progress in the core evolution models, which under some assumptions on the heat flux at CMB QCMB provide the present size of the inner core. From the point of view of the whole energy budget of the Earth modern QCMB is quite small being about one third of QS=44TW now. However for the core's dynamic it is one of the most crucial parameters. Usually in the models QCMB is prescribed to decrease slightly, say of order 20% from the end of accretion by now. Such kind of models provide quite young inner core about 1-2 billions years old.

It can happen, that the assumption of the more or less constant in time QCMB can be wrong, because QS, in its turn, decreased several times. This change was caused by the different mechanisms, including appearance of the proto oceans, atmosphere, as well as by the exponential dependence of the mantle viscosity on the temperature. The decrease of the temperature in the mantle results in increase of viscosity, and as a result in suppression of convection and cooling of the mantle. If we accept that QCMB repeats behavior of QS, than large values of QCMB should be tested in the models as well. We check this possibility using joint model of the cooling of the core and mantle. The core's model is similar to that one in [1], where QCMB is prescribed and controls cooling of the core. The one-layer model of the mantle's cooling is based on that one, described in [2]. Combination of these models with the condition of continuity of QCMB gives the self-consistent solution for the whole core-mantle system. Note that the strong heat fluxes in the early archaea would lead to an increase in the inner core's age, which is confirmed by the paleomagnetic observations. We report various scenarios of the Earth evolution and consider applications to the geodynamo and magnetic field evolution.

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PHASE BEHAVIOR OF CHARGED MAGNETIC NANOPLATELETS

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In recent decades, advances in synthesis techniques have opened up a new subfield in the study of magnetic soft matter: the study of anisotropic and anisometric magnetic colloidal suspensions. The persistent interest in investigating and refining anisotropic colloidal systems comes from the knowledge that colloidal anisometry can be used as an effective control parameter to tune both self-assembly scenarios and thermodynamic, rheological and phase behavior of dipolar (magnetic) soft matter[1]. For instance, a suspension of discotic mesogens with a dipole moment perpendicular to the long axis of the particle can form a macroscopic ferromagnetic nematic phase at room temperature[2].

While the phase behavior of hard platelets is already well-known, the influence of the added dipole moments on the isotropic to nematic phase transition is not yet fully understood. This contribution will focus on the computational work to characterise the phase behavior of such systems, recreating them through Molecular Dynamics simulations in different approximations (raspberry and Gay-Berne), then studying the influence of parameters such as the dipole moment or aspect ratio on the phase transition, as well as analysing the structural properties of the system in different phases.

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THE INFLUENCE OF ION-NEUTRAL COLLISIONS ON THE AMPLIFICATION OF THERMALLY UNSTABLE MAGNETOACOUSTIC WAVES

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Recently, there have been numerous studies of the features of the propagation of MHD waves in partially ionized plasma. It was suggested to use a two-fluid model consisting of ion-electronic and neutral components [1, 2] to properly describe the dynamics of high-frequency perturbations taking into account the effects associated with ion-neutral collisions. It can be important for describing waves in such astrophysical media as the chromosphere, photosphere of the Sun, prominences, and the photodissociation regions (PDRs) of the interstellar medium. However, these studies did not take the effect of thermal misbalance into account. It can lead to the appearance of wave dispersion [3, 4], as well as their additional damping or amplification (thermal instability) [5]. In the current work, we consider the dispersion properties of magnetoacoustic (MA) waves, taking into account the effects associated both with thermal misbalance and ion-neutral collisions. A dispersion relation for MHD modes was obtained using a two-fluid model, which was subsequently reduced in the approximation of a constant degree of ionization to the dispersion relation for MHD modes in a one-fluid model, which lowers the order of the equation and simplifies its analysis.

It is shown that ion-neutral collisions lead to attenuation of MA waves at high frequencies even under thermal instability. The characteristic frequency at which the waves are attenuated is proportional to the degree of ionization. When it is compared with the characteristic frequency of the heat release, which occurs in a weakly ionized plasma, the effects associated with ion-neutral collisions are most pronounced. The amplification of the fast MA waves becomes possible only in weak magnetic fields (the Alfvén speed is less than the speed of sound). Slow MS waves are amplified in strong magnetic fields (the Alfvén speed is greater than the speed of sound) with a restriction on the angle with respect to the external magnetic field vector. With a further decrease in the degree of ionization, a transition to hydrodynamics is observed: one of the magnetoacoustic modes completely decays, while the other decays only at the low frequencies and amplifies at frequencies associated with the heat release.

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NUMERICAL SIMULATION OF TIDAL SYNCHRONIZATION OF THE LARGE-SCALE CIRCULATION IN RAYLEIGH-BÉNARD CONVECTION WITH ASPECT RATIO 1

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The coincidence between the apparently phase-stable 11.07-year solar cycle and the alignment cycle of the tidally dominant planets Venus, Earth and Jupiter was the subject of some recent papers [1–3]. The resonant excitation of intrinsic helicity oscillation of the kink-type (m=1) Tayler instability (TI) by tide-like (m=2) forces was discussed as a possible linking mechanism. In order to elucidate this type of interaction, we study a related process for the case of Large Scale Circulation (LSC) of thermally driven Rayleigh-Benard Convection (RBC). The sloshing and torsional oscillations [4] of the m=1 mode of the LSC are connected with helicity oscillations just as the TI [5]. We consider a RBC in a cylindrical container filled with the low Prandtl number eutectic liquid metal GaInSn. The container with radius R=0.09 m and aspect ratio of $\Gamma = 1$ is equipped with two thermally controlled Copper-plates at the bottom and top. The tide-like forces are imposed to the fluid by an electromagnetic field that is generated by two coils situated on opposite sides of the container.

The flow in the cell is computed by solving the incompressible Navier-Stokes equation and the continuity equation

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\nabla\frac{p}{\rho} + \nu\nabla^2\mathbf{u} + M(t)\mathbf{F}_{em}, \quad \nabla\mathbf{u} = 0$$

in the open source library of OpenFOAM 6. The Lorentz force $\mathbf{F}_{em} = \mathbf{j} \times \mathbf{B}$ was pre-computed by solving the Maxwell equations in Opera 1.7. This body force is amplitude-modulated by the factor $M(t) = sin(t \cdot f_{LSC} \cdot \pi)^2$, wherein the dominant frequency of the LSC f_{LSC} fis usually chosen to meet the resonance point for the interaction of the LSC and the tidal forcing.

In a preliminary step, however, the body force $\mathbf{F}_{em}$ was applied with a constant factor $M(t) = 1$ to an $\mathbf{u} = 0$ base state, without considering the RBC. Depending on the strength of the introduced body force, a quasi-steady state with a flow velocity of a few mm/s was generated [6]. A clearly dominant m=2 mode was then observed in the flow. When the amplitude of the body force was modulated by the sinusoidal factor M(t), the modulation frequency f_{LSC} can be seen in the Fourier analysis of the m=2 component of the flow field. By adding the RBC to the numerical simulation, a resonant excitation of the dominant frequency f_{LSC} is expected.

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NUMERICAL MHD MODELING OF HOT JUPITER TRANSIT ABSORPTIONS IN THE METASTABLE HELIUM LINE

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It is known that the atmosphere of many hot planets consists mainly of hydrogen. However, the *Ly*-α line, most popular in transit spectroscopy, undergoes absorption by the interstellar medium and is also distorted due to the effect of geocoronal emission. The line of metastable helium $\lambda = 10830$ A does not undergo significant distortions and absorptions, and therefore can be used to obtain the most complete information about exoplanetary systems.

In this work, we investigated the influence of the concentration and speed of the stellar wind, the radiation flux of the star in the ultraviolet and soft X-ray regions, as well as the abundance of metastable helium in exoplanetary atmosphere (He / H) on the absorption in the spectral lines of metastable helium and *Ly*-α. For this, the MHD 3D code was used taking into account the processes of photoionization, recombination and plasma photochemistry of hydrogen and helium components, the results of which are transit and spectral absorption curves of planets like «hot Jupiters» at various parameters of the model system.

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CONTINUOUS COMPONENT OF SOLAR AND STELLAR ACTIVITY SPECTRA IN LIGHT OF DYNAMO THEORY

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The main feature of temporal evolution of solar activity is presented by well-known 11-year activity cycle which is believed to be associated with an eigen-solution of mean-field dynamo equation. Recent results wavelet analyses of solar and stellar activity data demonstrate however that solar activity spectrum as well as stellar activity spectra contains apart from a spectral line which corresponds to this eigen-oscillation a continuous spectrum. It is far to be clear in advance how this continuous spectrum can be included in the framework of dynamo theory. We discuss various possibilities under discussion.

THE SIMPLEST LINEAR SOLAR DYNAMO AND NON-LINEAR GEODYNAMO

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The simplest hydromagnetic dynamo models are followed here from the components of the vector product of the fluid velocity on the magnetic field. The parallel to an electric current component produces such non-linearity that is not the conventional cubic or its similar nonlinearity, but the nonlinearity inversely proportional to the local/averaged current or magnetic field. The corresponding averaged geodynamo model consists of only one non-linear ordinary differential equation.

A solar-like dynamo consists of two simplest linear ordinary equations, which in a somewhat new way describe the global alpha effect and the effect of differential rotation – almost traditionally. The obtained simple models could successfully both reproduce and clarify the physical nature of the main manifestations of the planetary/stellar dynamos and could be useful potentially up to the nature clarifying of the super-jerks/super-flares in their actually singular non-linear parts found here.

EXPLORATORY STATISTICAL ANALYSIS OF WOLF NUMBERS, THEIR TIME DERIVATIVES AND VARIATION TIMES OF THE SOLAR ACTIVITY

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We propose an exploratory statistical study of the annual Wolf numbers W, their time derivatives W' and the variation times $T = W/W'$.

A significant deviation of the probability distribution W from the normal one is characterized by the most probable value of W equals to only 18 with a root mean square value $RMS = 100$, a median $MDN = 65$ and an arithmetical mean $M = 79$. The maximum values of W could be unreliable.

Time derivatives W' is characterized by the most probable value equals to -12/year, $MDN = -6.1$/year, $M = -0.02$/year, $RMS = 33$/year, maximum $MAX = 112$/year, minimum $MIN = -74$/year and deviate from the normal distribution less significantly. The ratios of the mean values of W and W' are consistent with the characteristic times of rise/fall of the activity of about 2.5/3 years and with 11-year Solar cycle.

A large bimodal deviation of T from the normal distribution is noted. The most probable value is $T = -1.6$ years, and the median and mean values are -1.3 and -1.8. To estimate the half-period of variations, the times T should be razed in a several times. The root-mean-square $T = 15$ years is large due to «heavy tails» with a reliable maximum of 35 and an insufficiently reliable minimum of -150 years.

Dynamo estimations give a dynamo-generating radial velocity of ~ 1 m/s and several times lower alpha effect, which indicates rather deeply situated sources of the observed sunspots.

POSSIBLE SYNCHRONIZATION MECHANISMS FOR SHORT- AND LONG-TERM CYCLES OF THE SOLAR DYNAMO

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A synoptic analysis of algae-growth data from the early holocene and of direct observations and cosmogenic isotope data from the last millennium points to a surprisingly phase-stable Schwabe cycle of the solar dynamo [1]. With estimations of 11.04 and 11.07 years for the two respective time intervals, this cycle fits amazingly well to the 11.07-year cycle of the spring tides due to the tidally dominant planets Venus, Earth and Jupiter.

Due to their weakness, tidal forces have only a chance to influence the solar dynamo when acting on rather quite zones of the sun, such as the radiation zone or the tachocline. One of the promising synchronization mechanisms relies on the tidal (m=2) excitation of those helicity oscillations that are connected with the kink-type (m=1) Tayler instability in the tachocline [2,3]. The resulting oscillations of the helical turbulence parameter α might be capable of impressing an average 22.14-year Hale cyclicity on the underlying conventional α-Ω dynamo if its «natural» period is not too far from that value [4]. A similar mechanism based on tidal effects on magneto-Rossby waves is also conceivable.

In addition of being exposed to tidal forces, the Sun also undergoes a rosetta-like orbital motion around the barycenter of the planetary system. While also influenced by the outer planets, this motion is dominated by the 19.86-year synodic cycle of Jupiter and Saturn [5]. With all details yet unexplored, we expect a spin-orbit coupling to transfer orbital angular momentum into some internal motion, thereby influencing the pressure field and the field storage capacity of the tachocline. A corresponding dynamo model leads then to a 193-year beat period (between the 22.14-year Hale cycle and the 19.86-year synodic cycle of Jupiter and Saturn) which manifests itself in periodic changes of the North-South asymmetry of the solar magnetic field. This 193-year period is suspiciously close to the usual Suess-de Vries cycle. For stronger forcing, also Gleissberg-type cycles appear as overtones of the Suess-de Vries cycle.

On millennial time scales, our dynamo model exhibits transitions between regular intervals and more irregular intervals during which the usual dipole field is partly replaced by quadrupole or hemispherical fields. While those transitions between regular and irregular intervals are of chaotic nature, they seem to require a certain critical value of the North-South asymmetry [6].

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HEAT TRANSFER IN CASE OF MIXED BOUNDARY CONDITIONS

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Turbulent thermal convection was numerically investigated in a cubic cavity under homogeneous and inhomogeneous heating for Rayleigh number from $Ra = 10^7$ to $Ra = 2.0 \cdot 10^9$ and Prandtl number $Pr = 6.46$. Inhomogeneous heating was created only at the lower boundary using mixed boundary conditions. Three configurations of the heated regions distribution of the same heating area were considered. The total heat flux through the lower boundary substantially depends on the distribution of the heated regions and increases with decreasing of the heaters size, which is in a good agreement with [1,2]. We also proposed physical mechanism which provides increasing of heat flux with spatial frequency of conducting-adiabatic pattern, alternative to the one described in [2]. We have shown that the temperature boundary layer in case of mixed boundary conditions at the bottom is strongly non-uniform. This non-homogeneity is a result of several factors such as conducting-adiabatic pattern, large-scale circulation and small-scale motions over conducting plates. The thickness of the thermal boundary layer strongly depends on the size of the conducting plates and can be substantially smaller than for a classical Rayleigh-Benard convection. This effect increases the heat flux with decreasing the size of hot plates, which corresponds to the increasing of spatial frequency of conducting-adiabatic pattern. Details of our results are presented in [3,4].

The financial support of grant RFBR 19-41-590004 is gratefully acknowledged. The simulations have been done using the Triton supercomputer of the ICMM UB RAS, Perm, Russia.

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COMPARISON OF Q2D AND 3D MODELS OF MHD DUCT FLOW INSTABILITY

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Magnetohydrodynamic (MHD) phenomena can be found in various industrial applications and laboratory researches, for example, metallurgical casting, stirring, pumping, in a number of cases it is controlling metal feed, nuclear power engineering, thermonuclear syntheses (TOKOMAK) and etc. One of the most important phenomenon in magnetohydrodynamic is instability flow at difference modes and state. Existing of the phenomenon can result in as improving a technological process, for example, in a number of cases of solidification as getting worse, for example, in MHD pumps. Understanding of instability flow phenomena under magnetic field will support to solve such problems as design of induction pump developing pressure exceeds 8 bar at flow rate above 3 m^3/s [1].

In the paper duct flow affected by idealized traveling magnetic field is considered using numerical simulation implemented by open source codes (OpenFOAM, Elmer and EOFLibrary coupler). Two models is calculated for various flow modes and dimensionless numbers, generally hydrodynamic Reynolds, magnetic Reynolds, Hartman, Stuart numbers and their modifications according behavior of flow. These models have classical formulation of Hartman problem, but ones are considered in traveling magnetic field instead permanent magnetic field as in classical formulation. Also one of these models is taken into account slip of side walls (Shercllif's wall) and other one is not considered slip of flow on these walls and used periodic boundary condition. This way of comparison may numerically show order of influence of wall-bounded shear instability mechanism for each walls (Hartman and Schercllif walls).

The motivation of the study consist of existing different approaches to scaling of magnetohydrodynamic phenomena at present. Conventionally, Reynolds number is calculated by hydraulic diameter instead characteristic for internal flow [2]. Also there are number of works [3–4], where authors suggest to take distance between Hartman walls for characteristic length, then in the case they do not consider influence of bounded layers shear for side walls. It is well known, that gradient of shear stress into normal direction of the wall result can be taken as evaluating parameter of appearing instability, and the most high value of the gradient is in the domains close to the walls. Therefore authors [5] suggest using thickness of Hartman layers instead hydraulic diameter to calculate dimensionless numbers for duct, pipe and channel flows. In this case the gradient of shear stress is lack for side walls.

The comparison of quasi two dimensional (Q2D), when the Scherclif's walls being simulated as the periodic condition, and full three dimensional models (3D), when all walls being simulated by slip boundary conditions, can show the need to introduce characteristic parameter accounted distance between Schercliff's walls as well. Also the study suggest the modernized parameter to analyze duct flow instability, which include evaluation of high value of the shear stress gradient fro all walls.

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NATURAL CONVECTIVE IN MHD DUCT FLOW

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The phenomenon of a magnetic field imposed on a flow of an electrically conducting fluid resulting in occuring forces is used to pumping liquid metal in metallurgical and nuclear energy industries. Temperature of pumping metal, for example magnesium, aluminum or titanium is limited by temperatures of solidification and appearing thermal effects and dramatically increasing aggressive behavior of liquid metal with wall of pipe. Authors [1] show calculation of induction pumps for pumping magnesium, where the purpose of those calculations was to design a pump such that the temperature of its separate elements during operation did not exceed an ultimate thermal resistance of the material used for constructing the pump elements. Similar study was provided in [2], where the problem of overheating have been solved by special flat coils. In [3] authors show possibility of improving induction pumps by core-free design due-to high values of currents without saturation, but physical explanation of expected phenomenon was not given. Part of answers can find in work [4], that high values of the magnetic permeability of the steel of the inductor, its dendritic fragmentation and the concentration of conducting impurities lead to deformation of the magnetic field lines and a change in the type of magnetic wave, and in some cases to a change in the nature of the flow. Aggressive and high temperature environmental can influence on above mentioned parameters. Influence of thermogravitational convection in such system was shown in [5].

In the present study a attempt is being done to resolve duality of Joule power, on one hand it is lead to reducing kinetic energy of flow and stable mode, but other hand it is result in heating up liquid metal and increasing of role of natural convection. The mechanism of duct flow instability and appearing balckflow are bounded-wall shear stress. The gradient has the same direction as natural convection (spanwisie), because gradient of temperature along motion of metal (streamwise) can be neglected, as consequently natural convection. In this way, natural convection will lead to instability state of system. The study is provided by numerical simulation using verificated codes. The general purpose is to consider influence of natural convection on behavior of flow at point of view of instability and evaluate its action on working conditions of a number of metallurgical pups. The general formulation of this task was chosen because of possibility to scale easily the results for other cases.

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JOINT INFLUENCE OF MAGNETIC FIELD AND NORMAL VIBRATIONS ON THE INSTABILITY OF TWO-LAYER SYSTEM, CONTAINING MAGNETIC AND NON-MAGNETIC FLUIDS

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The joint influence of normal magnetic field and normal vibrations on the instability of the system of two horizontal fluid layers has been investigated. One layer contains magnetic fluid, other contains non-magnetic fluid. Both fluids are dielectric. These two layers are bounded by rigid horizontal walls. Problems was studied in the approximation of small viscosity. The instability of the basic state was studied. For this purpose the multiscale method was used. For describing boundary layer «fast» coordinate was introduced.

Two types of instability were studied. First the influence of vibrations on the critical value of magnetic induction at which the instability is observed. It was found that normal vibrations increase the critical value of magnetic induction at which instability appears, excluding longwave mode (wave number tends to zero), which exist for sufficiently thin layers.

Secondly, the influence of magnetic field on the parametric instability (resonant modes) was studied. It was shown that for sufficiently small values of vibration frequency for sufficiently thick layers (when longwave mode is less dangerous than shortwave mode) resonant modes split on three or two modes. For sufficiently large vibration frequencies magnetic field decrease critical vibration amplitude (at which instability appears) and increase critical wave number.

Separately the case one-layer system with upper free boundary was considered. In the case of finite depth layer the results are obtained from previous cases as particular case. The case of infinitely depth layer was considered separately. The results for increasing of the critical value of magnetic induction (excluding longwave mode) and splitting of resonance modes on three or two are qualitatively the same. The character of influence of magnetic field on the critical vibration amplitude is more complex.

High-frequency limit of this problem can be considered. Formally, results for this case are the same with results for the first type of instability. Namely, the vibrations increased the critical value of magnetic induction. Resonant modes (parametric instability) in this case are absent.

APPLYING MASS-SPRING MODELS WITH TUNABLE POISSON'S RATIO TO THE COMPUTER MODELING OF MAGNETIC ELASTOMERS

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We report our recent progress in the computer simulation modeling of magnetic elastomers. Our modeling approach combines explicit magnetic particles with an implicit representation of the polymer matrix. The latter is modelled as a dense network of elastic springs coupled to the magnetic particles and, thus, constraining mechanically their movements [1]. This type of elastic network representation of a continuum soft material, known as mass-spring models, can be tuned to provide a mechanical response that matches any given experimental Young's modulus at a moderate computing cost. However, simple mass-spring networks miss an important property of most real elastomeric materials, that is, incompressibility. Whereas most elastomers under moderate working loads show a Poisson's ratio close to $\nu \approx 1/2$, any simple network of elastic springs following Hooke's law is significantly compressible, having $\nu \approx 1/4$.

In the last decades, different modifications to simple mass-spring models have been proposed in order to obtain incompressible networks. Most of such approaches are based on the application of forces, either on the network boundaries or on each of its nodes, that oppose the changes in the overall enclosed volume (see [2] and references therein). Despite its conceptual simplicity, this type of approach requires well defined boundaries for the system under any observed deformation. This can be problematic for large and/or anisotropic deformations, under which the network nodes that define the boundaries can change dynamically. In addition, boundary applied forces are meaningless in pseudo-infinite systems [3].

Recently, a novel approach for volume conservation in systems of mass-spring networks that avoids the limitations of the aforementioned schemes has been introduced [4]. In this case, forces are applied to all nodes of the network according to the local stress, thus fully avoiding the treatment of boundaries. Importantly, the model can be tuned to provide arbitrary Poisson's ratios up to the incompressible limit. Here, we apply for the first time this local scheme to the modeling of magnetic elastomers, discussing the impact of incompressibility on the deformations induced by the application of external magnetic fields.

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INTERACTION OF BUOYANCY AND EM FORCED CONVECTION DURING HORIZONTAL DIRECTIONAL SOLIDIFICATION

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Directional horizontal solidification is carried out by cooling the metal melt from one of the side walls. The solidification process begins from this surface, when the liquid metal is cooled below the melting point. Moreover, such temperature conditions correspond to the case of vertical convection [1–3]. Such convection occurs when a horizontal temperature gradient is applied to the volume of the liquid. The flow caused by thermal buoyancy forces affects the temperature distribution and, therefore, the shape and evolution of the liquid-solid interface.

Another issue under consideration is the onset of solutal-driven convection. In the case of solidification of a two-component alloy, the phase with a lower melting point solidifies faster and a layer saturated with the second phase is formed near solid interface. In this case the concentration gradient will be a source of buoyancy forces that can be directed against the thermal convective flow.

Such thermal and solutal driven convective flows play an important role in solidification processes and have a significant and multifaceted effect on the structure and segregation formation of solid metal [4]. By controlling them by means of the electromagnetic (EM) forces, it is possible to have a positive effect on the as-cast structure.

The influence of electromagnetic forces on convective flows in the liquid phase of a solidifying alloy is considered in the presentation. Natural convective flows are characterized by the Grashof number, while electromagnetically induced flows by the EM forcing parameter. The interaction of these two flows is described by the ratio of the Grashof number to the EM forcing parameter given in [5, 6]. The study was carried out using validated numerical models of vertical convection with a low Prandtl number liquid metal [7], pure Ga phase transition [8], and solidification of a two-component SnPb alloy [9]. All numerical models based on the finite volume method and realised in the OpenFOAM software.

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MATHEMATICAL MODELLING OF STATIC MAGNETIC PROPERTIES OF MULTICORE PARTICLES

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Magnetic nanoparticles first synthesized in the middle of the last century have been widely used in technology and continue to be used in the creation of new magnetoactive materials. Ferrofluids and magnetorheological suspensions are one of the most widespread composite materials based on magnetic nanoparticles. These materials are a suspension of magnetic nano- (for magnetic fluids) or microparticles (for MRS) particles in a liquid carrier. Aggregate stability is provided either chemically or electrostatically. Along with magnetic and magnetoreological fluids, magnetic particles are actually used to obtain «solid» materials (ferroelastomers, ferrogels e.t.c.) in which magnetic nanoparticles are fixed in a polymer matrix. The development of these directions in the production of magnetic composites has led to the appearance of such objects as magnetic multicore particles (MCP) [1] and suspensions based on them.

A MCP is a polymeric non-magnetic particle (characteristic size of the order of 100 nm) inside which a number of magnetic cores (nanosized single-domain magnetic crystallites) are fixed. As a whole, such a particle, being suspended in a liquid, behaves similarly to a particle in an ordinary magnetic fluid, having some effective physical and chemical characteristics. The typical size of MCPs is between the size of particles in standard ferrofluids and in magnetorheological suspensions. So their physical properties occupy an intermediate position between the properties of these systems. In part, the multicore-based ferrofluids are more sedimentary stable than the standard magnetorheological suspensions with micron-sized particles. At the same time, they demonstrate much stronger magnetorheological effects [2] than standard ferrofluids with single-core nanosized particles.

To study possible applications, which are based on the response of MCPs to applied magnetic fields, the principal question is the determination of the magnetic moment of a single MCP and the magnetic properties of MCP suspensions. It is obvious that the magnetic characteristics of the MCP are determined by the microstructure formed by the embedded magnetic cores. It is clear that due to the compact arrangement of the magnetic cores in a particle, taking into account their interparticle interaction is extremely important [3].

This work is devoted to the problem of calculating the magnitude of the magnetic moment of the MCP as a function of the strength of the external field, taking into account the interparticle interaction in an ensemble of superparamagnetic nanoparticles. To take into account interparticle interactions, a first-order modified mean field theory [4] is used in this work.

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IMPURITY DISTRIBUTION IN A RECTANGULAR CELL UNDER TRAVELLING MAGNETIC FIELD

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In metallurgy there is a problem of impurities distribution in the melt. It is required either to distribute the alloying additives evenly over the ingot or, on the contrary, to concentrate them in one part of the ingot. There are various ways to achieve the specified result. One of the well-proven ones is the influence of a running magnetic field on the melt. Recently, due to the development of numerical simulation and experimental techniques for studying magnetohydrodynamic processes in the melt, it has become possible to study more complex phenomena. It is shown that modulation of forces on the melt is possible [1].

In addition, as shown in previous works [2], there is an influence of the asymmetry of the power supply on the character of the flows in the cell. This fact has been established by numerical simulation [3] and confirmed experimentally [4]. Based on the above, there are works that consider the distribution of passive impurity under the action of magnetic fields [5], which shows that this approach is promising.

The studies were performed using FEM in COMSOL Multiphysics, using a decoupled 2D model verified by experimental data. During the experiment, the supply voltage and phase shifts were varied. The resulting forces were transferred to the calculation of turbulent flows using the k-e model. As a result, the distribution dependence on the supply voltage parameters was determined.

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THE EFFECT OF MAGNETIC FIELD ON WAVES IN A CENTRIFUGED CONDUCTING VISCOUS LAYER INSIDE A ROTATING CYLINDRICAL CONTAINER

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We consider the waves in an electrically conducting liquid in the presence of a uniform external magnetic field. The liquid partially fills the internal volume of a hollow circular infinitely long cylinder rotating uniformly with angular velocity Ω around the axis of symmetry. The gravity force is very small as compared with the centrifugal force and gravity effects are disregarded. In the undisturbed state the liquid under the centrifugal force action forms a cylindrical layer on the inner surface of the rotating non-conductive cylinder. The vector of unperturbed magnetic induction is directed along the spinning rotor axis. The resonant excitation of waves in a fluid in the rotor chamber is the main cause of instability of stationary rotation of rotor systems [1, 2]. Some aspects of the wave motion of a conducting fluid in the rotor cavity were considered in a non-inductive approximation in the work [3]. The linearized equations of conducting liquid motion in uniformly rotating cylindrical coordinate system are

$$\frac{\partial v}{\partial t} = -\nabla\left(\frac{p}{\rho} - \frac{1}{\mu\rho}B_0 B\right) + 2\left[v\times\Omega\right] + \upsilon\Delta v - \frac{1}{\mu\rho}B_0\frac{\partial}{\partial z}B,$$
$$\frac{\partial B}{\partial t} = B_0\frac{\partial}{\partial z}v + \frac{1}{\mu\sigma}\Delta B, \quad \mathrm{div} v = 0, \quad \mathrm{div} B = 0,$$

where Ω is angular velocity of rotation, $B_0, (B_0 = B_0 e_z)$ is the unperturbed magnetic induction, other designations are standard. Boundary conditions on the non-conductive rigid wall and on the free surface are obvious and are omitted here. We use the technique of work [1] to find a solution to this problem. The velocity and magnetic field can be represented exactly through a superposion of partial waves $v = \hat{v}(r)e^{i(-\tau t+m\phi+kz)}$, $\quad B = \hat{B}(r)e^{i(-\tau t+m\phi+kz)}$, where

$$v = (u, v, w)^T, \quad B = (B_r, B_\phi, B_z)^T, \hat{w} = \sum_{j=1}^{5}\widetilde{w}_{mj}, \quad \hat{u} = \sum_{j=1}^{5}\left(\frac{im(k_j-k)}{\lambda_j^2 r}\widetilde{w}_{mj} + \frac{ik}{\lambda_j}\widetilde{w}_{m-1j}\right),$$
$$\hat{v} = \sum_{j=1}^{5}\left(\frac{m(k_j-k)}{\lambda_j^2 r}\widetilde{w}_{mj} + \frac{k}{\lambda_j}\widetilde{w}_{m-1j}\right), \quad \widetilde{w}_{mj} = C_{2j-1}H_m^{(1)}(\lambda_j r) + C_{2j}H_m^{(2)}(\lambda_j r),$$
$$B_z = \sum_{j=1}^{5}\frac{ikB_0}{i\omega + \sigma^{-1}\mu^{-1}k_j^2}\widetilde{w}_{mj}, \;\ldots, \tau = \omega/\Omega,\; k' = ka,\; \kappa' = \kappa a,\; E = \upsilon/(\Omega a^2),\; \mathfrak{R}_m = \mu\sigma\Omega a^2,$$
$$Al = B_0^2/(\mu\rho\Omega^2 a^2), \quad E\kappa^5 + i\tau(1+\mathfrak{R}_m E)\kappa^3 - 2ik\kappa^2 + (k^2 Al - \tau^2)\mathfrak{R}_m\kappa + 2\tau Re_m k = 0,$$

where a is the cylinder inner radius, $\delta a, (\delta < 1)$ is the radius of the unperturbed free surface, $H_m^{(1,2)}(r)$ are Hankel functions. k is the dimensionless axial wave number, m is the azimuthal wave number, τ is the dimensionless frequency. The dispersion characteristics of waves are investigated at low Ekman numbers and low values of the magnetic Reynolds number. For stability analysis, a method is also used that does not require the study of the dispersion equation. The conditions are found under which the magnetic field has a stabilizing effect.

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NUMERICAL SIMULATION OF TWO-DIMENSIONAL MHD TURBULENCE BEHIND A GRID IN AN ANNULAR CHANNEL

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The theory of magnetohydrodynamic (MHD) turbulence plays a key role for mathematical modeling of the origin and development of large-scale cosmic magnetic fields characteristic of planets with a liquid core, stars, galaxies, and even galactic clusters. Experimental verification of these models in laboratory conditions is practically impossible. In fact, interstellar and solar plasma are the only transparent medium suitable for observing developed turbulent MHD flows. Moreover, the verification of particular aspects of the theory can be carried out using examples of laboratory MHD flows with characteristic values of the magnetic Reynolds number of the order of unity [1]. Earlier, a scheme for an MHD experiment was proposed, which makes it possible to obtain a pulsed flow in a toroidal channel with the required characteristics [2]. The series of experimental studies was carried out to mimic some elements of dynamo mechanisms. The theoretical interest in turbulence behind the grid has motivated new laboratory experiments [3]. Some results remain unexplained or require verification. This paper presents the results of direct numerical simulation that can be used to interpret the measurement data.

We consider a two-dimensional flow of an incompressible electrically conductive fluid in an annular channel. The section is partially blocked by obstacles. The flow arises under the action of an impulsive mass force parallel to the inner axis of the channel (in a real experiment, the inertial force arising when the torus is decelerating). Magnetic field pulsations are induced due to the interaction of velocity pulsations and an external magnetic field. The parameters of the computational experiments were selected in accordance with the parameters of the experiment [3,4]. The purpose of this work is to carry out a comparative analysis of the numerical and experimental results. An exact match cannot be achieved due to the fact that the calculations are carried out in a two-dimensional formulation, and the experimental flow has an essentially three-dimensional structure. Nevertheless, the result of the computational experiment makes it possible to obtain a physically similar picture and, in particular, to obtain the relationship between the distinguished peaks in the spectra of the kinetic and magnetic energy of fluctuations observed in the experiment [4].

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VELOCITY MEASUREMENTS IN THE ELECTROVORTEX FLOW IN THE SYSTEM WITH TWO SUBMERGED ELECTRODES

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Electrovortex flow (EVF) of liquid metal in container with submerged electrodes and bifilar current supply relates to problem of melt stirring in electrometallurgical aggregates like welding, electroslag remelting, direct current (DC) electrical arc furnaces (EAF) and others [1,2].

The photo of experimental setup is presented in figure 1. Liquid metal (In-Ga-Sn) was placed in a cylindrical container with diameter 200 mm and depth 20 mm, two copper cylindrical electrodes with diameter 20 mm are built in bottom-up through the container bottom and are fully submerged into liquid. Bifilar power supply scheme was used so that electrical current circuit was closed through a liquid metal between cylindrical walls of electrodes. Total current I could be changed in the interval from 0 till 800 A.

Figure 2. *Electrovortex flow in the bowl with two submerged electrodes visualized by hydrogen bubbles. $I = 800$ A.*

The temperature correlation method was used to measure the velocity in the liquid. The thermocorrelation probe consisted of two thermocouples spaced 3 mm apart. At currents above 70 A, turbulent pulsations are present in the flow, allowing measurements to be taken. We calculate the cross-correlation function of two thermocouple signals (oscillograms) and from the position of the maximum we can determine the average delay time of the arrival of the temperature pulsation to the second thermocouple Dt. Thus, the average flow velocity can be determined as $U = L/Dt$ [3].

In the area between the electrodes, the collision of two jets occurs and it leads to the appearance of large-scale pulsations in the liquid, thus, the flow is essentially unsteady and relatively long averaging times are required when measuring the velocity — about 1 minute. Longer times do not improve the quality of measurements. Measurements of the dependence of the average flow velocity on the electric current at various points of the working bath were carried out. Velocity profiles were also measured along the axis between the electrodes at different depths. Surface velocity was measured with hydrogen markers. A solution of hydrochloric acid was poured onto the surface, as a result of a chemical reaction with In-Ga-Sn oxides, hydrogen bubbles were released, which were recorded by video filming.

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STUDY OF ASTROPHYSICAL MAGNETIC TURBULENCE WITH NEW GENERATION X-RAY POLARIMETERS. APPLICATION TO SUPERNOVA REMNANTS

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MHD turbulence is naturally formed in astrophysical environment especially in the sources with high energy release. It can be studied by observation of the polarized synchrotron emission radiation that is sensitive to the direction of the magnetic field projection to the sky plane. However this is not an easy task because of the projection effects along the line of sight, strong Faraday depolarization effect in the radio band, thermal and line emission contamination in the optical band. X-ray observations look very promising, because Faraday effect is negligible in this band and electrons responsible for X-ray emission are located in the vicinity of the particle acceleration sites that makes possible to study magnetic turbulence in these sites alone. New generation X-ray polarimeters that will have good sensitivity together with 0.5 arcmin angular resolution could become an indispensable tool for study of the MHD turbulence in astrophysical objects.

IXPE (NASA) is going to be the first polarimeter of this kind. In this work IXPE perspective in the study of MHD magnetic turbulence in supernova remnants (SNRs) is discussed. In the paper [1] X-ray synchrotron radiation polarization maps of Tycho SNR were simulated with XIMPOL python package under various assumptions on the mechanisms of magnetic turbulence generation and evolution. It was shown that for 1 Ms IXPE observation time some mechanisms of magnetic field generation should produce specific observable features on the synchrotron polarization maps. In this work better accounting is done for polarization degree dependence of the synchrotron radiation in a turbulent medium on the photon energy. In order to determine the most sensitive energy range for study of the MHD turbulence in SNRs with IXPE polarimeter, simulations of Tycho SNR polarization maps are performed with XIMPOL package for various energy filters in the X-ray energy band. Some calculations were carried out with the computers of the MSCC RAS.

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ELIMINATION OF MAGNETIC FLOWMETERS NONLINEARITY CAUSED BY THE MHD-EFFECT

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The article is devoted to the development of the sodium magnetic flowmeters for pipelines of larger diameter. The main function of such flowmeters is to measure the flow in fast sodium reactors.

The fluid flow regime in the channels of the fast reactor corresponds to large values of the hydraulic Reynolds number, small values of the Hartmann number and values of the magnetic Reynolds number (Re m) of the 15-40 and more order. This gives grounds to neglect the influence of the magnetic field on the velocity profile and to consider the flow as developed turbulent.

Large values of Re m indicate a noticeable distortion of the inductor magnetic field by currents that arise when a liquid moves in a magnetic field. The nonlinearity of the signal from the electrodes of the magnetic flowmeter, caused by the MHD effect, appears.

The article analyzes possible ways to eliminate the nonlinearity of the signal from the electrodes of the magnetic flow meter, which arose for this reason. Various ways of eliminating the influence of the MHD effect on the metrological characteristics of the flow meter are considered: the choice of the number of electrodes and their locations on the measuring pipe section, the size of the excitation magnetic field in the working section, the signal processing algorithms.

All decisions are based on the known result [1], which indicates the characteristic of the electric field of the flow meter, independent of Rem.

Elimination of the nonlinearity of the flowmeter characteristics by the proposed methods allows the flowmeter to be calibrated on a low-power sodium test bench and opens up the practical possibility of manufacturing large-diameter magnetic flowmeters.

Calculations of the nonlinearity of the flow meter carried out depending on the magnetic Reynolds number, the distribution of the magnetic field of excitation, the locations and number of pairs of electrodes, mathematical methods of signal processing, etc.

The proximate calculation methods for evaluating the nonlinearity of the flowmeter characteristics are considered. Analytical dependences of the flowmeter characteristics on the magnetic Reynolds number and design parameters of the inductor are obtained.

The optimal parameters of the flowmeter design are determined depending on the flow regime, characterized by the magnetic Reynolds number, on the size of the working area and the number of electrode pairs. The signal processing algorithm using approximate integration weight coefficients calculated by the Gaussian method is proposed.

Practical recommendations for designing large-diameter flowmeters are given.

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MAGNETIC FLOWMETER FOR FAST SODIUM REACTORS

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All operating and most of the fast reactors currently under development are sodium cooled reactors.

Requirements for flowmeters of the heat carrier are determined by the properties of the medium being measured, its physical characteristics and measure modes. High temperature (up to 500–580°C), difficult radiation conditions, as well as extremely high requirements for the reliability of the device limits the selecting the design of the flow meters. Currently, the most common flowmeters for reactor heat carriers are magnetic flow meters.

A traditional magnetic liquid metal flowmeter consists of a stainless-steel pipe, two measuring electrodes welded to the outer surface of the pipe, a permanent magnet inductor and a electronic device [1]. The informative signal of magnetic flowmeters is determined by the integral value of the flow velocity over the channel cross-section, that is, the flow rate. The flowmeters provide a direct conversion of the flow rate into the electrical signal. There are no structural elements in the channel of the device that impede the flow and distort the velocity diagram. The readings of the flowmeters depend relatively little on changes in the physical properties of the measured medium: density, viscosity, distribution of the velocity in the channel. The accumulated experience allows us to assert that classical magnetic flow meters are the most competitive due to sensor reliability, accuracy, the electronic device simplicity, resistance to vibrations, industrial noises, impurities in heat carrier [2].

Permanent magnet flowmeters are ubiquitous thanks to the simplicity of the design. Nevertheless, they do not consistent with the modern requirements for nuclear industry devices. Their main disadvantages are: low stability of the magnetic field in time, sensitivity to thermo-EMF of electrodes, low noise immunity, lack of the ability to calibration of the flowmeter during operation. High temperature and high electrical conductivity, lack of internal lining, leads to the fact that the readings of flowmeters are significantly affected by changes in the temperature of the heat carrier. As a result of heating the magnetic system, the induction of the magnetic field and, consequently, the induced EMF decrease.

This paper describes the magnetic flowmeter IRMU-1 of the new design, developed by JSC NIITeplopribor [3]. The flowmeter is designed to measure the sodium heat carrier and has the inductor, which is an electromagnet that generates a pulsed low-frequency magnetic field. Using of a pulsed magnetic field makes it possible to separate the informative component of the signal from all interference of electromagnetic origin, the change of which in time is not a multiple of the frequency of the inductor magnetic field. Thus, the interference of the industrial frequency and thermo-EMF is completely eliminated, the accuracy of flow measurement significantly increased, and it is possible to reduce the magnetic field in the channel by an order of magnitude. The inductor power does not exceed 0.5W. The flowmeter is able to measure low flow rates and reverse flows, it is not required zero correction. These features are not possessed by other types of liquid metal flowmeters (including flowmeters with permanent magnets, vortex and correlation flowmeters). The design features of the flowmeter, its technical characteristics and test results are considered.

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COHERENT COLUMNAR VORTEX IN THREE-DIMENSIONAL ROTATING TURBULENT FLOW: STRUCTURE AND SPATIAL CORRELATIONS

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The Navier-Stokes equation, the main one for hydrodynamics, will soon be 200 years old [1]. However, until now, its solution for many experimentally observed systems and practically important problems [2] is difficult if the flows are characterized by a large Reynolds number. In recent decades, the accuracy of recording the flow velocity has sharply increased due to technological advances in optical systems. Besides, the power of computers increased that made possible to perform massive simulations of the Navier-Stokes equation [3,4]. All this provided material for constructing the theory of two-dimensional coherent vortices, which has been done in the past few years [5]. One of the following achievements of statistical hydrodynamics may be the results of the proposed study — the statistical theory of three-dimensional coherent vortices in a liquid. Such vortices are observed both in nature and in an artificial experiment [6].

Coherent vortices are statistically stable formations. In a two-dimensional flow, such vortices compensate the energy loss due to friction by its arrival directly from small-scale fluctuations [5]. It is worth noting that in two-dimensional and three-dimensional flows, the energy flow between a large-scale one and fluctuations occurs differently [7]. In particular, in a twodimensional coherent vortex, small-scale fluctuations excited by external stochastic forces transfer kinetic energy to the vortex. Whereas in a three-dimensional flow energy is transferred from a large-scale shear flow to small-scale fluctuations. The two-dimensional flow model is in a range of cases a simplified representation of the three-dimensional flow, in which the third velocity component is suppressed. However, the suppression of the third velocity component can be caused by rotation and be unrelated to the geometric mechanism. The Proudman-Taylor theorem states [8] that for a large Rossby number, the flow velocity ceases to change along the axis of rotation due to the action of the Coriolis forces. As a result, the flows in the planes remote from the center and in the third direction are separated. A widely known example of such a flow is a tornado [9]. Similar flows are also realized in the liquid outer core of the Earth [10]. The fundamental principle of constructing the theory of coherent vortices is the possibility of dividing the flow into a strong mean (coherent), long-lived and statistically stable, and into weak fluctuations. This would be incorrect to do for developed isotropic turbulence, since fluctuations in it cannot be considered as weak.

In this paper, three-dimensional motion is studied against a background of strong rotation and weak shear flow. The aim of this work is to describe the evolution of weak velocity fluctuations in a large-scale shear flow of a rotating fluid. The work establishes relations between the transverse correlations of the fluctuating part of the velocity and the velocity field of the large-scale flow. The big part of results connected to structure of vortex is presented at [11].

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STUDY OF KEEPING A PERMANENT MAGNET SUSPENDED IN A PULSED MAGNETIC FIELD

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There are various ways to implement magnetic levitation as a method of holding or lifting an object using only a magnetic field. These can be methods using eddy currents that hold the body in a potential well, or a permanent magnet in feedback with a pulsed magnetic field. The idea of levitation considered in this paper is quite simple and is widely used for practical demonstration of holding the body in a suspended state. A small cylindrical neodymium magnet is held by electromagnetic interaction with the current flowing through the coil. To create a levitation effect, when the magnet approaches the coil, the current through it is turned off by an electronic switch triggered by a photo sensor or a digital Hall sensor located on the axis of the coil. It is of interest to develop calculation methods that allow predicting the fact and parameters of body levitation for a given coil design, the current through it, the Hall sensor parameters, and the size and properties of a permanent magnet.

The aim of the paper is to study the dynamic parameters of a permanent magnet suspended in a pulsed magnetic field and to create a simple computational and experimental technique to predict the behavior of a body in a suspended state under specified conditions. For experimental studies and computer simulations, a cylindrical NdFeB neodymium magnet with axial magnetization and specified geometric dimensions is used. A distance between the coil and the permanent magnet, at which the current switch-off occurs, is determined experimentally.

A simplified computational and experimental method is proposed to determine the magnetic moments for a permanent cylindrical magnet and a coil with a current, as well as the values of the average coordinate of the body position in the suspended state. A mathematical model of a magnet one-dimensional motion under the influence of gravity and the electromagnetic force of interaction with a pulsed magnetic field is developed. It is proved by computer modeling and experimental studies that the higher the pulsation frequency, the lower the pulsation amplitude and the more stable equilibrium are observed when the body is suspended. The pulsation frequency, other things equal, decreases with increasing mass of the permanent magnet and a decrease in the amplitude of the current through the coil, and there exist critical values that define the boundaries of the body suspension in an electromagnetic field.

The results of the work can be used for a simplified technique that allows prediction of the position and parameters of motion in the suspended state of a cylindrical magnet, to determine its relative stability when changing the position of the Hall sensor and the parameters of a pulsed magnetic field.

HYDRODYNAMIC CHARACTERISTICS AND HEAT TRANSFER IN THE LAMINAR COCURRENT FLOW OF TWO PARALLEL FLOWS OF LIQUID METALS

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We consider a laminar layer at the interface of two liquid metals moving in parallel with different velocities U1 and U2. Due to the viscous friction, a velocity distribution arises, and it can be assumed that the transition from the velocity U_1 to the velocity U_2 occurs in a thin mixing zone, and the initial cross-stream velocity component v is everywhere small compared to the along-stream component u. The boundary layer differential equation can be applied to both regions of the flows [1]. When solving the boundary value problem, the following boundary conditions are set. In the undisturbed flow region, $u = U_1|_{y\to\infty}$, $u = U_2|_{y\to\infty}$. In the contact region of the two liquids, we consider the velocities and tangential stress at the interface of the two flows to be continuous: $u|_{y=0+} = u|_{y=0-}$, $\rho_1\nu_1^{1/2}(\partial u/\partial y|_{y=0+}) = \rho_2\nu_2^{1/2}(\partial u/\partial y|_{y=0-})$ where ρ_1, ν_1 and ρ_2, ν_2 are densities and coefficients of kinematic viscosity of the first and second liquid metals, respectively.

To integrate the continuity equation, we introduce a stream function $\psi(x, y)$ as $u = \partial\psi/\partial y$, $v = -\partial\psi/\partial x$ and a nondimentional y-coordinate as $\eta = y\sqrt{U_1/(\nu\chi)}$ and obtain the expression for the cross and along-stream velocity components: $u = U \cdot f'(\eta)$, $\nu = 0.5\sqrt{\nu U/\chi} \cdot [\eta f'(\eta) - f(\eta)]$. The result is a system of ordinary differential equations: $2f_1''' + f_1 \cdot f_1'' = 0$; $2f_2''' + f_2 \cdot f_2'' = 0$.

An approximate analytical solution is obtained in the form of an asymptotic approximation. We have $\eta_1 \to \infty$, $u \to U_1$; $\eta_2 \to \infty$, $u \to U_2$, and this implies $\eta_1 \to \infty$, $f_1' \to 1$, $\eta_2 \to -\infty$, $f_1' \to U_2/U_1 = \lambda_0$, therefore we obtain the conditions at the interface of the two liquids $f_1'(0) = f_2'(0)$, $\rho_1\nu_1^{1/2}f_1''(0) = \rho_2\nu_2^{1/2}f_2''(0)$.

The velocity of the laminar boundary layer at the interface of the two parallel flows at $\eta_1 = [0, +\infty]$ is

$$u_1(\eta_1) = 1 - \frac{\sqrt{\lambda_0}\rho'\nu'(1-\lambda_0)}{1+\rho'\nu'\sqrt{\lambda_0}} \cdot \mathrm{erfc}\left(\frac{\eta_1}{2}\right)$$

and at $\eta_1 = [-\infty, 0]$,

$$u_2(\eta_1) = \lambda_0 - \frac{\lambda_0 - 1}{1+\rho'\nu'\sqrt{\lambda_0}} \cdot \mathrm{erfc}\left(-\sqrt{\lambda_0}\frac{\eta_1}{2\nu}\right),$$

where $\rho' = \rho_2/\rho_1$; $\nu' = \sqrt{\nu_2/\nu_1}$.

The distribution of the velocity profile in the motion of two immiscible metals with different properties at different ratios of their velocities λ_0 is analyzed.

Heat transfer is considered during the cocurrent motion of two flows of liquid metal with different temperatures and properties. It is assumed that heat transfer is determined by the size of the thermal boundary layers, which, in turn, are related to the hydrodynamic boundary layers in the first and second liquid metals.

An analytical expression is obtained to determine the local and length-average heat transfer coefficient between two liquid metals in a laminar cocurrent parallel flow and in the presence of slip between them.

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AN EFFECT OF THE MAGNETIC FIELD ON HEAT TRANSFER OF BOILING MAGNETIC FLUID ON A HORIZONTAL HEATER WITH SPOT HEAT INPUT

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An effect of a uniform magnetic field on heat transfer during the bubble boiling of a nanodisperse magnetized fluid (magnetic fluid) on a horizontal surface with a point heat supply was experimentally studied. The boiling curves are obtained for magnetic fluids with a volumetric concentration of the solid phase of 12%, 8%, and 5.5% in magnetic fields of different strengths. It was found that the curves have a nonmonotonic character. The magnetic field strength at which the heat flux is maximum was determined. It was found that with increasing concentration of the solid phase, the influence of the magnetic field on the heat flow increases. An equation based on a theory of approximate liquids boiling [1] heat transfer is obtained. The equation satisfactorily describes the experimentally observed effect of the magnetic field on the heat flow at bubble mode boiling. The derivation of the expression for the forces acting on a vapor bubble in a nonuniformly heated magnetic fluid is given.

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HYDRO-GAS DYNAMICS OF VAPORIZATION IN A MAGNETIC LIQUID IN A MAGNETIC FIELD

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The process of vapor bubbles formation in boiling magnetic fluid in a uniform constant magnetic field has been studied. Bubble formation occurred at a single vaporization center. Two fundamentally different vapor bubbles frequency formation observe were used. One of them is visual, which consists in high-speed video filming of pop-up bubbles. The bubbles were observed in a two-layer medium consisting of an opaque magnetic fluid and a transparent non-magnetic fluid. Another method is induction. It is based on the occurrence of an induction current in the turns of the coils through which the steam bubbles moved. A comparative analysis of the results obtained by calculating the frequency of formation of bubbles by these methods is carried out. The mechanism of the influence of a magnetic field on the frequency of formation of vapor bubbles during boiling of a magnetic fluid is analyzed.

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DYNAMO MODEL IN ANISOTROPIC UNIFORM TURBULENT FLOW WITH SHORT-TIME CORRELATIONS

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Averaging the magnetic induction equation over a random velocity field forms the basis of the dynamo theory, which describes the formation of large-scale astrophysical magnetic fields. The standard approach to averaging is the asymptotic method proposed by Krause and Radler for two-scale turbulence, that is, for such a random velocity field that can be represented as the sum of a large-scale slowly varying component and a small-scale fluctuating component. For example, by this method the classical systems of the Parker solar dynamo and the galactic disk dynamo were obtained. In this report, we will talk about a different averaging method proposed by Molchanov, Ruzmaikin, and Sokoloff in 1985 for working with a random flow shortly correlated in time. This method is very close to the method of functional integrals used in quantum mechanics. It does not require the assumption of a spatial two-scale velocity field and allows one to derive dynamo equations for the first and second moments of the field under anisotropic and inhomogeneous conditions. The advantages and disadvantages of the multiplicative approach and possible areas of application of the results obtained in the theory of the MGD-dynamo will be demonstrated.

MAGNETIC FIELD SYMMETRIES IN THE FRAME OF SPHERICAL DYNAMO FOR EXOPLANETS AND HOST STARS

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Based on the symmetry of the sources of the large-scale magnetic field of the convective spherical shell in stars and exoplanets, we consider the possible types of magnetic fields in these objects and the structures of the current sheets associated with them. We show that in addition to the usual configurations of current sheets of a dipole magnetic field, current sheets, associated with magnetic fields of quadrupole symmetry and with magnetic configurations of mixed symmetry, can also arise. These conclusions are verified by the numerical simulations of the magnetic field transfer by the stellar wind, the boundary conditions of which are determined by the spherical dynamo-mechanism of Parker's type.

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VISCOELASTICITY MODULES IN FERROFLUIDS WITH CLUSTERED NANOPARTICLES

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The ability to control the properties and behavior of liquids using a magnetic field allows to find new solutions to many applied tasks. All natural liquids are diamagnetic, therefore they very weakly interact with the field. Materials that can be effectively controlled by a weak and moderate magnetic field are ferrofluids.

The particle diameter in typical ferrofluids varies within 7-20 nm. In these systems, strong magnetorheological effects are observed only at low shear rates. In suspensions of micron magnetizable particles, strong rheological effects are observed in a wide range of shear rates, but such suspensions are sedimentary unstable. That is why the problem of manufacturing of magnetic fluids, which would combine the sedimentation stability with strong magnetorheological properties is actual. It turns out that magnetic fluids, consisting of iron oxide nanoparticles united in clusters fastened with a polymer shell, allow solving this problem [1, 2].

Cluster magnetic fluids, consisting of multi-core particles, attract considerable interest because they look very promising for various technical and biomedical applications. The typical size of the composite particles ranges from tens to few hundred nanometers, whereas the individual single-domains ferroparticles, they consist of, vary in the range 5 to 20 nm.

Rheological phenomena in these fluids (high magnetorheological effect; slow viscoelastic relaxation; shear thinning effects) are determined by the particles aggregation in the applied field; dynamics and rupture of the aggregates under the macroscopic deformation flow. From our best knowledge, the micro/mesoscopic nature of the macroscopic rheological phenomena in the clustered magnetic fluids has not been sufficiently studied yet.

We present results of experimental and theoretical study of the non-linear viscoelastic effects in the multicore ferrofluids and influence of an applied magnetic field on these phenomena. In the experiments volume concentration of the composite particles varied in the range of several percent. The experiments demonstrate strong dependence of both, the storage G' and loss G" fluid moduli on the applied magnetic field, Mason number and frequency of the flow oscillations as well. Time of the viscoelastic relaxation of the fluid is about 1 sec; that is several orders more than that for the ferrofluids with individual ferromagnetic nanoparticles.

A theoretical model, based on the idea of the clustered particles unification in the linear chain-like aggregates, is suggested. The calculations show that the angles of deviation of these chains from the direction of the magnetic field are very small. Therefore, in the shear stress, only a linear term in the angles can be remained, and, consequently, this shear stress linearly depends on the oscillating shear rate. This situation allows us to obtain non-cumbersome mathematical expressions for the fluid moduli G' and G". Theoretical results are in quantitative agreement with the experiments.

We assert that these results contribute to the understanding of the complex, magnetic field-induced rheological properties of magnetic colloids and will stimulate further investigations.

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TRANSFER PHENOMENA IN MAGNETIC FLUID COMPOSITES

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In this work, we study composite magnetic fluids that were obtained by introducing larger microparticles of various materials into a magnetic colloid. In particular, magnetic fluids based on kerosene were studied, in which microparticles of graphite and aluminum were introduced. Magnetic emulsions obtained by dispersing a magnetic colloid in a non-magnetic liquid medium or a non-magnetic liquid in a magnetic colloid also were studied. The processes of structure formation in such media under the influence of stationary external magnetic fields were analyzed. It is shown that at low concentrations of the dispersed phase, chain structures are formed in the medium, and at an increase in the concentration, dense columnar structures are formed.

The macroscopic properties of these magnetic fluid composites were measured and the influence of structure formation processes in a magnetic field was studied. In particular, the effective electrical conductivity and thermal conductivity of the samples were studied. The phenomenon of charge and heat percolation in a composite magnetic fluid, which occurs when the concentration of the dispersed phase increases, is detected. The phenomenon of percolation also occurs when exposed to a magnetic field as a result of the formation of conducting bridges from particles of the dispersed phase, which have a high conductivity compared to the dispersion medium. Computer simulations of structure formation and transport processes in the studied media were carried out.

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NONSTATIONARY INSTABILITY OF AXISYMMETRIC FLOW OF A LIQUID IN A ROTATING MAGNETIC FIELD

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Non-stationary instability of axisymmetric laminar flow of a viscous conducting liquid in infinitely long circular cylinder, arising under the influence of coaxially rotating magnetic field (RMF) of any rotary symmetry, is investigated. Stability is investigated both in relation to axially and to non-axially symmetrical disturbances, The problem is studied in linear presentation both in the low-frequency approximation, and for any value of relative frequency. The nearest analogue of a flow of the conducting liquid induced by the RMF is Couette flow between two concentric cylinders from which internal one rotates and external remains motionless. Analysing stability of such flow, Lin [1] has noticed, that the first approximation equations for small perturbations of velocity and pressure allow for periodic solution with respect to ϕ and z:

$$f = f(r) \cdot exp(\gamma t + in\phi + i\alpha z),$$

where n is the integer number (azimuthal wave number), and α is the real (dimensionless axial wave number).

Using analogy to Couette flow for a flow excitable of RMF we will consider a special case of rotary symmetry $n = 0$ Stability of a primary azimuthal flow and three-dimensional hydrodynamic structures thus arising – Taylor's vortices – are investigated by us in sufficient detail [2, 3].

The case of $n \neq 0$ corresponds to the occurrence of the so-called wavy vortices. In this case stability of a primary azimuthal flow in relation to non-axially symmetrical disturbances is investigated. Thus, the vortical structure is transformed in such a manner that the centres of Taylor's vortices form a wave extending in an azimuthal direction. In hydrodynamic experiments with the Couette flow, in some cases the motion of wavy vortices in the azimuthal direction with a certain phase angular velocity was observed. Therefore, in our case, in contrast to the Taylor vortex problem, when, according to the principle of stability change $\gamma = 0$ the eigenvalue γ will now be complex. It describes waves, moving in an azimuthal direction with phase angular velocity $\omega_{ph} = \mathrm{Im}\,(\gamma) \ln \omega$. Executed with use of Galerkin method, the calculations have led to unexpected results. Thus, the loss of stability of a primary flow can lead both to the appearance of Taylor's vortices, and to the direct appearance of wavy vortices of this or that mode, by-passing a stage Taylor's vortices. It is actually established that Taylor's vortices arise in sufficiently limited range of parameters of a flow only for a case of homogeneous RMF. In all other cases the loss of stability of a primary flow can lead to occurrence of directly wavy vortices of this or that mode. When solving the problem in a low-frequency approximation for sufficiently big Hartmann numbers, interesting regularity has been discovered: critical numbers Re_ω coincide for various axial and neighboring azimuthal wave numbers. Calculations of $Im(\gamma)$ have shown that for each concrete azimuthal wave number n $Im(\gamma)$ increases with growth of the Hartmann number. With the increase of n in points of bifurcation, the value $Im(\gamma)$ (and furthermore ω_{ph}) decreases step-wise. It is logical to assume, that at coinciding critical Re_ω the variant with the least phase angular velocity ω_{ph} so with the greatest n will be realized. Apparently, these conclusions would likely be fair for sufficiently long cylinders of finite length as well when it is possible to neglect the influence of end faces on a flow in the central part of the vessel.

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MAGNETIC AND RHEOLOGICAL PROPERTIES OF SUPRACOLLOIDAL MAGNETIC POLYMERS IN A POISEUILLE FLOW

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In the last decade, it has become possible to construct magnetic fimanets or supracolloidal magnetic polymers (SMP). By this term we mean polymer-like structures in which magnetic nanoparticles are playing the role of monomers. The advantage of such SMPs is that they keep their structure independently from the temperature and can be potentially used as an alternative to nanoparticles in magnetic fluids to obtain a desired and easily controlled magnetic or rheological response. This is important for predicting behavior in closed geometries, such as microchannels used in microfluidic devices. Microchannels are tubes which size does not exceed hundreds of microns, and has several advantages, for example, a high speed of heat and mass transfer.

We assume SMPs formed by monodisperse magnetic colloids, modeled as identical spherical beads. We consider SMPs of four different topologies: chain-, Y-, X- and ring-like ones. Our systems consist of 512 identical SMPs with a size of either 10 for chain-, Y- and ring-like SMPs or 9 for X-structures. We use coarse-grained molecular dynamics simulations to investigate the magnetic response of SMP clusters. Using Langevin dynamics simulations, we pay our attention to suspensions of filaments, the magnetic nanoparticles in which are not only interacting via dipole-dipole potential but also via short-range attractive forces (Lennard-Jones type). Such filaments tend to aggregate in dense spherical droplet-like clusters. The resulting composite soft colloid is placed in the microchannel, where its behavior in Poiseuille flow under influence of an external field is investigated, varying a wide range of system parameters.

We considered the influence of hydrodynamic interactions and long-range magnetic forces on the transport of nanocomposite particles in a Poiseuille flow. It was found that the external magnetic field enhances the deformation of the cluster in the microchannel in a flow. We found a critical value of flow rate when clusters are disintegrated for which type of topologies. The magnetic response of suspensions per particle also was considered.

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ON SOME PROPERTIES OF SLOW MAGNETOACOUSTIC AND ENTROPY WAVES IN THE HEAT-RELEASING CORONAL PLASMA

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MHD waves of various types are routinely observed in the coronal plasma. Such waves often demonstrate the behavior that differs significantly from the forecasts proposed by modern mathematical models. This result can be due to a number of reasons. In particular, this may be due to incomplete data or incomplete/incorrect consideration of the processes that determine the dynamics of waves in the medium. An example of effect, whose influence on the dynamics of waves in the solar atmosphere is still not well understood, is the thermal misbalance between the unspecified corona heating and radiation cooling. Due to the fact that the rates of the heating and cooling processes depend on the thermodynamic parameters of the plasma, the collisional waves can violate the thermal balance and, as a result, some feedback (positive or negative) between the waves and the medium can be established. In addition, heating and cooling processes significantly change the dispersion properties of waves, leading to the dependence of the phase velocity and the increment/decrement on the wavelength (frequency) of the disturbance. However, as shown in our researchthe heating and cooling processes, in addition to mentioned effects on waves also determine how the energy of the initiated disturbance is distributed in and between the plasma eigenmodes modes.

The dependence of energy distribution on heating and cooling processes was obtained using the exact analytical solution to the linear evolutionary equation describing the one-dimensional evolution of a perturbation in a coronal loop in the approximation of an infinite large magnetic field. In this approximation the main modes that determine the perturbation are two slow magnetoacoustic modes and one entropy wave. Two characteristic times were used as the main control parameters, which are determined by the dependence of the heating and radiation cooling function on temperature and density. An isobaric disturbance, in the form of a Gaussian function was chosen for illustration. The dependence of the ratio of the entropic and magnetoacoustic waves is shown to be a nonlinear function. Using this function we showed that in the case when both characteristic times associated with thermal misbalance significantly exceed the value of the characteristic travel time of the magnetoacoustic wave along the loop, then the energy ratio between the entropic and magnetoacoustic waves is about unity. While, in the opposite case, almost all the energy falls on magnetoacoustic waves.

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