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D23-磁流体-磁流变

分会主席：李德才、张志力、余淼、王建梅、牛小东

D23-01

微纳磁性颗粒密封

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密封是我国高端装备的关键基础零部件，所支撑的产业是保证国家安全和经济发展的基础性、战略性产业，是国家的重大战略需求。交变高低温、强核辐射、超高洁净等极端环境下的密封，是核能、航天等领域重大事故的主要原因，是国内外亟待解决的难题。微纳磁性颗粒密封是一种新型的密封，制备了微纳磁性颗粒并表征了微纳磁性颗粒的性能，研究了微纳磁性颗粒在强核辐射的环境下关键技术及应用，研究了微纳磁性颗粒在高低温环境下关键技术及应用，研究了微纳磁性颗粒在超高洁净环境中关键技术及应用，攻克了极端环境下微纳磁性颗粒的关键技术难题，取得了重要性成果。

D23-02

Preparation and Molecular Dynamics Simulation of Hollow Triiron Tetraoxide Magnetic Fluid with Dual Active Agents

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A silicone oil-based hollow Fe3O4 magnetic fluid based on oleic acid (OA) and sodium dodecylbenzenesulfonate (SDBS) dual active agents was prepared. Hollow Fe3O4 magnetic particles with a hollow degree of 50% and a particle size of 400 nm were synthesized by chemical co precipitation method, with a density of only 40% of solid Fe3O4 particles. The microstructure and magnetism of hollow particles were characterized in detail using transmission electron microscopy (TEM) and vibrating sample magnetometer (VSM). The magneto rheological properties of the prepared hollow magnetic fluid were analyzed using an MCR302 rheometer, and molecular dynamics simulations were conducted to study its rheological properties. Compared with traditional silicone oil based solid magnetic fluids, the anti deposition stability of hollow Fe3O4 magnetic fluids has been improved by 10 times. The low-density characteristics of hollow particles not only reduce the settling rate of particles in a stationary state, but also enhance the response performance of magnetic fluids when a magnetic field is applied. In addition, the low-density characteristics of the hollow structure also allow the magnetic fluid to maintain a low initial viscosity under zero field conditions. The molecular dynamics simulation results show that hollow particles can quickly form chain and columnar structures when a magnetic field is applied, and these structures can be effectively transformed into layered microstructures in shear flow, thereby significantly improving the dynamic yield strength and shear stability of magnetic fluids.

D23-03

The Effect of Eccentricity of Large-Diameter Magnetic Liquid Sealed Spindles on Pressure Resistance and Rotational Torque

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Magnetic fluid sealing technology is widely used in vacuum and gas sealing applications due to its high reliability, “zero” leakage, and long service life. Under ideal conditions, the magnetic fluid seal gap is uniformly distributed. However, in actual operating conditions, the bearing clearance and magnetic field force generated by permanent magnets in large-diameter magnetic fluid seals can cause the main shaft to shift to one side during rotation, resulting in radial runout. This leads to an uneven seal gap, thereby affecting seal performance and rotational torque. This paper first simulates and analyzes the influence of eccentricity on the magnetic induction intensity within the sealing gap, followed by experimental studies on the effects of eccentricity and sealing gap on sealing pressure resistance and rotational torque. The research results indicate: the magnetic induction intensity within the seal gap exhibits an axisymmetric distribution along the eccentricity direction, and the magnetic field gradient at the maximum gap decreases as the eccentricity increases; when the eccentricity increases from 0 to 0.15 mm, the maximum pressure resistance values of each group of pole shoes decrease by 17% to 84.6%; under the same eccentricity, the smaller the theoretical seal gap, the more significant the decrease in pressure resistance; the rotational torque exhibits an exponential growth relationship with eccentricity, and when considering only the gap effect, the rotational torque is approximately inversely proportional to the minimum gap (with an error of 7.88%). This study provides a theoretical basis for the anti-eccentricity design of large-diameter magnetic liquid seals, confirms the significant influence of eccentricity on seal pressure resistance and rotational torque, and offers engineering references for addressing radial runout issues in high-speed, large-diameter applications.

D23-04

小齿距多齿磁性液体密封的压力传递过程研究

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磁性液体密封件是一种非接触密封形式，因其“零泄漏”等优势而被广泛应用于机械设备中。 然而，大量实验表明，由于压力加载过程的影响，其密封耐压能力的理论预测并不准确。 本研究模拟了齿距较小的多齿磁性液体密封件的加压过程，揭示了小齿距多齿磁性液体密封耐压能力低于理论值的原因：压力双向传递导致的复杂磁液流动以及磁液体积的减少。 这项工作将为磁性液体密封的耐压理论提供新的视角，并为预测磁性液体密封的压力能力提供指导。

D23-05

磁性液体低温性能及其动密封应用

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磁性液体兼备磁性和流动性，利用其特性进行密封是一种新型的密封技术，其原理是利用磁场将磁性液体约束在磁回路的密封间隙中，从而起到密封作用。这种密封方式在许多应用场合展现出传统密封方式无法替代的优势，具有“零”泄漏、结构简单、可靠性高等优点。然而在低温环境下，磁性液体的流动性降低、粘度增加，导致密封启动力矩显著增大。目前，这一关键问题仍未得到有效解决，严重限制了其在航空航天等高端领域的应用。磁性液体低温动密封的启动力矩和阻力矩不仅与磁性液体本身的低温性能密切相关，还受到环境温度、转速、压力和静置时间的影响。针对低温环境下磁性液体密封启动力矩增大的问题，论文提出了适用于低温工况的磁性液体及其影响密封性能的研究。主要工作和结论有：

（1）制备了低温性能好、高稳定性、高体积分数的煤油基和硅油基磁性液体，揭示了表面活性剂、载液影响磁性液体低温性能的机理。以硬脂酸作为表面活性剂，研究了不同体积分数磁性液体的流动性随温度变化，结合流动曲线、Masson 曲线、粘温曲线，分析了硬脂酸影响磁性液体流动性的机理。发现含有聚集大颗粒的磁性液体在不同温度下非牛顿效应更显著。(2）设计了磁性液体密封装置以及可变温环境密封实验台，研究了不同因素对密封耐压能力及 zhulij 研究表明，基载液的粘温性能是影响磁性液体低温动密封阻力矩的主要因素，而磁性液体的体积分数和大颗粒数量则是次要因素。此外，静置时间是导致密封装置启动力矩增大的关键，且密封装置的阻力矩随着温度的降低和转速的增加而急剧升高。研究成果对磁性液体动密封在低温环境中应用具有重要的理论意义和实用价值，有利于拓宽磁性液体密封的应用范围。

D23-06

Investigation and Optimization of Composite Magnetic Field Ferrofluid Seal for Hydrogen Energy Systems

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This study presents a novel composite magnetic field ferrofluid seal (CMFS) for high-pressure hydrogen energy applications. The proposed CMFS seal integrates four strategically positioned permanent magnets with alternating polarities, producing enhanced magnetic flux intensity and steep gradients within multiple sealing stages. A two-dimensional axisymmetric finite element model was established to analyze the magnetic flux distribution, while sealing performance was theoretically evaluated using a modified Bernoulli equation. The parametric analysis and structure optimization with response surface methodology (RSM) of geometric parameters such as pole tooth height, slot-to-tooth width ratio, axial width of boundary magnets, and radial thickness of inner magnets on the seal performance were conducted. The results indicated an average 23.89% enhancement in pressure resistance compared to traditional structures. In addition, the optimized CMFS achieved a 26.07% improvement over its initial configuration. These findings provide theoretical and practical guidelines for advancing ferrofluid seal design in hydrogen energy and fuel cell systems.

D23-07

低温工况下磁流体密封性能的实验研究

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为了研究密封环境温度对磁流体密封起动扭矩和耐压能力的影响，设计了一种能够提供低温环境的磁流体密封实验装置。通过实验测量了在-100℃—20℃温度下，使用不同磁流体种类、不同磁流体注入量时磁流体密封起动扭矩和耐压性能的变化规律。实验结果表明，随温度的降低，磁流体密封的起动力矩持续增加，耐压能力增大到一定程度后不再变化。在同一温度下，不同磁流体种类和磁流体注入量均会影响磁流体密封的起动力矩和耐压能力。其中低温下磁流体中磁性颗粒链状结构的形成，是造成磁流体密封起动力矩和耐压能力随温度变化的主要因素。

D23-08

水萃取塔磁性液体密封设计与应用研究

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水萃取塔传动轴与外壳间的动密封一旦发生泄漏，将导致塔内环境受污染，进而影响萃取效率。为防止外部污染物侵入密封腔并维持其内部压力，本文设计并研制了一种应用于水萃取塔的磁性液体密封装置，同时为阻隔磁性液体向密封腔的渗入，在装置底部集成了磁脂密封与接液盘结构。基于有限元分析，获取了密封结构的磁场分布，并对极齿的关键结构参数进行了优化，据此确定了该磁性液体密封装置的最佳极齿尺寸参数。通过磁性流体动力学方程推导出修正的伯努利方程，确立了磁性液体密封的边界条件，进而导出了其耐压公式。利用该公式，计算了不同密封间隙下装置的耐压值，从而确定最优的密封间隙值。依据优化的尺寸参数制备了磁性液体密封装置样机，并应用于水萃取塔传动轴动密封，实验验证表明，该装置能有效满足水萃取塔的密封性能要求。

D23-09

磁流变塑性体复合多胞元结构的动态力学特性及缓冲机理研究

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随着我国深空探测范围拓展，天体表面复杂地形和着陆姿态不确定性使着陆工况预测难度增大，对缓冲防护技术提出严苛要求。传统缓冲材料因结构参数与缓冲性能固定，对冲击工况适应性差，威胁探测设备及航天员安全。为此，提出将磁流变塑性体(Magnetorheological plastomer, MRP)填充至轻质高强多胞元

结构中构建复合吸能器。针对现有 MRP 响应模式单一、常见多胞元结构平台应力水平低、初始峰值载荷力高等问题, 围绕 MRP 复合吸能器开展多项工作: 采用聚硼硅氧烷等开发具有磁-热敏感的剪切变硬 MRP, 建立力-磁耦合本构模型，所制备 MRP 磁流变效应最高达 4177.6%，剪切变硬效应提升至 2365.4%，且具有温度调控性能；设计具有负泊松比的折返式结构与基于拓扑优化的双 K 型多胞元结构，揭示负泊松比效应对能量耗散机制的增强机理，双 K 型结构比吸能较折返式结构提高 4.1 倍，准静态平台应力提升 3.3 倍；构建可调谐 MRP 复合吸能器，通过优化励磁单元提升磁场，分析磁场、应变率及温度对吸能器动态平台应力的调控机制；提出基于平台应力模型的梯度吸能结构设计方法，构建具有三级相对密度梯度的多胞元缓冲结构，其平均平台应力较双 K 型周期结构提升 10.9%，与 MRP 复合后形成具有多重敏感调谐机制的梯度结构，为复杂冲击环境下的高效防护提供新方案。

D23-10

The Floating Islands Formed by Ferrofluids

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In this study, the floating islands constructed by ferrofluids and two kinds of immiscible liquids are systematically characterized. The silicone oil based ferrofluids are placed at the interfaces between water and perfluoropolyether. The density of silicone oil based ferrofluids is 1.197 g/cm3, which is higher than the density of the water (1.00 g/cm3), but lower than the density of perfluoropolyether (1.80 g/cm3). The “islands” are formed by the Rosensweig instability between immiscible fluids and ferrofluids. Based on our previous works about instability between ferrofluids and immiscible fluids, the density and surface tension differences between ferrofluids and immiscible fluids are responsible for the peaks. This work is meaningful for understanding the Rosensweig instability and constructing a future real floating island.

D23-11

Study on the properties and lubrication effect of perfluoropolyether-based magnetic fluids

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Bearings predominantly utilise liquid lubrication. In space, the unique environment (high vacuum, microgravity) can cause issues such as oil migration and loss, leading to oil depletion and subsequent lubrication failure. Magnetic fluids, a superparamagnetic material that can be flexibly controlled by an external magnetic field, offer a low friction coefficient and starting torque, and can achieve localized lubrication, making them particularly suitable for space applications. The present study, set in the context of deep space exploration, employs perfluoropolyether oils of varying molecular weights to develop a series of perfluoropolyether-based magnetic fluid lubricants. The study also characterises these magnetic fluids in terms of saturation magnetization strength, viscosity, and lubrication performance. Utilising a state-of-the-art magnetic ball bearing lubrication test bench, the present study investigated the relationship between the concentration of magnetic fluid lubricants and bearing life. The findings indicate that magnetic fluid lubricants have the potential to prolong the operational lifespan of bearings. It has been demonstrated that an increase in the concentration of magnetic fluid results in a decrease in the bearing life. Conversely, at a constant concentration, a reduction in the molecular weight of the perfluoropolyether oil has been shown to enhance the lubrication effect, thereby prolonging the bearing life.

D23-12

一种新型磁性液体制备及其耐液体冲刷特性实验研究

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本研究通过化学共沉淀法结合双表面活性剂协同包覆，成功制备出新型酯基磁性液体。借助 X 射线衍射(XRD)、透射电子显微镜(TEM)和傅里叶变换红外光谱(FTIR)等表征手段，证实该材料具有完整的晶体结构、均匀的纳米级分散特性及稳定的表面修饰层。性能测试表明，该磁性液体兼具高饱和磁化强度与优异的流变学特性，经腐蚀介质长期浸泡及液体动态冲刷实验验证，该材料展现出显著的耐化学腐蚀性能与抗液体冲刷稳定性，在存在腐蚀性介质环境及液体冲刷的工业应用中具有广泛的应用前景。

D23-13

磁性液体滑动轴承润滑机理与实验研究

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传统润滑剂在高端装备滑动轴承面临的重载荷、宽温域和高真空等极端工况下难以满足稳定运行的要求。本研究提出一种表面功能织构与磁性液体协同润滑的新策略，设计了基于压力映射的非平面梯度织构结构，采用计算流体力学与实验相结合的方法，系统分析了不同织构类型及其织构参数对轴承承载力与摩擦性能的影响规律。同时，构建了以 Fe3O4 磁性颗粒和油酸为分散体系的磁性液体分子动力学模型，深入揭示磁性颗粒在纳米尺度剪切作用下的运动特征与润滑机制。研究结果表明，功能梯度织构显著提升了滑动轴承的润滑性能，其中圆形织构结构可获得最佳润滑效果；磁性液体中的颗粒表现出典型的剪切稀化现象与滚滑协同运动特性。本研究从宏观设计和微观机制两个层面揭示了磁性液体润滑的多尺度协同机制，为磁性液体润滑技术在极端环境下的实际工程应用提供了理论指导与技术支撑。

D23-14

多物理场耦合作用下的磁性颗粒成链演化机制研究

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为了研究多物理场耦合作用下磁流变液中磁性颗粒的成链演化机制，首先构建了磁场-流场-颗粒之间相互作用的多物理场耦合模型，其次系统分析了磁场梯度、剪切速率及体积分数对磁性颗粒成链过程及其变化机制的影响。研究结果表明，磁场强度和颗粒浓度对磁性颗粒的成链过程有显著影响，在高磁场强度下，磁性颗粒更易形成稳定的链状结构，增强链状结构的抗剪切能力。此外，颗粒浓度的增加会导致链状结构的密度增大，颗粒链结构由单链主导转向网状交联模式，进一步增强了磁流变液的屈服强度。本文的研究为磁流变液在密封、阻尼减震等领域的进一步应用提供了重要的理论依据和技术支持。

D23-15

Study on the inhibition of comet tail defect generation in magnetorheological polishing by modified CeO2

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K9 glass has broad application prospects in the field of optoelectronic information due to its excellent physical and chemical properties such as high hardness and abrasion resistance, good chemical stability, high dielectric constant, and high transmittance in the visible-infrared wavelength band, such as in the field of optical storage (DVD-ROM, etc.), and in the field of optoelectronic displays (optical engines for LCD projectors, etc.). The hard and brittle nature of K9 glass also makes it difficult to achieve ideal processing results with traditional polishing methods. Magnetorheological polishing has been widely proven in recent years as a new type of high-end optical parts manufacturing technology. However, magnetorheological polishing is prone to “comet tail” defects, which seriously affect the quality of high-end optical parts. In this study, it was first determined that the formation of “comet-tail” defects is due to the accumulation of abrasive grains. Then a method is proposed to reduce the number of defects by modifying CeO2 abrasive grains with KH550. The KH550-modified CeO2 abrasive was successfully synthesized after verification by XPS, FTIR and XRD characterization. Due to the improved hydrophobicity of the modified CeO2 abrasive grains, it is difficult for the CeO2 abrasive to stay in the defects of the workpiece, which reduces the probability of producing “comet tail” defects. The results show that the modified CeO2 abrasive reduces “comet-tail” defects by about 36% while maintaining a high removal rate.

D23-16

A lattice Boltzmann-based quantum computing frame for complex flows

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In my talk, I will report our recent effort in the Quantum computing (QC) in lattice Boltzmann method(LBM). QC has advanced rapidly in recent years,showing significant potential for improving Computational Fluid Dynamics (CFD), which often pushes the limits of current high-performance computing. The integration of QC into CFD promises both scientific advancements and innovative methodologies. The Lattice Boltzmann Method (LBM), an alternative to traditional Navier-Stokes Equation (NSE)-based solvers, has proven useful in computational fluid mechanics, particularly in complex flow problems. In QC-based LBM (QCLBM), particle distribution functions (PDF) are encoded as qubit probability amplitudes. While most existing QCLBMs neglect the non-linear collision operator and are limited to simple flows, this work proposed a hybrid QC-Classic CFD frame based on LBM(HQLBM) to overcomes these challenges by introducing a non-equilibrium linear collision operator and modular quantum circuit implementation. The proposed HQLBM frame uses modular DmQ5 and DmQ7 lattice models, which can easily scale to D2Q9 or D3Q19 models, reducing quantum circuit width and CNOT gate requirements, thus enabling more efficient simulations of complex fluid flows.

D23-17

Thermal Conductivity Characteristics and Enhancement Mechanism of Composite Magnetic Nanofluids

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In this report, I will present the recent research findings of our group on the thermal conductivity characteristics and enhancement mechanisms of composite magnetic nanofluids. With the rapid advancements in technology driving further improvements in the performance of composite materials and equipment, traditional Fe_3O_4-based ferrofluids are increasingly inadequate for meeting higher application demands, such as wide-range temperature sealing and cooling of high-power electronic devices. Composite magnetic nanofluids, which integrate magnetic nanoparticles with other functional nanoparticles, exhibit both magnetic field responsiveness and functional tunability, offering potential for performance enhancement and breakthrough applications, with notable theoretical and methodological innovations. However, existing studies adopt diverse perspectives on the effects of particle types, concentrations, temperatures, and magnetic fields on the thermal conductivity of composite magnetic fluids. Traditional macroscopic theories fail to fully explain their heat transfer mechanisms, and the microscopic heat transfer mechanisms remain unclear and warrant further exploration. In this study, we prepared water-based composite magnetic nanofluids doped with different nanoparticles (MCNTs, Cu, Ag) and experimentally investigated their thermal conductivity under varying conditions, including magnetic field, concentration, and temperature. Additionally, molecular dynamics simulations were employed to construct a composite nanofluid model, exploring the mechanisms by which the arrangement and movement of microscopic particles enhance heat transfer. The findings provide a theoretical foundation for further performance optimization and future applications of composite magnetic nanofluids.

D23-18

简化格子玻尔兹曼方法结合新型相场模型的磁流体多相动力学研究

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在本文中，我们提出了一种将简化格子玻尔兹曼方法（simplified multiphase lattice Boltzmann method）与新型相场模型相结合的数值模拟方法，用于研究均匀磁场作用下铁磁流体中液滴的变形行为以及铁磁流体中气泡的合并过程。该相场模型通过在自由能函数中显式引入磁能项以驱动界面演化，从而取代了传统方法中在动量方程中直接引入磁力的处理方式。相比之下，该方法不仅提升了模拟的物理一致性，还简化了磁场与界面耦合机制的数值实现。通过基于 SMLBM 的框架，我们对不同磁场强度条件下铁磁流体体系的动力学演化过程进行了模拟，涵盖了液滴和气泡的界面变化、压力分布、速度场结构、磁感应强度及磁能密度等多个方面。模拟结果验证了所提方法在磁流体多相系统中的有效性和可行性，为复杂磁场下多相流动动力学行为的建模提供了一种高效而稳定的数值路径。

D23-19

Lattice Boltzmann Simulations of Ferrofluids

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This chapter focuses on the numerical simulation of ferrofluid dynamics using a simplified Lattice Boltzmann Method (LBM) framework, coupled with a self-correcting scheme for magnetic field computation. It begins with an overview of the fundamental principles of ferrofluid behavior and a derivation of the governing magnetic field equations that underpin ferrohydrodynamics. A novel approach is introduced to integrate magnetic body forces into the LBM formulation, enabling efficient and stable simulation of ferrofluid systems. The chapter presents several case studies, including wetting dynamics, ferrofluid droplet formation, and Rosensweig surface instabilities, to illustrate the model's capability in capturing complex interfacial and magnetically induced phenomena. Additionally, a mathematical representation of a permanent magnet is formulated to generate a non-uniform magnetic field for practical applications. This work aims to bridge the gap between theoretical modeling and computational simulation, offering valuable insights for researchers working in the fields of ferrohydrodynamics, magnetofluidics, and multiphase flow simulation.

D23-20

Phase-field lattice Boltzmann model with adaptive meshrefinement for ferrofluid interfacial dynamics

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In this talk, we report a phase-field model that integrates the lattice Boltzmann method with an adaptive mesh refinement technique to study the interfacial dynamics of ferrofluids. In this model, we employ the second-order conservative Allen–Cahn equation to accurately capture the ferrofluid interface. The velocity-based hydrodynamic equations and a magnetic scalar potential equation with a pseudo-time term are utilized to describe the flow and magnetic fields. All governing equations are solved using a finite difference lattice Boltzmann scheme. To effectively resolve the interfacial dynamics of ferrofluids while reducing computational overhead, the numerical scheme is implemented on a block-structured adaptive mesh. To evaluate the accuracy and efficiency of the proposed model, we conduct simulations on several benchmark problems, including a circular cylinder in a uniform magnetic field, the deformation of a ferrofluid droplet, and the rising of a bubble in ferrofluid. The results obtained show good agreement with exact solutions and well-validated results in the existing literature. Furthermore, three types of ferrofluid instabilities under a uniform magnetic field—namely, the Rosensweig instability, the Rayleigh–Taylor instability, and the Kelvin–Helmholtz instability—are also investigated. Numerical results demonstrate that the magnetic field can significantly promote or suppress the occurrence of flow instabilities.

D23-21

微观力竞争与基载液逾渗耦合的磁性液体密封失效机制

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磁性液体的密封耐压性能是磁性液体在密封领域应用的关键，目前的研究大多聚焦于宏观密封机理分析，对于微观磁性颗粒-基载液力场耦合作用对密封失效的影响机制尚不明晰。本研究创新采用基于 MatDEM 离散元方法的磁性液体颗粒链式动力学模型，研究不同密封工况下的压力与磁性液体微观结构、颗粒作用力与基载液之间的联系，并建立微观力场失衡与宏观密封失效的关联判据。结果发现在亚临界压力状态下，磁偶极子力与开尔文力形成复合作用，实现颗粒-基载液固液耦合稳定；当压差突破临界阈值时，失效力超过开尔文力和磁偶极子力的合力，引发颗粒链发生断裂并重新聚集，从而实现基载液迁移通道的扩大，导致密封失效。另外，复合磁液类似于纳米磁液，但由于复合磁液特殊的柱网状结构，提升了密封力，增强了对失效力的抵抗作用。本文能为如何从根本上调控磁性液体的密封性能提供参考。

D23-22

基于磁性液体一阶浮力原理的多密度物体分离方法

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本研究聚焦于利用磁性液体一阶浮力原理实现对不同密度材料的高效分离。磁性液体作为一种由纳米级磁性颗粒、基载液和表面活性剂构成的新型功能材料，具备独特的磁能与力学特性。其在非匀强磁场作用下展现的一阶浮力原理，即能将密度大于自身的非导磁体悬浮起来，为材料分离领域开辟了新路径。

研究通过构建特定的实验装置，以永磁体为磁源，借助调整永磁体与磁性液体间的距离，改变磁性液体中的磁场分布，进而调控非导磁材料所受一阶浮力大小。经理论分析与实验验证，明确了影响分离效果的关键因素，如磁场强度、磁性液体密度与饱和磁化强度等。

利用 ANSYS Maxwell 软件对模型进行仿真，结果表明，在特定参数设定下，可精准控制不同密度非导磁材料在磁性液体中的悬浮高度，实现高效分离。本研究提出的基于磁性液体一阶浮力原理的分离方法，相较于传统分离技术，具有设备简单、操作便捷、分离精度高且对环境友好等优势，在矿物分选、材料回收等领域具有广阔的应用前景，有望为相关产业发展提供创新性技术支撑。

D23-23

热磁可调谐折纸式吸波结构的设计与优化

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超材料吸波器（MMAs）通过人工设计电磁特性，克服了传统吸波材料的局限性，在轻量化设计、效率和定制化方面具有显著优势。通过集成各种动态调谐机制，可以根据外部条件灵活调整超材料的电磁特性，以满足不同操作场景的要求。本研究利用含有片状羰基铁粉（FCIP）和还原氧化石墨烯（RGO）的形状记忆聚合物（SMPs）开发了一种折纸式可调谐电磁波吸收结构。利用遗传算法优化折纸单细胞的结构参数，提高其吸收带宽。该折纸结构在平面状态下的总厚度为 3.40 mm，在热和磁场激活下可实现平面和折叠状态的双向切换。在折叠状态下，在 3.60-18.00 GHz 的频率范围内实现了 14.40 GHz 的有效吸收带宽。结果表明，该吸收体具有可重构的形状记忆性能和良好的热和磁场下宽带吸收特性，为微波吸收体的设计和应用提供了新的方向。

墙报

D23-P01

适用于低频振动工况的磁性液体制备及其性能研究

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针对磁性液体吸振器的应用需求，本文研制了一种适用于低频振动控制的新型微-纳复合磁性液体智能阻尼材料，优选出具有最佳包覆效果的微米和纳米铁磁颗粒，并将所优选的两种铁磁颗粒相结合，采用控制变量法分别改变两种铁磁颗粒的用量配比、铁磁颗粒的体积分数、添加剂种类和用量研制了一系列不同组分配比的微-纳复合磁性液体。针对所研制的微-纳复合磁性液体开展稳定性、黏温特性、悬浮特性以及摩擦学特性测试，并提出了一种基于 GMDH-GA 混合模型的磁性液体摩擦学性能预测方法，通过试验数据与预测数据对比，验证了该预测方法的有效性。

D23-P02

Low-Temperature Magnetic Sedimentation for Magnetic Fluids and Its Performance in Sealing Applications

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In low-temperature environments, the increased yield stress of magnetic fluids leads to excessively high starting torque in magnetic fluid seals, limiting their applications in aerospace and related fields. To address this challenge, this study proposes a low-temperature magnetic sedimentation post-treatment method. By reducing the concentration of large particles in the magnetic fluid, this approach effectively decreases low-temperature yield stress and significantly lowers the starting torque. Three types of magnetic fluids with distinct base carrier liquids were experimentally tested. The magnetization intensity of these fluids was measured using a vibrating sample magnetometer (VSM), confirming the efficacy of the low-temperature magnetic sedimentation method in removing large particles. Flow curves obtained via a rheometer and fitted yield stress values further validated the method’s effectiveness. Additionally, a novel experimental setup for magnetic fluid seals was designed, enabling precise control of magnetic field intensity in sealing gaps by adjusting the number of magnetic conductive blocks. This allowed accurate measurement of starting torque under varying magnetic field strengths. Experimental results demonstrate that both reducing magnetic field intensity and employing low-temperature magnetic sedimentation-treated magnetic fluids significantly reduce starting torque, albeit with a slight trade-off in pressure resistance. This research provides a robust solution for optimizing magnetic fluid seal performance in low-temperature environments, highlighting its importance for enhancing the reliability of high-end equipment under extreme conditions.

D23-P03

“咖啡环效应”对复合磁性液滴靶向治疗黏附力的研究

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假设：复合磁性液滴的黏附特性取决于液滴的三相接触线长度。含有纳米颗粒的液滴蒸发中诱导了液滴内部的马兰戈尼流，纳米颗粒被带到并钉扎在液滴边缘，会阻碍接触线的扩展和收缩，因此我们推测液滴的黏附特性取决于液滴边缘的“咖啡环效应”。

实验：制备具有不同浓度的 SiO2/Al2O3 悬浊液代替包裹药物的复合磁性液滴，并通过抽取/蒸发的操作获得颗粒分布均匀/颗粒聚集边缘线的液滴。在 PDMS/PETS 基底上直接测量液滴的 Snap-in 力和法向黏附力以及记录液滴形貌轮廓。

发现:由于自然蒸发过程中，纳米颗粒（SiO2）会“钉扎”在接触线边缘，因此在 PDMS/PETS 基底上液滴黏附功和最大黏附力会由于“咖啡环”的存在而随着增大，阻碍液滴接触线的收缩；另一种纳米颗粒（Al2O3）在自然蒸发中并未形成“咖啡环”，因此液滴黏附功和最大黏附力差别不明显。

本研究报告的“咖啡环效应”对复合磁性液滴靶向治疗黏附力的影响将有利于磁流体在癌症靶向治疗中的黏附调控提供理论支撑，实现药物的高效释放。

D23-P04

外源磁场激励下磁性液体液固体系润湿行为的表界面调控研究

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磁性液体作为一种多组分超顺磁性材料，对磁场表现出显著的响应特性，已在微流控、自清洁材料、微纳制造及靶向药物递送等众多领域展现出广阔的应用前景。近年来，磁性液体的润湿特性研究已成为前沿研究热点。本文针对外源磁场对不相溶磁性液体基底上固着液滴润湿行为的调控展开系统研究，构建了以磁性液体为中间相的液-液-固复合润湿体系。采用光学接触角测量技术对静态接触角进行了精确测量与深入分析，探讨了利用磁性液体精密调控液滴润湿特性的可行性，并深入研究了其对液滴润湿行为的调控效应及相关机制。研究发现，由于 Rosensweig 不稳定性而在磁性液体表面形成的尖峰拓扑结构，能够对不相溶液滴起到有效的支撑作用，并使其保持稳定的椭球形貌。特别地，实验观察到液滴在与其不相溶的磁性液体所形成的尖峰拓扑结构接触时，其表观接触角表现出显著增大。

D23-P05

对狭窄密封通道中高剪切率下磁性液体微观和宏观相结合下磁流变效应的研究

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磁性液体兼具磁场响应能力和流动特性，使其广泛应用于密封、阻尼器、光学器件等。然而，目前磁性液体在密封的狭窄通道中高剪切率下存在粘度非线性变化等独特的磁流变效应。这种效应将直接影响密封的发热，并影响密封的可靠性。因此，对于密封间隙的狭窄通道高剪切率特殊情况，本文从微观和宏观两个层面，探究了磁性液体微观结构对磁流变效应的影响机制。推导了微观系统的计算应力公式，建立了高剪切流下磁性颗粒成链与断裂的仿真模型，通过粘度仿真与流变仪测量，得到了狭窄通道中高剪切率下磁性液体的流变特性。在剪切率升高时，磁性液体的粘度会显著下降，表现出剪切稀化现象。在弱磁场下，磁场增强会加强磁粘效应；在强磁场下，磁场增强会出现磁粘降效应。研究结果将为用于密封的磁性液体制备提供理论基础，对于拓宽磁性液体的应用领域具有显著的作用。

D23-P06

磁性液体密封寿命预测研究

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磁性液体密封一直以零泄漏、长寿命著称，但在使用过程中，需要进行磁性液体的补充，对于何时进行磁性液体补充一直没有预测时间与手段，本文的磁性液体密封寿命即指磁性液体从第一次加注到第二次补充的时间，进行一个补充磁性液体的时间预测。本文从磁性液体挥发入手，设计了挥发装置，模拟磁性液体在密封间隙中极齿下的挥发工况，研究磁性液体挥发速率，得到磁性液体的平衡体积，建立了寿命预测模型，进行寿命预测。

D23-P07

基于磁流体的摩擦-电磁双模振动俘能器设计与性能研究

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针对传统俘能器在收集微弱振动能量方面的不足，本研究基于液-固摩擦纳米发电机理，结合封闭式 TENG 的振动俘能实验结果，提出了一种结构紧凑的磁流体摩擦-电磁双模振动俘能器。通过液滴与 PTFE 薄膜管动态接触过程的多物理场耦合模拟仿真，揭示了电极表面电荷转移的不均匀分布现象和电压变化机制，实验断路电压极值可达 200mV。搭建了基于 PTFE 薄膜管-铝箔电极的封闭式液-固摩擦纳米发电机（L-S

TENG）实验装置，系统地研究了振动激励和 TENG 结构对装置发电性能的影响，实验表明在频率 10Hz 振幅 2mm 条件下，使用磁流体作为摩擦液体比去离子水提高约 42％的电压输出。基于此通过磁-机-电多场耦合设计开发了结合摩擦发电（TENG）和电磁感应发电(EMG)的复合能量转换振动俘能器，TENG 组件由聚四氟乙烯（PTFE）内壁、电极及磁流体组成，EMG 组件由线圈、永磁体及磁流体组成，两者对应的短路电流输出分别为 0.1μA 和 0.35μA，进一步提升了俘能器的输出功率。设计整流电路后俘能器实现超过 100mV 的稳定电压输出，适用于微功率电子产品、分布式传感器网络等设备的自供电需求，展示了其在低功耗分布式设备的广阔前景。

D23-P08

Numerical Study on Magnetic Liquid Rotary Sealing for Large Shaft Diameter

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As an advanced sealing technology based on novel nano-functional materials, magnetic liquid seals exhibit advantages including zero leakage, long lifespan, high reliability, and low friction. To enhance the sealing performance of magnetic liquid rotary seals for large shaft diameter, a physical model of the sealing device was established using the finite element method. This study reveals the magnetic field distribution patterns and fluid flow dynamic characteristics of large-diameter magnetic liquid rotary seals, with a focus on investigating the coupled effects of multiple parameters—such as pole tooth profiles, geometric parameters of pole teeth, and machining positions of pole teeth—on sealing mechanisms. The research demonstrates that sealing performance decreases with an increase in sealing gap, first increases and then decreases with a higher ratio of pole tooth width to groove width, and initially declines before improving as pole tooth height increases. This study provides a theoretical basis for the design of large-diameter magnetic liquid rotary sealing.

仅发表论文

D23-PO01

基于亲水二氧化硅的复合磁性液体在稳态剪切下的磁流变行为

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本文研究了一种基于亲水型气相二氧化硅的复合磁性液体在稳态剪切条件下的磁流变行为。通过向水基磁流体中引入不同质量分数的亲水性 SiO_2 纳米颗粒（初级粒径约 7–14 nm），制备出结构稳定的复合磁流体，并在外加磁场强度范围为 0–300 kA/m 下进行了系统的剪切流变性能测试。研究参数包括磁场强度、剪切速率以及二氧化硅颗粒的添加量。实验结果表明，在稳态简单剪切流动中，Mason 数（Mn）可有效表征体系的流变行为，尤其在低至中等 Mn 范围内展现出良好的数据标度性。在低 Mn 区域，体系表现出两种典型的流变特征：其一，黏度随剪切速率降低而持续升高，表明存在屈服应力；其二，在低剪切速率下出现黏度平台，表征体系接近屈服而未完全发生结构重构。在中等 Mn 区域内，体系黏度呈幂律衰减趋势，符合 $\eta \propto Mn^n$ 的关系，幂指数 n 位于−1 至−2/3 之间。进一步采用宏观与微观尺度下的建模方法，从椭球形、圆柱形以及单尺度粒子链的构型假设出发，对体系的屈服行为进行了解释。本研究有助于深入理解亲水性 SiO_2 在复合磁流体中对磁响应与屈服行为的调控机制，为其在低剪切流动环境下的功能化应用提供理论支持。

D23-PO02

化学共沉淀法制备磁性液体过程中影响表面活性剂包覆因素的研究

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本文首先通过化学共沉淀法制备磁性颗粒，以 XRD、TEM 和 VSM 测试表明了磁性颗粒最佳制备温度为 40℃，此条件下制备的磁性颗粒饱和磁化强度大，达到 79.06 emu/g，颗粒粒径较小，分散度高，平均粒径仅为 14nm 左右，满足制备磁性液体的要求；随后通过红外和热重等测试证明了表面活性剂油酸对磁性颗粒的改性，发现当改性溶液中仅含有氨水时，油酸对磁性纳米颗粒的改性效果最佳，接触角测量和吸附能模拟计算进一步表明，通过这种方法获得的磁性纳米粒子与水的接触角最大，吸附能更大，油酸包覆效果最佳；此种磁粉分散在煤油基载液后所得的磁性液体饱和磁化强度高，可达到 27.49 emu/g，稳定性好，经过永磁铁 12 小时的磁沉，磁性液体的饱和磁化强度仅下降了 9.96%，为 24.75%，仍可满足密封要求。本研究探究了共沉淀法制备磁性液体过程中表面活性剂改性纳米颗粒的最佳条件，探索了高质量的煤油基磁性液体的制备工艺，为后来者的研究提供一定的参考价值。

D23-PO03

Preparation and characterization of irradiation-resistant perfluoropolyether-based magnetic fluid

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Traditional water-based magnetic fluid and kerosene-based magnetic fluid have poor stability under strong irradiation, which cannot meet the sealing requirements for long-term stable operation under strong irradiation and corrosive environments in special fields such as nuclear energy and aerospace. In this paper, a method for the preparation of irradiation-resistant perfluoropolyether-based magnetic fluid is proposed, perfluoropolyether-based magnetic fluid with different average molecular weights are prepared, and the magnetic properties of the prepared magnetic fluid are investigated after being irradiated by gamma irradiation at different doses. The results show that the magnetic properties of the prepared perfluoropolyether-based magnetic fluid are excellent and remain unchanged after 10 MGy gamma irradiation.

D23-PO04

High-Uniformity Magnetic Field and Ultra-Stable Temperature Modules for the Parallel-Plate Magnetic Fluid Rheometer: Design, Simulation, and Experimental Validation

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This paper presents a parallel-plate magnetic fluid rheometer integrated with a high-uniformity magnetic field module and an ultra-stable temperature control module, addressing the limitations of conventional rheometers in terms of magnetic field uniformity, thermal stability, and measurement accuracy. The rheometer employs a circulation cooling mechanism and an optimized magnetic circuit design, achieving precise temperature control (±0.1°C) and 99% magnetic field uniformity in the measurement zone. Through theoretical derivation and simulation validation, the system generates tunable magnetic fields exceeding 1.4 T and operates across an extended temperature range from −60°C to 120°C. In the thermal conduction analysis, steady-state heat transfer models for multilayer cylindrical and flat walls were established, deriving the distribution laws of heat flux density and thermal resistance. Combined with a loop active refrigeration system, the thermal field stability was significantly enhanced. For the magnetic circuit analysis, a closed-loop magnetic circuit model was developed based on Maxwell's equations and Ampère's circuital law. High-permeability cores and multi-layer shielding structures were optimized to suppress edge magnetic gradients. In addition, a three-section rotor (non-magnetic/magnetic composite structure) is innovatively designed to reduce magnetic field distortion and improve the uniformity of the magnetic field in the measurement area. Experimental results demonstrate that the

magnetic field uniformity deviation in the measurement zone is below ±1%, and the temperature control system has excellent stability under extreme conditions. This platform provides a novel methodology for investigating multiphysics-coupled rheological behavior of magnetic fluids in extreme environments, with potential applications in high-precision fields such as aerospace seals and smart damping systems.

D23-PO05

硅油基磁性液体的制备及其在高温密封中的性能研究

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磁性液体密封具有零泄漏、无接触磨损、寿命长，可靠性高等优点，被广泛应用于真空及高端装备密封领域，然而磁性液体本身受材料分子量限制，难以在宽温域下保持较低的粘度变化。针对上述问题，在现有磁性液体密封结构的基础上，以羧基硅油作为表面活性剂制备了不同粘度的硅油基磁性液体，对其磁学性能和流变学性能进行了表征，通过实验研究了其在变温工况下的密封摩擦力矩和自恢复性能。该硅油基磁性液体具有良好的磁化性能、较低的粘温系数和挥发率，饱和磁化强度可达 300Gs，挥发率量级在 10^{-6} $g/cm^2 \cdot h$，粘度随温度的变化程度低，能够有效降低磁性液体密封随温度变化时的力矩波动，并提高高温密封的自恢复性。

D23-PO06

Influence of surfactant content on the performance of kerosene-based magnetic liquid

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Magnetic liquid is a novel functional material with significant applications in sealing, vibration reduction, and sensing. Composed of magnetic particles, surfactant and base liquid, the surfactant plays a crucial role in determining the magnetic liquid's particle size, saturation magnetization, and stability. To explore the impact of the surfactant content on the magnetic liquid's properties, this study optimized the preparation of kerosene-based magnetic liquid. Magnetic particles were synthesized via chemical co-precipitation at 40°C. Characterization with a vibrating sample magnetometer (VSM)and transmission electron microscopy (TEM)reveals a saturation magnetization of 67.31 emu/g and an average particle size of 15 nm. Subsequent surface modification with different oleic acid volumes showed that 6 ml of oleic acid yielded the highest saturation magnetization (39.68 emu/g), but the liquid lost its fluidity after one year. In contrast, 7 ml of oleic acid produced a liquid with slightly lower magnetization (29.14 emu/g) that retained fluidity, meeting sealing application requirements. This research provides valuable insights into the role of surfactant content in kerosene-based magnetic liquid preparation.

D23-PO07

Design and Experimental Study of Magnetic Fluid Seal under High and Low Temperature and Vacuum Conditions

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Uranium enrichment is the core technology of nuclear energy production and nuclear weapon development, which is related to the national economy, people's livelihood and national security. Uranium enrichment pump is one of the indispensable key equipment in the process of uranium enrichment. In the process of work, it relies heavily on efficient and reliable sealing to prevent the leakage of radioactive materials and ensure the safe, stable and continuous work of the equipment. Therefore, it has extremely high requirements for sealing performance, and the traditional sealing methods cannot meet the requirements. Magnetic fluid seal have shown great application potential in the field of nuclear energy due to their outstanding advantages such as zero leakage, long life, high reliability, and no pollution. In this paper, aiming at the problem of poor high and low temperature resistance and vacuum resistance when the magnetic fluid sealing is applied to the uranium enrichment pump, the theory, material, structure, simulation and experiment are systematically studied. The preparation method of high and low temperature resistance and vacuum resistance magnetic fluid is proposed, and the perfluoropolyether oil-based magnetic fluid with different molecular weights and different mass fractions with stable performance are prepared and characterized. The corresponding magnetic fluid sealing scheme is designed, and the simulation optimization and experimental verification are carried out. Finally, the designed magnetic fluid sealing device has excellent applicability and feasibility to the uranium enrichment pump.

D23-PO08

基于广义保守相场-简化格子 Boltzmann 模型的气-液界面磁流体液滴变形动力学数值研究

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本文采用一种数值模型研究了悬浮于空气与液体基底之间的铁磁流体液滴在垂直均匀磁场作用下的动力学机制与典型变形行为。流体流动与相界面的演化由一种广义保守型相场简化多相格子玻尔兹曼模型求解，该模型在处理高密度比三相流动问题中展现出良好的稳定性。磁场由静磁学中的麦克斯韦方程给出，并通过自校正数值方案进行求解。在此基础上，我们系统地模拟并分析了铁磁流体液滴在垂直磁场作用下的动态演化过程，重点考察了液滴形态随时间的演变特征。为定量描述液滴变形行为，本文引入了液滴纵横比、拉伸速度与质心高度等表征指标，研究表明这些特征量均与磁邦德数密切相关。数值模拟结果与已有实验数据保持良好一致性，验证了所提模型的准确性与有效性。进一步地，基于标度分析方法，揭示了液滴纵横比与磁邦德数之间存在明确的幂律关系。

D23-PO09

磁性液体加速度传感器的设计

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设计了一种小型化的磁性液体加速度传感器，旨在利用磁性液体的独特物理特性实现加速度测量。研究工作涵盖了磁性液体的基本理论分析、性能参数测量、加速度传感器理论建模、磁场仿真、实体模型设计、LabVIEW 数据采集系统开发以及传感器性能测试等多个方面。通过对磁性液体的密度、粘度、磁化特性等参数的详细测量，结合传感器的二阶惯性系统模型，深入分析了一阶和二阶浮力原理对传感器性能的影响。利用有限元仿真验证了传感器内部磁场分布的合理性，并基于霍尔检测模式开发了小型化的传感器实体模型。实验结果表明，煤油基磁性液体在传感器中的表现最为优异，有更好的静态和动态性能。这些性能优势与煤油基磁性液体的物理特性密切相关。未来工作将聚焦于进一步研究磁性液体的特性对传感器性能的影响机制，探索更多优化途径，进行更深入的理论分析和实验研究，推动磁性液体加速度传感器技术向更高精度、更小尺寸和更广泛应用的方向发展。

D23-PO10

Optimization and lightweight design of magnetic fluid sealing device

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The application of magnetic fluid sealing device in the aerospace field puts forward higher requirements for its weight. How to reduce the weight of the device on the basis of ensuring the pressure resistance is an urgent problem to be solved. In this article, we use ANSYS and Design-Expert software to optimize the parameters of the pole teeth at first, and then the weight of the sealing device with the optimal pole teeth parameters is reduced by removing two parts of the pole shoes. The results show that there is an optimal pole teeth parameter to maximize the pressure resistance of the device, and these two parts of the pole shoes are removed reasonably can not only reduce the weight of the sealing device, but also adjust the distribution of magnetic lines to reduce magnetic leakage, and further improve the pressure resistance of the device.

D23-PO11

基于压力传感器的磁性液体等效密度精确测量方法

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针对传统标准密度珠法在不透明磁性液体中等效密度测量存在的局限性，本文提出了一种基于压力传感器的磁性液体等效密度精确测量方法，并建立了多物理场耦合模型。通过理论推导，建立了磁性液体内部压力梯度与等效密度的关系式，提出利用压力传感器直接测量不同高度压力变化以计算等效密度的新方法。实验设计采用硬质空心杆集成压力传感器，结合永磁体（N54）和三种基液磁流体（水基、机油基、煤油基），通过数据采集卡记录压力信号，并通过红外辅助观测标准密度珠悬浮位置验证结果。基于 COMSOL 仿真建立了磁场-流场耦合模型，引入磁化曲线修正磁性液体非饱和特性，仿真结果与实验数据对比显示，等效密度最大偏差为 3.4%（铜球）和 4.9%（铝球），验证了方法的准确性。实验表明，压力传感器法适用于不透明磁流体，且测量效率较传统方法提升显著。本研究为磁性液体在分选、密度测量等领域的应用提供了高精度、便捷的测量方案。

D23-PO12

Design and pressure resistance analysis of a magnetic seal with variable groove width

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Abstract: The magnetic seal includes magnetic fluid seal and micro-nano magnetic powder seal, which have advantages such as long service life and adaptability to a wide temperature range. However, they often face problems such as limited axial dimensions. In order to reduce the axial dimensions of the magnetic seal and at the same time to ensure the pressure resistance of the magnetic seal, a magnetic sealing scheme with variable tooth groove width was designed, and two kinds of equal groove width seal structures with the maximum and minimum groove widths in the range of variation were used as controls. The magnetic field distribution of the seal was investigated by using finite element simulation method respectively. The results show that the magnetic induction intensity difference between the seals at all levels is reduced by the scheme of directly reducing all the tooth width, which will significantly reduce the pressure resistance of the seal. With the program of variable tooth groove width, the axial dimensions of the seal is reduced and the pressure resistance is not much different from that when the tooth groove width is the maximum. According to the simulation results, a magnetic fluid seal structure was optimized. The distribution of magnetic lines of force was analyzed by finite element method and the pressure resistance of the two sealing structures was compared.

D23-PO13

Oil-based magnetic fluids as well as simulation and experimental study of its combination seals

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In the context of modern industrial machinery such as reactors, which require zero leakage and the ability to withstand pressure fluctuations, a magnetic fluid based on engine oil was selected and characterized. Based on this, a device combining a labyrinth seal and magnetic fluid was designed to meet the sealing requirements of complex operating conditions. Using ANSYS finite element software, magnetic field simulations were performed on the combined seal, and the theoretical maximum pressure resistance value of the combined seal structure was calculated. A combined seal test bench was constructed, and the total pressure resistance of the combined seal test components was obtained through pressure resistance tests. Experimental studies were conducted on the sealing lifespan and self-healing capabilities of the combined seal and the single magnetic fluid seal. The results showed that the sealing duration of the combined seal increased by 12%, and the self-healing capability of the combined seal was superior to that of the single magnetic fluid seal structure.

D23-PO14

单向磁性液体微差压传感器设计及特性研究

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磁性液体兼具流体的可流动性与固体磁性材料的磁响应特性，本研究基于此原理提出了一种结构紧凑的单向磁性液体微差压传感器。传感器将磁性液体填充于 U 型管底部，在一侧 U 型管底部嵌入永磁体，管径设计为小于永磁体直径，以有效防止永磁体在管内卡滞；同时在该侧管壁设置透气端口，实现与大气压的连通，并防止因腔内气压过大导致永磁体溢出。传感器通过置于永磁体侧的霍尔元件实时采集局部磁场强度变化，将其与管内液柱高度差—亦即微小压差一一对应，实现压力信号的精准转换与输出。与现有磁性液体微差压传感器相比，本传感器在保持结构小型化与低成本优势的同时，显著提升了灵敏度与响应速度，并凭借优异的稳定性与重复性，满足了高精度压力测量的应用需求。

D23-PO15

基于磁性液体二阶浮力效应的高线性度倾角传感器设计

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磁性液体兼具流体的可流动性与固体磁性材料的磁响应能力，能够在重力与外加磁场共同作用下维持稳定结构。基于磁性液体的二阶浮力效应，本文设计了一种新型磁性液体倾角传感器。该传感器利用倾斜时永磁体位置变化引起的磁场分布改变，通过霍尔元件输出与倾角成正比的电压信号。系统采用单片机内置 ADC 模块对信号进行实时采集与处理，并将数据在液晶显示屏上直观呈现。相比传统磁性液体倾角传感器，本系统引入预先标定的磁场-检测量耦合曲线进行补偿校准，有效提升了传感器的线性度与长期稳定性，具有良好的应用前景。

D23-PO16

非对称异形极齿磁性液体密封机理及实验研究

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磁性液体是一种稳定的胶体溶液体系，由纳米级磁性颗粒均匀分散于基载液中，并借助表面活性剂稳定悬浮而成。其独特的磁-流耦合特性使其在密封领域展现出显著优势，然而传统磁性液体密封多采用对称极齿结构，在高速、高压等复杂工况下，对称磁场分布易导致磁流体界面失稳，降低密封性能，针对这一问题提出一种非对称异形极齿磁性液体密封实验装置。通过理论建模与实验验证相结合的方法，建立非对称异形极齿结构的磁场-流场耦合模型，分析极齿倾角、齿距及非对称度对密封性能的影响规律。通过有限

元仿真，优化极齿参数以提高磁流体界面的稳定性。实验结果表明，非对称异形极齿结构可有效抑制磁流体涡流和飞溅现象，在相同工况下泄漏率降低，密封性能得到明显提升，显著增强了磁性液体密封的动态稳定性和抗扰动能力。

D23-PO17

Non-equilibrium Flow Characteristics of Magnetic Fluids

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In a flowing magnetic fluid, when the flow timescale is comparable to the magnetization relaxation time of the fluid, the magnetization relaxation effects cannot be neglected. In such cases, the magnetization equation must be used to describe the magnetization process of the fluid. This paper comprehensively reviews the non-equilibrium flow characteristics of magnetic fluids under magnetization relaxation, including Couette–Poiseuille flow, pipe flow, concentric circular flow, and spin-up flow under uniform constant magnetic fields, constant magnetic fields with gradients, and time-varying magnetic fields. These flow patterns serve as theoretical models for applications such as magnetic fluid seals, micropumps, and vibration damping.

D23-PO18

Structural design and research of magnetorheological damper with anti-temperature rise and anti-sedimentation function

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In this study, a magnetorheological damper (MRD) with double tube full circulation structure was designed. This design aims to effectively solve the problem of temperature rise and sedimentation of magnetorheological fluid (MRF) in traditional MRD. The performance of the new MRD structure in alleviating the problems of temperature rise and sedimentation was systematically evaluated through numerical simulation, theoretical calculation and experimental test. The results of transient thermal simulation showed that the temperature rise rate of MRF in the MRD decreased by 19.28% after the introduction of antifreeze coolant. The results of fluid simulation indicated that the flow hole at the bottom of the inner cylinder enabled the MRF in the sedimentation area (the bottom of the model) to circulate within the MRD, thereby realizing redispersion. The experimental results of temperature rise experiment show that the temperature rise rate of MRF in the new MRD is reduced by 23.64%, when the current increases from 0.5 A to 2 A. The experimental results of sedimentation experiment show that the density of MRF at the top of the model is increased by 41.5%, with the piston speed of 9 mm/s, the amplitude of ± 30 mm, and the operation cycle of 200 cycles. The results of MRD performance experiments show that the new MRD can redistribute the already sedimentary MRF during operation and maintain stable output damping force in long-term working conditions. This study proposes an innovative structure-based methodology to address the sedimentation and temperature rise issues in MRD systems.

D23-PO19

Structural design and research on transmission performance of wedge groove type extrusion-shear magnetorheological clutch

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A wedge-shaped squeeze shear magnetorheological clutch is proposed to address the problem of small torque transmission and large axial size of traditional single cylindrical magnetorheological clutches with shear effects. The wedge block is used to squeeze the magnetorheological fluid, which may increase the magnetic flux density in the working area, and thus increasing the shear yield stress of the magnetorheological fluid and improving the transmission performance of the clutch. The Finite Element Method was used to simulate the electromagnetic field of the clutch model, and the effects of current, coil arrangement, wedge size and shape on the magnetic flux density in the working area of the clutch were analyzed. A new torque transmission mechanics model for magnetorheological clutch was established based on Bingham model, and the performance of the designed clutch in this model were analyzed under different parameters such as current, speed, and clearance thickness. Experiments were conducted on no-load transmission, static characteristics, and constant torque characteristics, by building a magnetorheological clutch test platform. The results showed that under the working conditions of current 1A and speed 300r/min, the new magnetorheological clutch transmitted a torque of 4.76N·m, while the traditional clutch transmitted a torque of 3.33N·m. The torque transmission ability of the new clutch is superior to that of the traditional magnetorheological clutch, verifying the effectiveness of the wedge groove structure in improving transmission performance.

D23-PO20

表面织构与磁性液体协同作用的滑动轴承润滑性能研究

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传统润滑介质在重型油膜滑动轴承等领域的高载荷、高低温和真空等工作条件下，轴承寿命急剧缩短，运动副稳定性降低，无法满足工作需求。磁性液体具有空间位置可调、异物排它性、粘度可调和油膜自恢复等优势，表面织构在摩擦过程中可以起到捕捉磨屑、存储润滑剂和产生流体动压效应的作用，且加工简便。基于表面织构和磁性液体润滑的研究，提出一种新的基于压力映射的非平面织构的磁性液体轴承结构，建立轴承流体域模型，使用 FLUENT 软件求解并分析其流场润滑特性。通过分析不同压力映射方式、织构的类型和重要参数的磁性液体滑动轴承流体域的承载力和摩擦系数，对比确定流场润滑特性较优的结构形式与参数。结果表明：圆形织构承载力最高，摩擦系数最低，润滑效果最好；织构位于油膜最薄处时，承载力下降，织构位于主承载区，承载力提升；全织构和三种压力映射模型相比于无织构模型承载力均增大，摩擦系数均减小，压力映射Ⅲ最优；织构底面的倾角增大，承载力增大，摩擦系数减小；织构直径增大，承载力先增大后减小，摩擦系数先减小后增大，存在最优的织构直径 1.5mm 使得润滑效果最好；织构深度增大，承载力先增大后减小，摩擦系数先减小后增大，存在最优的织构深度 50μm 使得润滑效果最好。

D23-PO21

DIOS 基磁性液体润滑的分子机制与多因素影响研究

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磁性液体润滑剂在极端工况下展现出独特的润滑性能，其中 DIOS 基磁性液体因其优异的稳定性和磁响应特性受到广泛关注。为研究 DIOS 基磁性液体在纳米尺度下的润滑机制，分析外部因素（温度、剪切速率和压力）对润滑性能产生的影响，通过构建以油酸为表面活性剂，Fe_3O_4 为磁性颗粒分散于 DIOS 基载液中的复合体系模型，开展限制性剪切模拟。模拟揭示了磁性颗粒在剪切作用下的动态行为与润滑机制，阐明了温度、剪切速率和压力外部因素对 DIOS 基磁性液体润滑性能的影响规律。结果表明，随着温度的升高，DIOS 基磁性液体流动特性增强，润滑性能提升；随着剪切速率的增加，DIOS 基磁性液体表现出典型的剪切稀化现象，流动特性增强，但润滑性能有所下降；随着压力的增大，DIOS 基磁性液体流动特性减弱，润滑性能提升；由 Fe_3O_4 磁性颗粒运动轨迹可知，随着剪切过程的进行，Fe_3O_4 磁性颗粒除随着剪切发生了滑动与滚动，即滚滑协同运动。上述研究发现不仅深化了对 DIOS 基磁性液体润滑机理

的理解，同时为该材料在工业润滑领域的实际应用提供了理论基础。

D23-PO22

多级离心式磁性液体密封的密封机理及实验研究

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磁流体密封是基于磁性纳米流体在梯度磁场中形成动态密封的非接触式密封技术，有零泄漏、长寿命等优势。但在高速、高压复杂工况下挑战众多：一是磁流体受离心力易飞溅损耗；二是高速运转产热严重，高温降低磁流体粘度与磁化强度，削弱密封耐压能力。本研究旨在克服高速离心力影响，提高密封耐压能力。鉴于离心密封可解决磁流体飞溅问题，在此创新：一是设计新型极齿结构，以减少磁流体产热；二是采用多级离心密封增强耐压能力。通过构建多级离心结构的磁场 - 流场 - 温度场模型，分析新型极齿结构参数对产热、离心级数对耐压能力的影响。实验表明，新型极齿结构可以降低高速工况时磁流体产热，多级离心式结构可大幅削弱高速离心力对磁流体的作用，显著提升密封耐压能力。多级离心式密封结构在高速、高压工况有良好适用性。

D23-PO23

基于铁磁流体的磁控靶向药物递释系统用于黑色素瘤化学-光热协同治疗研究

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癌症是人类疾病史上需要攻克的重大难题。化疗目前仍是癌症治疗的常用办法，但有极大的副作用和药物利用率。为了降低药物副作用，提高药物靶向性，本项目提出了一种基于铁磁流体的磁控药物靶向治疗系统。铁磁流体可以负载化疗药物在磁场控制下穿越复杂血管网络到达指定地点并停留释放，加之铁纳米颗粒的光热转换性能实现肿瘤的光热治疗，最终实现化疗-光热的联合靶向治疗。本项目开展了基于生物相容性铁磁流体的药物靶向递释系统治疗肿瘤的研究。本项目首先制备了一种生物相容性铁磁流体，并装载了化疗药物。本课题搭建了一套磁控系统，体外验证了磁流体的运动能力和自适应形变穿越复杂血管的能力。然后通过磁场控制磁流体到达肿瘤部位，进行药物释放和光热联合治疗。细胞实验和动物实体肿瘤的杀伤实验证明，磁流体负载化疗药物治疗肿瘤和光热杀伤肿瘤的联合治疗效果显著。为将来进一步探索磁控药物靶向治疗提供了新的方式。

D23-PO24

基于分子动力学磁性液体导热强化机理研究

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复合磁性液体因相较于传统磁性液体具有更为优异的导热性能而得到广泛应用，然其微观作用力和内部运动对导热性能的影响较为复杂，导热强化机理难以完全由传统宏观理论解释。为深入探究复合磁性液体导热强化机理，我们基于分子动力学方法，采用非平衡分子动力学（NEMD）模拟流体传热过程，将水基 Fe3O4 磁性液体与 Ag@Fe3O4 复合磁性液体模型，分别简化为氩基铜（Cu@Ar）纳米流体与氩基铜-银复合纳米流体(Ag-Cu@Ar)模型。并结合径向分布函数（RDF）与均方位移（MSD）分析，具体分析了微观受力运动的影响。研究发现，含有单一颗粒（Cu）和复合(Ag-Cu）氩基纳米流体的 RDF 结果均表现了液体“短程有序，长程无序”的典型特征。通过对比复合纳米流体模型的 MSD 分析，发现低浓度时，Cu 纳米颗粒的扩散效果要优于 Ag 颗粒，随着纳米流体浓度的增加，Ag 纳米颗粒在纳米流体扩散效果更好，因其具有更为优异的热物性能，对纳米流体导热性能提升方面发挥更大的作用。在因浓度升高而形成的高致密性液体膜和纳米颗粒团聚二者的共同作用下，流体内部微观结构发生了近似于固体的变化，提高了复合纳米流体的导热性能。本研究为复合磁性液体导热强化机理提供了微观层面的科学解释，具有重要的学

术价值。

D23-PO25

In-situ Co-precipitation Synthesis of Silicone Oil-based Magnetic Fluids and Performance Study on Multi-walled Carbon Nanotubes Doping

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This paper presents the synthesis of two types of silicone oil-based magnetic liquids through in-situ co-precipitation. Oleic acid, a widely used surfactant in the preparation of magnetic liquids, was utilized to stabilize the synthesized magnetic fluids. Different amounts of multi-wall carbon nanotubes (MWNTs) were doped to explore their effects on the properties of the magnetic fluids. The synthesized nanoparticles were characterized using X-ray diffraction (XRD) and infrared spectroscopy (IR) to determine the phase and structural information. The results clearly show that the samples consist of Fe_3O_4 particles and MWNTs coated with oleic acid. The stability of the magnetic liquids was evaluated by the L-C oscillator circuit method, while the rheological properties of the silicone oil-based magnetic fluids with varying MWNT concentrations were examined using an Anton Paar Physica MCR 302 rotational rheometer. Rheological studies indicate that the magnetic fluid containing 0.6 g of MWNTs demonstrates superior viscosity-temperature performance compared to that containing 0.5 g of MWNTs. In the absence of a magnetic field, the magnetic fluids behave as Newtonian fluids, and their viscosity can be significantly affected by the application of a magnetic field.