汽车与交通工程学院 2023 届研究生培养成果展

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发表论文：

[1]：Cai W, Zhang Y, Huang F, Ma C (2023) Delivery routing problem of pure electric vehicle with multi-objective pick-up and delivery integration. PLoS ONE 18(2): e0281131. https://

doi.org/10.1371/journal.pone.0281131

软件著作：

[1] 物流运输配送车辆智能定位跟踪管理系统.V1.0．(2021SR1700566)．湖北文理学院．

发表论文截图：

Delivery routing problem of pure electric vehicle with multi-objective pick-up and delivery integration

Wangang Cai, Yihao Zhang, Fuyou Huang, Chao Ma

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Abstract

With the growth of people's environmental awareness and the encouragement of government policies, the use of electric vehicles in logistics distribution is gradually increasing. In order to solve the dual demand of customers' simultaneous pick-up and delivery in the "last kilometer logistics", an electric vehicle routing problem with simultaneous pick-up and delivery and time window (EVRPSPDTW) is considered from the perspective of multi-objective distribution in this paper. Firstly, a decision-making model based on distribution cost and power consumption function is established. In this model, distribution cost includes transportation cost, vehicle use cost, penalty cost of not arriving on time and charging cost. Power consumption function is the energy loss caused by air resistance, tire rolling friction and transmission system. Secondly, a multi-objective genetic algorithm (NSGA-II) optimization solution with fast nondominated ranking and elite strategy is designed, and in view of the shortcomings of traditional NSGA-II, it is proposed to complete population initialization through greedy algorithm and random rules, introduce adaptive cross-mutation strategy in the chromosome crossing and mutation stage, and design three different neighborhood operators in mutation operation based on variant fitness function. Finally, the sensitivity analysis of traffic congestion coefficient further proves the effectiveness of the proposed model and the improved algorithm.

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大赛官网：https://3DDS.3DDL.net

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授权专利名称：

[1] 基于加密球的双窗口结构智能防盗钥匙柜．发明专利授权，CN202110115725.5．

[2] 一种用于密集烤烟房专用的智能烟叶图像采集装置．实用新型专利授权，CN202230229622.7．

[3] 烤房专用摄像头．外观专利授权，CN202230229622.7．

授权专利截图：

证书号第5045705号

发明专利证书

发明名称：基于加密球的双窗口结构智能防盗钥匙柜

发　明　人：张华;程子健;徐锐;刘政;邹梅;王培元;张海军;杨迎化

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第1页(共2页)

其他事项参见续页

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实用新型专利证书

实用新型名称：一种用于密集烤烟房专用的智能烟叶图像采集装置

发　明　人：张华;刘政;程子健;徐锐;陶彦清;邹梅;桂石鼎;王培元
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设　计　人：邹梅;张华;程子健;陶彦清;徐锐;桂石箭;王培元;刘政
赵素浩

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其他事项参见续页

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冯占雄（1995-），女，河北唐山人，预备党员，汽车与交通工程学院 2020 级机械专业研究生，导师是汪云教授。科研方面：研究生期间主要从事车用质子交换膜燃料电池铂碳催化剂的制备及其氧还原性能研究，参与项目 3 项，发表 SCI 论文 2 篇，EI 论文 1 篇。获奖情况：2020-2021 年度获三等学业奖学金；2021-2022 年度获三等学业奖学金；2022-2023 年度获国家奖学金、一等学业奖学金、优秀研究生；湖北文理学院 2023 届优秀毕业研究生。目前已考取武汉科技大学博士研究生。

发表论文：

[1] Zhang C，Feng Z X，Lei Y J，et al．Batch synthesis of high activity and durability carbon supported platinum catalysts for oxygen reduction reaction using a new facile continuous microwave pipeline technology[J]．Journal of Colloid&Interface Science，2022，628(B)：174-188．(SCI) https://doi.org/10.1016/j.jcis.2022.08.058.

[2] Feng Z X，Jadhav C D，Patil G P，et al．Solution processed 2D SnSe nanosheets catalysts：Temperature dependent oxygen reduction reaction performance in alkaline media[J]．Journal of Electroanalytical Chemistry，2022，916：116381．(SCI) https://doi.org/10.1016/j.jelechem.2022.116381.

[3] 冯占雄，汪云，马强，等．连续管道微波技术制备 Pt/C 催化剂及其氧还原性能[J]．化工进展，2022，41(12)：6377-6384．(EI) https://doi.org/10.16085/j.issn.1000-6613.2022-0305.

发表论文截图

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Batch synthesis of high activity and durability carbon supported platinum catalysts for oxygen reduction reaction using a new facile continuous microwave pipeline technology

Chuang Zhang [a,1], Zhanxiong Feng [b,1], Yijie Lei [a], Xun Zhang [c], Weitao Gao [a], Lianguo Sun [a], Zhuangzhi Liu [c], Jianlong Wang [a], Yun Wang [b,*], Cheng Wang [a,*]

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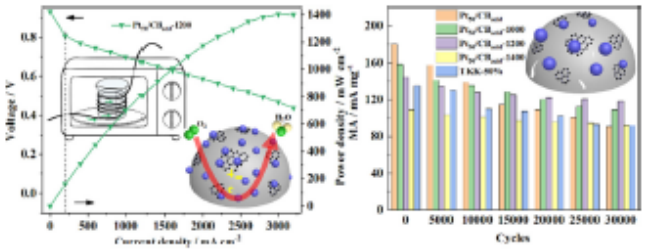
HIGHLIGHTS

- Mass production of high activity and durability of Pt/C catalysts with microwave pipeline technology.
- Retention rate of ORR catalytic activity of Pt_{SA}/CB_{acid}-1200 catalyst reaches 82% after 30,000 cycles attenuation.
- Power density of cell performance can reach 1.4 W-cm^{-2} and Pt content can reach 0.286 g_{Pt}-kW^{-1}.

GRAPHICAL ABSTRACT



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ABSTRACT

Traditional synthesis methodologies for fuel cell catalyst production involve long reactions and uncontrollable reaction processes. Synthesis methods for the production of catalysts typically have difficulties to achieve catalysts materials with consistency, high activity, and durability. In this study, a fast, simple, and suitable continuous pipeline microwave method for catalyst mass production was developed, with the carbon carrier being treated at different temperatures simultaneously. The method herein developed resulted in carbon-supported platinum (Pt) catalysts with high activity and high durability. In addition, the half-wave potential of the catalyst exceeded 0.9 V, the electrochemical active surface area reached 85.7 m^2-g_{Pt}^{-1}, and the mass specific activity reached 171.1 mA-mg^{-1}. Remarkably, after 30,000 cycles of Pt attenuation tests and 30,000 cycles of carbon carrier attenuation tests, the retention rate of the annealed carbon carrier catalyst reached 80 %. As a membrane electrode, the catalyst generated a single cell maximum power density of 1.4 W-cm^{-2}, and the Pt content reached 0.286 g_{Pt}-kW^{-1}. The work provides an effective and practical method for the mass production of high-performance and high-durability catalysts, which guiding significance for mass production of catalysts.

1. Introduction

Proton-exchange membrane fuel cells (PEMFC) are energy conversion devices and valuable assets for global carbon neutrality

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Solution processed 2D SnSe nanosheets catalysts: Temperature dependent oxygen reduction reaction performance in alkaline media

Zhanxiong Feng [a,1], Chandradip D. Jadhav [b,1], Girish P. Patil [b,1], Yun Wang [a], Chuang Zhang [a,d,*], Vijay S. Baviskar [c], Zhiyong Jia [a], Rafael Minnes [b,*]

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ABSTRACT

One of the most effective synthesis routes is the simple solution process, which is an inexpensive way to make single phase 2-Dimensional (2D) Tin Selenide (SnSe) nanosheets. X-ray diffraction (XRD), X-ray Photoelectron spectroscopy (XPS), and Field Emission Scanning Electron Microscope (FESEM) were used to confirm the structural and topographical investigations. 2D SnSe served for Oxygen Reduction Reaction (ORR) electrochemical performance in KOH solution. Later, 2D SnSe is annealed at 300, 400 and 500 °C later termed as SnSe-300, SnSe-400 and SnSe-500 respectively to investigate the electrochemical behavior of catalyst. As the temperature increases ORR performance improved. For the first time, 2- and 4-electron transfer pathway mechanism of SnSe catalysts is discussed. An enhancement in the performance of as prepared 2D SnSe catalysts ensured with various parameters like current density, electron charge transfer number and half-wave potential. SnSe-500 has a half-wave potential of −0.75 V, which is lower than other catalysts in this case. In addition, a current density of 4.50 mA/cm^2 was recorded, which is superior to other catalysts in this case.

1. Introduction

Scientific and technological research in the modern era has a strong interest in energy conversion and energy storage applications [1–3]. Nowadays, traditional energy sources like coal, fossil fuels, and others are competing to meet society's energy needs [4–6]. Because of their polluting nature, which causes an increase in Carbon Dioxide (CO_2) in the atmosphere, it is claimed that they cause a variety of problems in our human society, such as floods, earthquakes, and other natural disasters [7]. Due to the drastic change in weather conditions, it is now more important than ever to use renewable energy sources such as solar, hydrothermal, nuclear, and electrochemical energy [8]. Commercial applications such as Proton Exchange Membrane Fuel Cell (PEMFC), Water splitting, metal-air batteries, and others have recently sparked a lot of interest in the scientific community [9,10]. Moreover, non-hazardous, economical, easy-to-process scientific research attracts a large number of scientists [11,12]. Oxygen Reduction Reaction (ORR) is one of very important aspects to conclude whether catalyst can prove itself as good contender or not. ORR is a very important process in biological respiration and energy conversion systems like fuel cell, photo catalysis, metal-air battery, etc. [13]. 2- and 4-electron pathways are mainly considered for ORR electrochemical performances in aqueous solution. In the direct 4-electron reduction pathway from Oxygen (O_2) to Water (H_2O) and on the other hand, the 2-electron reduction pathway from O_2 to hydrogen peroxide (H_2O_2) [14]. To achieve the best ORR performance, catalysts must have certain characteristics, such as a large surface area, high porosity, and chemical stability, among others [15].

2D layered materials like MoS_2, $MoSe_2$, SnS, CuSe, SnSe, and others have attracted a lot of attention due to their unique properties such as favorable band gap, thermal and chemical stability, attractive electrical features and various topographical properties [16,17]. The 2D layered materials already proven themselves in optoelectronic/energy conversion and energy storage applications [18]. Among them nanostructured SnSe already established itself in optoelectronic application due to its suitable band gap of 1.2 eV [19]. SnSe belongs to the class of

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研究开发

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连续管道微波技术制备Pt/C催化剂及其氧还原性能

冯占雄[1]，汪云[1]，马强[1]，张创[2]，王诚[2]
（[1]湖北文理学院汽车与交通工程学院，湖北 襄阳 441053；[2]清华大学核能与新能源技术研究院，北京 100084）

摘要：传统的燃料电池催化剂合成方法除了反应过程不可控外，反应时间长，生产的催化剂难以保证一致性且耐久性差。由此，本文开发了一种快速、简单、生产一致性好的连续管道微波制备技术，该技术采用传统的乙二醇还原氯铂酸的方法，以1400℃高温处理的炭黑为碳载体制备合成铂载量为50%（质量分数）的催化剂。制备的Pt/C-1400催化剂的半波电位超过0.9V。在参考可逆氢电极为1.0-1.5V的高电位范围内经过20000次循环伏安碳载体衰减实验，Pt/C-1400催化剂的电化学活性表面积的保留率可达79%，质量比活性的保留率高达85%，表现出了显著的抗腐蚀性和优异的耐久性，为高耐久性催化剂的生产提供了一条有效可行的途径。

关键词：燃料电池；碳载体；催化剂；活性；稳定性
中图分类号：TM911.4 **文献标志码**：A **文章编号**：1000-6613（2022）12-6377-08

Preparation of Pt/C catalyst by continuous pipeline microwave technology and its oxygen reduction performance

FENG Zhanxiong[1]，*WANG Yun*[1]，*MA Qiang*[1]，*ZHANG Chuang*[2]，*WANG Cheng*[2]
([1] School of Automobile and Traffic Engineering, Hubei University of Arts and Sciences, Xiangyang 441058, Hubei, China;
[2] Institute of Nuclear Energy and New Energy Technology, Tsinghua University, Beijing 100084, China)

Abstract: Traditional preparation of Fuel cell catalyst is uncontrollable and takes long reaction time, and the produced catalyst has poor consistency and durability. In this work, a rapid, simple and consistent continuous pipeline microwave method for catalyst preparation was developed. Traditional ethylene glycol reduction of chloroplatinic acid was used to prepare catalyst with 50%(mass) platinum capacity using carbon black treated at 1400℃ as carbon carrier. The half-wave potential of Pt/C-1400 catalyst is more than 0.9V. After 20000 cyclic voltammetry decay tests of carbon carrier in the high potential range of 1.0—1.5V for the reference reversible hydrogen electrode, the retention rate of the electrochemically active surface area and the mass specific activity of Pt/C-1400 catalyst are up to 79% and 85%, respectively, showing its significant corrosion resistance and excellent durability. This work provides an effective and feasible way for the production of high durability catalyst.

Keywords: fuel cells; carbon support; catalyst; activity; stability

近年来，随着社会经济和科学技术的发展，能源短缺、环境污染问题日趋严重，世界各国开发绿色可持续的新型能源与能量转换设备迫在眉睫。质子交换膜燃料电池（proton exchange membrane fuel

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引用本文：冯占雄，汪云，马强，等. 连续管道微波技术制备Pt/C催化剂及其氧还原性能[J]. 化工进展，2022，41(12)：6377-6384.
Citation: FENG Zhanxiong, WANG Yun, MA Qiang, et al. Preparation of Pt/C catalyst by continuous pipeline microwave technology and its oxygen reduction performance[J]. Chemical Industry and Engineering Progress, 2022, 41(12): 6377-6384.

人物简介：

黄燕琴（1997-），女，甘肃天水人，中共预备党员，汽车与交通工程学院 2020 级机械工程（新能源汽车动力测控系统方向）专业研究生，导师是工学博士聂金泉副教授。科研方面：研究生期间主要从事动力电池测试评价研发，参与项目 3 项，发表论文 2 篇，申请发明专利 3 项，实审 3 项。学业获奖：2020 年学业奖学金二等；2020 年学业奖学金三等；2021 年学业奖学金二等。目前已签约格林美股份有限公司。

发表论文：

[1] 聂金泉，黄燕琴，高洋洋，等. 考虑动态曲线特征的退役锂离子电池分选方法[J]，重庆理工大学学报(自然科学)，2023，37(02)：19-27.

[2] 黄燕琴，聂金泉，王赦，等. 锂离子电池不一致性综述[J]. 时代汽车，2022，(05)：102-107.

专利：

[1]电池动态分选方法、装置、设备及储存介质，发明专利实审，CN202210585416.9，2022-05-20．

[2]电池分选方法、装置、设备及储存介质，发明专利实审，CN115099305A，2022-09-23．

[3]电池一致性分选方法、装置、设备及储存介质，发明专利实审，CN115248393A，2022-10-28．

发表论文截图

重庆理工大学学报(自然科学) . 2023,37(02) 北大核心

记笔记

考虑动态曲线特征的退役锂离子电池分选方法

聂金泉[1,2] 黄燕琴[1,2] 高洋洋[1,2] 李银银[3] 王鹏轲[3]

1. 湖北文理学院汽车与交通工程学院 2. 纯电动汽车动力系统设计与测试湖北省重点实验室 3. 襄阳市公共检验检测中心

摘要： 退役锂离子电池成组时，单体电池间的性能差异会造成模组性能的快速衰减，使得模组循环使用寿命降低，甚至引发安全问题。为此，以100节退役锂离子电池为研究对象进行充放电实验和内阻测试，提出了一种退役电池一致性分选方法。运用能量差表述电池极化差异，选用容量、能量差、充电电压、放电电压、充电内阻、放电内阻6个指标进行多参数预分选；综合考虑电压偏差与容量偏差，采用K-means算法进行动态曲线分选；针对K-means算法K值不确定的问题，分别对电压、能量曲线进行归一化处理，基于频率分布直方图和频率分布曲线分析确定K值。实验结果表明：该分选方法能有效地改善电池的不一致性，分选后的电池充电电压一致性提高60%～94%,放电电压一致性提高10%～41%,容量一致性提高54%～67%。

关键词： 退役动力电池；分选方法；一致性；

基金资助： 中央引导地方科技发展专项项目“动力电池系统测试与标准化创新平台”(2018ZYYD029)；湖北省高等学校优秀中青年科技创新团队计划项目(T201815)；

专辑： 工程科技Ⅱ辑

专题： 电力工业

分类号： TM912

时代汽车 . 2022(05)

记笔记

锂离子电池不一致性综述

黄燕琴[1,2] 聂金泉[1,2] 王敖[1,2] 刘建强[3] 李银银[3]

1. 湖北文理学院汽车与交通工程学院 2. 纯电动汽车动力系统设计与测试湖北省重点实验室 3. 襄阳市公共检验检测中心

摘要： 锂离子电池是电动汽车的关键部件之一，电池组作为电动汽车的供能部分，对整车性能起到决定性作用。本文首先剖析了电池一致性的产生机理及其表现形式。其次，针对锂离子电池安全性、使用寿命以及容量衰减等方面的问题，从电池不一致性评价方法和改善不一致性的措施展开分析。电池不一致性评价方法主要有单参数评价、多参数评价、动态特性评价的一致性评价方法。改善不一致性的措施主要有提高制造工艺和改进原材料水平，保证单体电池出厂时的一致性；电池成组使用前对电池进行选配，以减小单体电池初始差异；利用均衡技术减小各电池单体间的能量差异，进而提高电池组的一致性；利用电池热管理技术降低温度对电池一致性的影响，进而提高电池的使用寿命。最后，对改善一致性的措施进行了展望。

关键词： 锂离子电池；不一致性；电动汽车；

基金资助： 中央引导地方科技发展专项“动力电池系统测试与标准化创新平台”(编号：2018ZYYD029)；湖北省高等学校优秀中青年科技创新团队计划项目(T201815)；

专辑： 工程科技Ⅱ辑;经济与管理科学

专题： 电力工业

分类号： TM912

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申请号：202210567280.9

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申请人：湖北文理学院

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2022年4月28日

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金先志（1996-），男，湖北咸宁人，共青团员，汽车与交通工程学院 2020 级机械专业研究生，导师是工学博士丁华锋副教授。科研方面：研究生期间主要从事不锈钢、合金钢熔模精密铸造缺陷研究及工艺优化、铝合金材料改性研究，参与项目 4 项，发表学术论文 5 篇其中 SCI 论文 1 篇，申请发明专利 2 项，参加学术会议并进行汇报 2 次，参加国家级竞赛并获得奖励 2 次，获得“襄十随神”城市群首届自然科学优秀学术论文暨襄阳市第二十三届自然科学优秀论文二等奖一次。学业获奖：2020 年学业奖学金二等；2021 年学业奖学金二等；2022 年学业奖学金一等；湖北文理学院优秀研究生，湖北文理学院 2023 届优秀毕业研究生。

【发表论文】

[1] Ding H,Jin X,Chen T, et al. Study on Casting Defect Control of Austenitic 304 Complex Structural Parts[J]. International Journal of Metalcasting, 2022. DOI：10.1007/s40962-022-00865-y

[2]丁华锋，金先志，谷雨原，等．基于正交试验的车灯后盖壳体注塑

成型工艺优化[J]．合成树脂及塑料，2022，39(03)：55-59．

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【申请专利】：

[1]丁华锋，金先志．一种熔炼加料系统[P]．湖北省：CN114353522A，2022-04-15．

[2]陈涛，金先志，丁华锋．一种熔模铸造多功能铸件转运箱[P]．

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发表论文截图

STUDY ON CASTING DEFECT CONTROL OF AUSTENITIC 304 COMPLEX STRUCTURAL PARTS

Huafeng Ding
Hubei Key Laboratory of Pure Electric Vehicle Power System Design and Testing, Hubei University of Arts and Sciences, Xiangyang 441053, Hubei Province, China
Xiangyang Liqiang Machinery Co., Ltd., Xiangyang 441700, Hubei Province, China

Xianzhi Jin and Hongbing Li
Hubei Key Laboratory of Pure Electric Vehicle Power System Design and Testing, Hubei University of Arts and Sciences, Xiangyang 441053, Hubei Province, China

Tao Chen
Xiangyang Liqiang Machinery Co., Ltd., Xiangyang 441700, Hubei Province, China

https://doi.org/10.1007/s40962-022-00865-y

Abstract

Because the medium and large-scale Austenitic 304 stainless steel cable protection valve belongs to the cavity valve body, with complex surface shape and structure, there are often some problems in the casting process, such as difficult local heat dissipation and disordered solidification sequence of liquid metal. This will lead to different degrees of shrinkage porosity and shrinkage cavity defects at the ear of the valve body, the bulge at the bottom and the fault of the inner wall of the valve body, and the molding quality is very difficult to control. In order to solve the problem of serious shrinkage porosity and shrinkage cavity in the actual production of valve body parts, the mathematical model was established, and the filling and solidification process of investment casting under traditional gating system was simulated by ProCAST software, the thermodynamic behavior of molten metal in solidification process was analyzed, and the causes of casting defects under traditional methods were found out. A new gating system was designed, and the shrinkage of castings was predicted by Niyama criterion. The experimental results show that the simulation results are consistent with the actual results, and the surface precision of the optimized valve body casting is high and the density is as high as 98.5%.

Keywords: *cavity valve body, investment casting, niyama criterion, proCAST, gating system*

Introduction

performance and economy of alloy steel.[1–3] In order to obtain parts with high dimensional accuracy, good surface

车用水箱弯管接头熔模铸件工艺优化

丁华锋[1,2] 金先志[1,2] 陈 涛[3] 潘俊杰[2]
(1.湖北文理学院汽车与交通工程学院；2.纯电动汽车电力系统设计与测试湖北省重点实验室；
3.襄阳市立强机械有限公司)

摘 要 经验法熔模铸造成形的弯管接头零件在通孔内壁和底座圈上都普遍存在缩松。利用 ProCAST 软件，对弯管接头铸件进行缺陷分析，分别从浇注系统的优化和增设冒口及冷铁入手，研究两种可以降低铸件缩松率的方案。对比发现，对浇注系统进行优化为最优方案，并在此基础上设计了正交试验。结果表明，在浇注温度为 1 520 ℃，浇注速度为 0.6 kg/s，型壳预热温度为 1 120 ℃下，缩松率最大为 1.44%，有效提高了产品品质。

关键词 熔模铸造；ProCAST；弯管接头；工艺优化
中图分类号 TG249.5 **文献标志码** A
DOI：10.15980/j.tzzz.2022.02.025
开放科学(资源服务)标识码(OSID)：

Investment Casting Process Optimization of Water Tank Elbow Joint for Vehicle

Ding Huafeng[1,2], Jin Xianzhi[1,2], Chen Tao[3], Pan Junjie[2]
(1.School of Automotive and Traffic Engineering, Hubei University of Arts and Science; 2.Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle; 3.Xiangyang Liqiang Machinery Co., Ltd.)

Abstract: The shrinkage porosities in elbow joint parts formed by empirical investment casting generally exists on the inner wall of hole and base ring. The ProCAST simulation software was utilized to analyze the defects of elbow joint castings. With the optimization of gating system and the addition of riser and cold iron, two schemes for reducing the shrinkage rate were proposed. The comparative analysis reveals that the optimization of gating system is the optimal scheme and the orthogonal test is designed. The results indicate that when the pouring temperature is 1 520 ℃, pouring speed is 0.6 kg/s and shell preheating temperature is 1 120 ℃, the maximum shrinkage rate is 1.44%, effectively improving the quality of the product.

Key Words: Investment Casting, ProCAST Software, Elbow Joint, Process Optimization

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DING H F, JIN X Z, CHEN T, et al. Investment casting process optimization of water tank elbow joint for vehicle[J]. Special Casting & Nonferrous Alloys, 2022, 42(2): 248-252.

服强度变化不明显，伸长率随固溶处理温度的升高和人工时效温度的升高呈下降趋势，另外可以看出，延长人工时效时间和降低固溶热处理温度可以提高材料伸长率。

4 结 语

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合成树脂及塑料，2022，39(3)：55
CHINA SYNTHETIC RESIN AND PLASTICS

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基于正交试验的车灯后盖壳体注塑成型工艺优化

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摘　要： 利用Moldflow软件对车灯后盖进行注塑成型仿真，针对模具温度、熔体温度、注射时间、保压时间、保压压力5个工艺参数，设计正交试验，找出最优工艺参数调整方案，并对冷却系统进行了设计。结果表明：由冷却不均所引起的翘曲变形量与传统方案相比下降了30.28%，在最佳工艺参数方案下的总翘曲变形量下降了38.24%，翘曲变形优化明显。

关键词： 车灯后盖　注塑成型　正交试验　翘曲变形　优化

中图分类号： TQ 320.66　　**文献标志码：** B　　**文章编号：** 1002-1396(2022)03-0055-05

Optimization of injection molding process for rear cover of lamp based on orthogonal test

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(Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle, Xiangyang 441053, China)

Abstract: Moldflow software was used to simulate the injection molding of the lamp rear cover. The orthogonal experiment was designed for five process parameters of mold temperature, melt temperature, injection time, holding time and holding pressure. A group of optimal process parameters adjustment scheme was found by range analysis method, and the cooling system was designed. The results show that the warpage caused by uneven cooling is reduced by 30.28% compared with the traditional scheme, and the total warpage is reduced by 38.15% under the optimal process parameter adjustment scheme.

Keywords: rear light cover; injection molding; orthogonal test; warpage; optimization

塑料灯壳由于具有质量轻、耐化学药品腐蚀性强、耐热性好等优点被广泛应用于汽车工业中。随着国内外汽车行业的飞速发展，对汽车的外观和质量要求也越来越高。车灯作为汽车照明系统的重要组成部分，其结构和质量的改变都会影响汽车的外观和整车的轻量化[1]。为提高车灯壳体的成型精度，降低成型产品的翘曲变形量，提高产品的成型质量，找出合理的工艺参数就显得尤为重要。目前，国内外对于注塑成型工艺的程进行了研究，并通过Moldflow软件对柔性印刷电路板连接器外壳的翘曲变形进行预测，基于仿真模拟结果设计了符合工程实际的模具并进行了可靠性验证。Chen等[4]采用田口法和响应面法对聚甲醛材料的直齿圆柱齿轮进行了注塑模拟，最终确定了最优参数组合，仿真结果显示，翘曲变形量为0.188 6 mm，与实际翘曲变形量相比误差仅为2.7%。Shin等[5]通过分析聚碳酸酯(PC)/丙烯腈-

一种 304 不锈钢圆球阀的熔模铸造工艺优化

丁华锋[1,2]，金先志[1]，陈 涛[2]，胡泽奇[1]

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摘 要：在 304 不锈钢圆球阀传统的熔模铸造生产过程中，采用经验确定的工艺参数往往无法完全消除缺陷，在阀体与法兰转角处存在一些缩孔，严重影响产品质量。利用 ProCAST 软件对不锈钢圆球阀铸件的成形进行了仿真和缺陷分析，发现传统工艺方法在阀体与法兰转角处存在较多大而集中的缩松。重新设计浇注系统结构，调整工艺参数，设计了正交试验方案。结果显示，在浇注温度 1550℃、浇注速度 1.0 kg/s、型壳预热温度 1150℃工艺参数下，阀体与法兰转角处的缩孔消失。

关键词：熔模铸造；圆球阀；工艺优化

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Investment Casting Process Optimization of A 304 Stainless Steel Ball Valve

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Abstract: In the traditional investment casting production process of a 304 stainless steel ball valve, the process parameters determined by experience often cannot completely eliminate defects, some shrinkage holes appear at the corners of the valve body and the flange, which seriously affects the product quality. Simulation and defect analysis of the stainless steel round ball valve casting were performed by using ProCAST software, it is found that there are many large and concentrated shrinkage porosity at the corners of the valve body and flange by the traditional process method. The structure of the gating system was redesigned, the process parameters were adjusted, and the orthogonal test scheme was designed. The results show that under the process parameters of pouring temperature of 1550℃, pouring speed of 1.0 kg/s and shell preheating temperature of 1150℃, shrinkage holes at the corners of valve body and flange are eliminated.

Key words: investment casting; ball valve; process optimization

随着世界科技水平的提升，人们对能源的需求日益增多，节约材料已经是各个国家努力的目标。铸造行业中传统铸造既耗费人力又耗费财力，而熔模铸造能够较好地实现少、无余量加工[1-3]。计算机模拟与实际铸造工艺相结合的方法已经被越来越多地应用到铸造行业中，这样铸造出来的产品既具有科学依据，又可满足标准用于生产实践[4-5]。该不锈钢圆球阀的应用广泛，可用于相关流体输送控制路线口的控制阀上，所承受的压力大，因此对不锈钢圆球阀的生产质量要求也相当严格，不允许出现裂纹、冷隔和缩松缩孔现象。原工艺条件下生产的不锈钢圆球阀一般是依靠经验法成型，在阀体与法兰转角处往往存在缩孔缺陷，故成品率较低。为了减少缩松缺陷，提高不锈钢圆球阀的成品率，节约开发成本，为此重新设计成型工艺浇注系统是减少缺陷的一大途径[6]。

在熔模铸造的一些近期研究中，许荣福等[7]研究了高 Nb 钛铝基排气阀铸件的熔模离心铸造工艺，通过仿真与试验结合的方法，证实了将模壳充填时间为 3.8 s，粉液比 1.5:1、搅拌时间 30 min 条件下可生产出金相组织合格的铸件。杨新娣等[8]针对涡

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基于大学生方程式大赛的思维和实践创新能力培养

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摘 要：中国大学生方程式大赛是培养汽车创新型人才实践动手能力，思维创新能力的重要平台，学生通过对方程式赛车的设计优化、加工制造、试验调试以及赛车性能的数据分析等环节，结合本专业所学的专业知识，用理论联系实际的方法开阔思维，达到一个提高学生创造能力的效果。与此同时，大学生方程式大赛设计制造赛车过程中的各种不确定性因素也启发着学生要从多方面来考虑问题，激发学生的创新思维，也为以后提高创新能力做铺垫。从2010年至现今，大学生方程式大赛通过实践证明了，在汽车专业里方程式大赛每年都为社会及企业培养了将近25%的创新型人才，也为中国汽车工业发展输送创新型人才做出具大贡献。

关键词：大学生方程式大赛；创新；汽车型人才

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The Training Automobile Innovation Talents In Formula College Student Competition

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Abstract: China competition equations is to cultivate college students car innovative talents practice ability, thinking innovation ability important platform, students through design optimization of formula, processing and manufacturing, testing commissioning and performance analysis of data, combined with the professional knowledge of professional knowledge, open mind, using the method of theory with practice to achieve the effect of a to improve students' creative ability. At the same time, a variety of uncertain factors in the design and manufacture of formula inspire students to consider problems from various aspects, stimulate students' innovative thinking, and pave the way for improving their innovative ability in the future. From 2010 to now, it has been proved through practice that formula College Students competition in automobile major has cultivated nearly 25% innovative talents for the society and enterprises every year, and also made great contributions to the development of China's automobile industry and the transportation of innovative talents.

Keywords: formula college students competition; innovation; automotive talent

一 引言

随着现代工业的迅速崛起，汽车工业也有着突飞猛进的发展。近些年来，汽车行业的快速发展推动了我国由一个汽车大国迈向汽车强国的进程。而汽车强国的崛起必不可少的就是一大批车辆工程专业汽车创新型人才的涌现。随着大学生方程式大赛在国内外的兴起，该赛事为培养汽车创新型人才搭建一个了平台，是培养汽车人才科技创新的磨刀石[1]。创新是一个行业发展的不竭动力，是一个行业长久发展的好推手[2]。展望未来，人类的科技水平日益发达，人们对汽车的需求也是直线上升。为了响应全球以及国家的号召，研发新型节能减排的汽车是我们未来发展的大趋势。对于新型汽车的研发和生产就必需要有创新型汽车人才作为依托。

近几年来，我国各大高校增加了车辆工程专业招生人数，但是我国大多数高校的培养方案都是理论教学，实践机会过少。学生本科毕业后严重缺少自己动手的能力，实践和创新的能力也严重缺乏，面对如此突出的问题，对于企业来说传统车辆工程人才培养方式明显开始跟不上企业的发展需求了。这种立足于书本，缺少创新与实践的教学模式严重

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人物简介：

雷宇（1997-），男，湖北襄阳人，中共党员，汽车与交通工程学院 2020 级车辆工程（车辆零部件结构设计方向）专业研究生，导师是工学博士吴华伟教授。科研方面：研究生期间主要从事特种车辆装备及非标设备研发设计，参与项目 3 项，申请发明专利 6 项，授权 1 项，国际专利授权 1 项，授权实用新型专利 4 项。学业获奖：2020 年学业奖学金二等；2021 年学业奖学金二等；2022 年学业奖学金三等。

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第 1 页 (共 2 页)

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(54) **RAIL-BASED ANTI-DERAILMENT METHOD AND APPARATUS, RAIL VEHICLE, AND STORAGE MEDIUM.**

(57) Disclosed are a rail-based anti-derailment method, a rail-based anti-derailment apparatus, a rail vehicle and a storage medium. The method includes: acquiring an inertial centrifugal force of a target vehicle, a total reaction force corresponding to an outer rail, and a first angle; acquiring a total reaction force corresponding to an inner rail and a second angle; acquiring a first correspondence according to a gravity of the target vehicle, the total reaction force corresponding to the outer rail, the first angle, the total reaction force corresponding to the inner rail, and the second angle; acquiring a second correspondence and a horizontal component force of a preset direction according to the inertial centrifugal force; acquiring an anti-derailment factor according to the horizontal component force, the first correspondence and the second correspondence; and determining a target first angle and/or a target second angle according to the anti-derailment factor, and controlling the target vehicle according to the target first angle and/or the target second angle, so that by acquiring the angle of the preset direction and controlling the angle, the overall friction of the target vehicle is increased to prevent derailment.

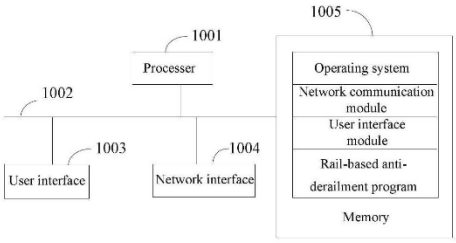

Fig. 1

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实用新型专利证书

实用新型名称：可转向路轨装置及公铁两用车

发　明　人：雷宇;吴华伟;王华;刘祯;程清思;万锐;陈阵

专　利　号：ZL 2020 2 2334196.1

专利申请日：2020年10月16日

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2021年06月15日

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证书号第14152199号

实用新型专利证书

实用新型名称：车辆搬运平台及立体停车库

发　明　人：钱伟;吴钊;吴华伟;李正;刘梦迪;雷宇

专　利　号：ZL 2020 2 2825757.8

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实用新型专利证书

实用新型名称：一种摩擦式变速结构

发　明　人：钱伟;吴钊;吴华伟;李正;刘梦迪;雷宇;赵千

专　利　号：ZL 2020 2 2807595.5

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证书号第14088157号

实用新型专利证书

实用新型名称：载车平台及立体停车库

发　明　人：刘梦迪;钱伟;吴钊;吴华伟;李正;雷宇

专　利　号：ZL 2020 2 2828379.9

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指导老师：吴华伟、刘祯

参赛学生：钱伟、李正、谢东升、赵千、雷宇、梁德湾

中国可再生能源学会
二〇二〇年十二月

证书编号：2020-KZS-231

NO.2021311

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参赛选手 Competitor：谢东升、雷宇、李正

指导老师 Advisor：刘 祯

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二〇二一年六月六日
6th June 2021

NO.2022383

获奖证书
Letter of Award

参赛选手 Competitor：赵千、雷宇、谢东升

指导老师 Advisor：吴华伟

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全国大学生创新体验竞赛组委会
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6th June 2022

创造学会 电子专用章

人物简介：

李正（1994-），男，湖北黄冈人，中共党员，汽车与交通工程学院 2020 级机械工程（新能源汽车动力测控系统方向）专业研究生，导师是工学博士刘祯副教授。科研方面：研究生期间主要从事流体机械性能仿真试验及热设计，参与项目 3 项，发表 SCI 论文 1 篇，CSCD 论文 1 篇，申请专利 7 项，授权 2 项，受审 5 项。学业获奖：2020 年学业奖学金三等；2021 年学业奖学金一等；2022 年学业奖学金一等。目前已签约东莞嘉拓自动化科技有限公司。

发表论文：

[1] Zhen L ,Zheng L ,Dongsheng X , et al. Unsteady characteristic and flow mechanism of a scroll compressor in small-scale compressed air energy storage system[J]. Journal of Energy Storage,2022,51.

[2]李正,刘祯,吴华伟等.涡旋压缩机切向泄漏瞬态流场特性[J].储能科学与技术,2021,10(05):1579-1588.

授权实用新型专利：

[1] 涡旋压缩膨胀一体机，ZL202120456080.7

[2] 氢气循环泵、氢燃料动力系统及氢燃料汽车，ZL202220519578.8

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Research papers

Unsteady characteristic and flow mechanism of a scroll compressor in small-scale compressed air energy storage system

Zhen Liu [a,b], Zheng Li [a,b,*], Dongsheng Xie [a,b], Huawei Wu [a,b]

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ARTICLE INFO

Keywords:
Flow field distribution
Tangential leakage
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Time-averaged performance

ABSTRACT

Tangential leakage loss reduction has significant impact on improving the performance of scroll compressors. In this study, the flow field of a scroll compressor working with air was numerically investigated. The characteristics of the tangential leakage flow in different radial clearances were studied, which was obtained by analyzing the field quantities distributions. Moreover, the influence of radial clearance on the time-averaged performance of the scroll compressor and the aerodynamic force on it in each direction are analyzed. The results showed that the gas flowed into the low-pressure chamber through the radial clearance, and the downstream gas in compression chamber was compressed and collides with the leakage flow, having aggravated the uneven distribution of the flow field in the compression chamber. The gas velocity was faster in the region with large pressure difference, and the peak velocity appeared near the radial clearance. Moreover, as the radial clearance continues to increase in a certain range, its influence on the working characteristic curve of scroll compressor has two sides. The research can provide theoretical basis for the structural design of scroll compressors.

1. Introduction

Compressed Air Energy Storage (CAES) has long been considered a means of improving power quality, reliability, in addition to yielding other benefits [1,2]. Compared with battery storage technologies, the CAES system has advantages of relative low cost, long life and simple maintenance. Various types of CAES systems have been investigated in industries [3,4]. Decentralized or small-scale CAES systems have gained large attention. They can be operated as an alternative to typical battery storage systems, such as lithium ion or flow batteries. This small-scale CAES can be implemented in the low-voltage grid solving the challenges of renewable energy feed-in [5]. A small-scale CAES system can connect renewable energy and remote communication devices to form a stand-alone system [6]. Scroll compressor is more suitable for small-scale CAES systems, due to its positive properties of wide working range, high efficiency, and low level of noise and vibration due to fewer moving parts [7–12]. Thus, it is also widely adopted in renewable energy system, distributed power generation and other fields. However, as a significant power output device for the CAES system, its leakage characteristics have negative impact on the operation, reliability and efficiency of the system.

The compressed fluid in the chamber formed by meshing the static and orbiting scroll is regarded as the three-dimensional unsteady compressible flow. It is difficult to capture and analyze the characteristics of internal flow field through visual experiments. Thus, the computational fluid dynamics (CFD) method was used to simulate the changing process of flow field in compression chamber, which has become a hotspot in the research field of scroll compressor [13–17]. During operation, the radial clearance formed by the meshing of orbiting and static scrolls is in a state of periodic change. The tangential leakage flow through the radial clearance has been considered to be the main factor affecting the overall performance of scroll compressors. The tangential leakage characteristics of scroll compressor are studied in detail, which is of great significance to optimize the time-averaged performance of scroll compressor. Mathematical models are the main methods to estimate the tangential leakage, which are used for numerical simulation of the tangential leakage of scroll compressors to obtain more intuitive visualization results. Besides the isentropic compressible nozzle model, the compressible adiabatic flow with fanno flow, the incompressible and viscous pipe flow, and one-dimensional laminar flow were also used for simulating the clearance leakage flows in some theoretical models of scroll machine [18,19].

Zheng [20,21] studied the non-constant flow characteristics of the

Abbreviations: Compressed Air Energy Storage, CAES; Computational Fluid Dynamics, CFD.

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物理储能十年专刊·压缩空气

涡旋压缩机切向泄漏瞬态流场特性

李 正[1,2]，刘 祯[1,2]，吴华伟[1,2]，谢东升[1,2]，钱 伟[1,2]
（[1]湖北文理学院纯电动汽车动力系统设计与测试湖北省重点实验室；[2]湖北文理学院汽车与交通工程学院，湖北 襄阳 441053）

摘 要：以某微型压缩空气储能涡旋压缩机为研究对象，采用计算流体力学(CFD)的方法对涡旋压缩机工作过程进行数值模拟，得到了涡旋压缩机内部压力场、温度场、速度矢量场的瞬态分布，研究了径向间隙引起的切向泄漏对涡旋压缩机工作腔流场分布特点，结果表明：高压腔中的气体通过径向间隙泄漏流入低压腔，会造成腔内速度矢量场、温度场分布不均匀，而泄漏对压力场分布不均匀程度影响较小，但对温度场、速度矢量场分布不均匀程度影响较大；单一腔内下游气体被压缩导致腔内压力分布不均匀，压差的存在影响速度矢量场分布的变化，排气孔偏置导致对称腔压力不对称。该研究可以为涡旋压缩机结构设计提供理论依据。

关键词：涡旋压缩机；径向泄漏；瞬态分析；数值模拟
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The transient flow field characteristics of tangential leakage in scroll compressor

LI Zheng[1,2], *LIU Zhen*[1,2], *WU Huawei*[1,2], *XIE Dongsheng*[1,2], *QIAN Wei*[1,2]
([1]Hubei Key Laboratory of Powertrain Design and Test of Pure Electric Vehicle, Hubei University of Arts and Science; [2]School of Automotive and Traffic Engineering, Hubei University of Arts and Science, Xiangyang 441053, Hubei, China)

Abstract: Focusing on a miniature compressed air reservoir scroll compressor, the computational fluid dynamics method numerically simulated the working processes of the scroll compressor. Additionally, the internal pressure field, temperature field, and the velocity vector field of the scroll compressor were obtained. The distribution characteristics of the tangential leakage, caused by the radial gap on the flow field of the scroll compressor's working cavity, were studied. The results showed that gas in the high-pressure cavity leaked into the low-pressure cavity through the radial gap, which caused the velocity vector and temperature fields in the cavity were not uniformly distributed, and leakage had little effect on the unevenness of the pressure field distribution; however, it had a greater impact on the unevenness of the temperature and velocity vector fields. The downstream gas in a single cavity was compressed, which gave rise to pressure within the cavity. The distribution was not uniform, and the existence of pressure differences affected changes in the velocity vector field distribution. The offset of the exhaust hole caused pressure asymmetry in the symmetrical cavity. This research presents a theoretical basis for the structural design of scroll compressors.

Key words: scroll compressor; radial leakage; transient analysis; numerical simulation

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授权专利部分截图

证书号第17449161号

实用新型专利证书

实用新型名称：氢气循环泵、氢燃料动力系统及氢燃料汽车

发　明　人：刘祯;李正;谢东升;刘增鹏

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2022年09月20日

第1页(共2页)

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证书号第14441999号

实用新型专利证书

实用新型名称：涡旋压缩膨胀一体机

发　明　人：李正;刘祯;谢东升;马飞

专　利　号：ZL 2021 2 0456080.7

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专利权人：湖北文理学院

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指导老师：刘祯、吴华伟

湖北文理学院
创新创业教育学院

湖北文理学院
汽车与交通工程学院

2022年5月20日

NO.2022345

获奖证书
Letter of Award

参赛选手 Competitor：黄腾君、刘增鹏、李正

指导老师 Advisor：刘 祯

所属学校 College：湖北文理学院

第五届全国大学生创新体验竞赛
“创新价值”一等奖
First Prize of ‘Innovation Value’ Award
of the Fifth National Innovation Experience Competition for College Students

中国创造学会
China Creative Studies Institute
全国大学生创新体验竞赛组委会
The Organization Committee
of the National Innovation Experience Competition for College Students
二〇二二年六月六日
6th June 2022

电子专用章

NO.2021311

获奖证书
Letter of Award

参赛选手 Competitor：谢东升、雷宇、李正

指导老师 Advisor：刘 祯

所属学校 College：湖北文理学院

第四届全国大学生创新体验竞赛
“创新价值”一等奖

First Prize of ‘Innovation Value’ Award
of the Fourth National Innovation Experience Competition for College Students

中国创造学会
China Creative Studies Institute
全国大学生创新体验竞赛组委会
The Organization Committee
of the National Innovation Experience Competition for College Students
二〇二一年六月六日
6th June 2021

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指导老师：吴华伟、刘祯

参赛学生：钱伟、李正、谢东升、赵千、雷宇、梁德湾

中国可再生能源学会
二〇二〇年十二月

证书编号：2020-KZS-231

NACTranS

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获奖作品：基于氢循环技术的氢能发动机设计

参赛学生：李正、谢东升、雷宇

指导老师：刘祯

湖北文理学院
创新创业教育学院

湖北文理学院
汽车与交通工程学院

2022年4月28日

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发表论文：

[1] Zhang Hua, Liu Zheng, Gui Shingweng，et al．Improved mayfly algorithm based on hybrid mutation[J]．Electronics Letters，2022，58(18)：687-689．

授权实用新型专利：

[1] 张华，刘政，程子健，等．一种用于密集烤烟房专用的智能烟叶图像采集装置[P]．中华人民共和国，实用新型，

ZL202230229622.7，2022-07．

发表论文截图

Improved mayfly algorithm based on hybrid mutation

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To improve the diversity and performance of the mayfly algorithm (MA), this letter adopts the mutation strategies in the process of MA. The opposition-based learning (OBL) and Cauchy mutation strategies are used to mutate the global optimal solution, and the artificial mutation operator is used in the offspring population. The hybrid mutation strategies are used in a cascaded structure. The performance of the proposed algorithms is demonstrated in simulations comparatively.

Introduction: The optimization algorithms based on evolutionary computation and swarm intelligence are studied and deployed widely. Among the algorithms, the mayfly algorithm (MA) [1] takes the main advantages of the genetic algorithm (GA) and particle swarm optimization (PSO) algorithm. Competitive with most of the bio-inspired optimization algorithms, MA has the potential for faster convergence and higher accuracy. Recently, MA has been used in kinds of information and control engineering applications. However, due to the weak global exploration ability of the mayflies, MA also suffers the problem of low diversity and stagnation in local optima as that in other optimization algorithms. Researchers have been trying to explore improved-optimization methods for MA. Gao et al. [2] utilized the worst solution to improve the optimal performance of MA with opposition-based learning (OBL) rules. Gao and Zhao et al. [3–5] improved the performance of MA in the velocity and positions updating step, with space constriction coefficient, guaranteed convergence strategy, or Chebyshev map strategy. Zhang et al. [6] proposed a bioinspired bare-bones mayfly algorithm (BBMA) with Gaussian distribution and Lévy flight strategy to update the velocity, which solves the minimum spanning tree (MST) problem. Shi et al. [7] used two sigmoid mapping functions to binary encode MA, and the switching conditions of the two positions updating strategies are set to control the migration trend distribution of MA. Meanwhile, Shaheen et al. [8] added a random coefficient into the initial population to achieve the Chebyshev map for MA, which improved the performance of the algorithm.

In this letter, mutation strategies are adopted to improve the diversity of MA according to the mayflies' social features. The OBL and Cauchy mutation strategies are used to mutate the global optimal solution. An artificial mutation operator is introduced to make some female mayflies have male characters in the offspring to enhance the search space diversity. The multiple mutation strategies can be used in a cascaded structure in various processes, and the performance is simulated comparatively.

Original MA: The MA is inspired by the social behaviour of mayflies, two sets of mayflies are generated randomly, representing the male and the female population, respectively.

In MA, the position of a mayfly is updated with a moving velocity,

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{1}$$

where x_i^t is the current position, v_i^{t+1} is the moving velocity, and x_i^{t+1} is the updated position.

For the male mayflies, which flock in groups, the position for the next iteration is updated based on the global best solution and the Cartesian distance between the personal best position and the global best position. The velocity of a male mayfly is calculated as

$$v_{mi}^{t+1} = \begin{cases} g*v_{mi}^t + a_1 * e^{-\beta r_p^2} * \left(x_{bi} - x_{mi}^t\right) & if\ f\left(x_{mi}\right) > f\left(x_{bi}\right) \\ +a_2 * e^{-\beta r_g^2} * \left(x_g - x_{mi}^t\right) & \\ g*v_{mi}^t + d * r_1 & if\ f\left(x_{mi}\right) \le f\left(x_{bi}\right) \end{cases} \tag{2}$$

where x_{bi} is the personal best position for the ith mayfly, x_g is the global best position, g is the gravity coefficient, $x_{mi}{}^t$ is the current position for male mayflies, $f(x)$ is the objective function, and are constants that are used to scale the contribution of the cognitive and social component, respectively, β is a fixed visibility coefficient, r_p is the Cartesian distance between $x_{mi}{}^t$ and x_{bi}, and r_g is the Cartesian distance between $x_{mi}{}^t$ and x_g, d is the nuptial dance coefficient and r_1 is a random value in the range $[-1, 1]$.

As the female mayflies do not gather in swarms, their positions are updated with a different way. The velocity of a female mayfly is

$$v_{fi}^{t+1} = \begin{cases} g*v_{fi}^t + a_3 * e^{-\beta r_{mf}^2} * \left(x_{mi}^t - x_{fi}^t\right) & if\ f\left(x_{fi}\right) \ge f\left(x_{mi}\right) \\ g*v_{fi}^t + fl * r_2 & if\ f\left(x_{fi}\right) < f\left(x_{mi}\right) \end{cases} \tag{3}$$

where a_3 is a positive attraction constant, β is a fixed visibility coefficient, $x_{fi}{}^t$ is the current position for female mayflies, r_{mf} is the Cartesian distance between the male and the female mayflies, fl is a random walk coefficient, and r_2 is a random value in the range $[-1, 1]$.

In the crossover step of MA, the best female is selected to breed with the best male to get two offspring, and the second-best female breeds with the second-best male, and so on. Then the positions of the offspring are generated as follows:

$$\begin{cases} offs\ 1 = L * m + (1 - L) * fm \\ offs\ 2 = L * fm + (1 - L) * m \end{cases} \tag{4}$$

where L is a random value within a specific range, m is the position of the male parent, and fm is the position of the female parent.

In MA, when the current iteration comes to the end, the positions of the offspring are evaluated on the predefined objective function. Accordingly, the offspring are nominated as male or female for the next iteration.

To deal with the situations of premature convergence that may lead to a local instead in MA, a normally distributed random number is added to the chosen offspring's variable for mutation, which is denoted as improved mayfly algorithm (IMA) in [1]. In this way the offspring is altered as

$$offs_{new} = offs + \delta N_n(0, 1) \tag{5}$$

where δ is the standard deviation of the normal distribution and $N_n(0, 1)$ is a standard normal distribution.

Methods: As the improvement strategies such as Gaussian distribution, Chebyshev map, and Lévy flight were used to optimize the velocity and position, the multiple mutation [9] methods can be studied for MA, and three improved MAs are explored. The multiple mutation strategies which conclude Cauchy mutation, OBL, and artificial mutation strategies are used in a cascaded structure in various processes.

OCMA method: As the OBL algorithm is proposed to learn opposition-based solutions based on the current solution, it can be used to mutate the global optimal solution to avoid the local optimal [10]. And the Cauchy mutation (OC) is used to reduce the probability of falling into local optimal. Thus, the OBL and Cauchy mutation strategies can be fused to mutate the global optimal solution when the positions of mayflies have been updated. The improved algorithm based on OBL and Cauchy mutation is named OCMA.

The formula of the OBL in MA is as follows:

$$x_{gbest}^{t'} = ub + r_3 * \left(lb - x_{gbest}^t\right) \tag{6}$$

$$x_{new}^{t+1} = a_4 * \left(x_{gbest}^t - x_{gbest}^{t'}\right) \tag{7}$$

where $x_{gbest}{}^t$ is the global optimal solution of each iteration, $x_{gbest}{}^{t'}$ is the opposition-based solution of $x_{gbest}{}^t$, ub, and lb are the upper and the lower of parameters, r_3 is a uniformly distributed random matrix, a_4 is the information exchange coefficient, and $x_{new}{}^{t+1}$ is the new target solution.

The new target solution is updated based on the Cauchy operator as

$$x_{new}^{t+1} = Cauchy * x_{gbest}^{t} \tag{8}$$

The global best position can be updated as follows:

$$x_{new}^{t+1} = \begin{cases} a_4 * \left(x_{gbest}^{t} - x_{gbest}^{t}\right), if\ P_s > rand \\ Cauchy * x_{gbest}^{t}, if\ P_s \le rand \end{cases} \tag{9}$$

where rand is a random value in the range (0, 1), ρ_s is a certain probability to fuse the OBL and Cauchy mutation, the formula as follows:

$$P_s = -e^{\left(1-\frac{t}{Iter\_MAX}\right)^{20}} + \theta \tag{10}$$

where *Iter_MAX* is the maximum iterations.

As the best solution is retained, the global optimal solution is updated as

$$x_{gbest}^{t} = \begin{cases} x_{gbest}^{t}, & if\ f\left(x_{gbest}^{t}\right) < f\left(x_{new}^{t+1}\right) \\ x_{new}^{t+1}, & if\ f\left(x_{gbest}^{t}\right) \ge f\left(x_{new}^{t+1}\right) \end{cases} \tag{11}$$

AMMA method: As the characters of the biological population are considered for crossover, the phenomenon that a few of the female mayflies may have the personalities of the males can be used to enhance the diversity of the positions. Accordingly, an artificial mutation operator is introduced to convert the genders of some females to males. Instead of updating the offspring population of each gender, the positions of the offspring are updated as follows, and the algorithm is named as artificial mutation mayfly algorithm (AMMA):

$$\begin{cases} x_{mi\ new}^{t+1} = (1-\rho)x_{mi}^{t+1} + \rho x_{fi}^{t+1} \\ x_{fi\ new}^{t+1} = (1-\rho)x_{fi}^{t+1} + \rho x_{mi}^{t+1} \end{cases} \tag{12}$$

where ρ is the artificial mutation operator, because of the biological characters and effective breeding of the population, ρ is set in [0, 1].

HMMA method: To further increase the diversity of search space for MA on the basis of OCMA and AMMA, the hybrid mutation strategies which conclude the OBL, the Cauchy mutation, and artificial mutation can be used in a cascaded structure in various processes. The OBL and Cauchy mutation strategies are used to mutate the global optimal solution when the positions of mayflies have been updated. After the global optimal solution is mutated, the artificial mutation operator is introduced to convert randomly the offspring population of each gender as the next iteration population. The improved algorithm based on the hybrid mutation is named as hybrid mutation mayfly algorithm (HMMA). When ρ is set to zero, HMMA is the same as OCMA.

Discussion: To verify the proposed algorithms, the original MA (denoted as MA) and the IMA are selected as baselines, and the standard 15 benchmarks F1 to F15 are used as test functions. To be abstracted, three types of functions are discussed in contrast.

F3 function is a unimodal testbench function

$$F_3(x) = \sum_{i=1}^{n}\left(\sum_{j}^{i} x_j\right)^2 \tag{13}$$

F7 function is a multi-modal testbench function

$$F_7(x) = \sum_{i=1}^{n}\left[x_i^2 - 10\cos(2\pi x_i + 10)\right] \tag{14}$$

F15 function is a fixed-dimension multimodal testbench function

$$F_{15}(x) = \sum_{i=1}^{11}\left[a_i - \frac{x_1 * \left(b_i^2 + b_i * x_2\right)^2}{b_i^2 + b_i * x_3 + x_4}\right]^2 \tag{15}$$

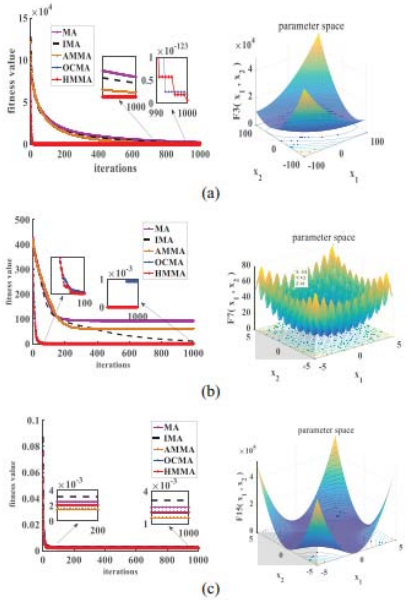

Fig. 1 *Convergence curves and parameter space of different algorithms. (a) F3 average convergence curves and parameter space. (b) F7 average convergence curves and parameter space. (c) F15 average convergence curves and parameter space*

In the simulations, the global optimums of F3 and F7 are located at the origin, and the global optimum of F15 is set to 0.00030. The iterations of the simulations are set as 1000, the parameters (a_1, a_2, a_3, *fl*, *g*, *ub*, *lb*. θ, *d*, *fl_damp*, *g_damp*, *d_damp*, ρ) are set as (1.0, 1.5, 1.5, 1, 0.8, 0.1, 10, 0.005, 5, 0.99, 1, 0.8, 0.1). The simulation is run 50 times independently, and the results are listed in Table 1, the average convergence curve and parameter space of F3, F7, and F15 are shown in Figure 1.

As in Table 1, the best solution to the multi-modal test function F7 is found by HMMA and OCMA. Meanwhile, the stability and robustness of HMMA perform better than OCMA in the average and standard deviation. The standard deviation of HMMA is far less than that of MA, which shows the potential for high stability and robustness, though the best solution for HMMA is not yielded in F3. As in Figure 1, the proposed AMMA, OCMA, and HMMA algorithms have higher convergence precision and faster-searching speed than MA, compared with the results of F3, F7, and F15 functions. From Figure 1 it can be concluded that the proposed algorithms have better exploration and exploitation abilities.

In order to analyze the effect of the various values of the artificial mutation factor ρ, four values of ρ in [0, 1] are tested in simulations with the multi-peak function F15. The results are shown in Table 2, and the average convergence curves of HMMA are shown in Figure 2.

According to Table 2 and Figure 2, the stability and the convergence rate of HMMA are the best when ρ is set as 0.1 in the standard deviation and mean. Therefore, the artificial mutation factor ρ should be set at a finite value, according to the real condition of the applications.

Conclusion: The letter adopts the mutation strategies in the process of MA to increase the diversity and performance of MA. The OBL and Cauchy mutation strategies are used to mutate the global optimal solution, and then an artificial mutation operator is introduced to convert the genders of some females to male for the next offspring population. The hybrid mutation strategies which conclude OBL, Cauchy mutation, and artificial mutation are used in a cascaded structure in

Table 1. Comparison of different algorithms with F3, F7, and F15

	Algorithm	Best	Worst	Average	Std	Median
F3	MA	38.34681438	5570.54223	1990.623611	1298.093088	1755.035755
	IMA	172.9991708	4070.999659	1389.873149	794.0436791	1166.967053
	AMMA	9.306114281	2032.942393	444.7573059	386.5839019	314.2271551
	OCMA	5.0043E-158	8.8989E-123	1.7798E-124	1.2458E-123	9.9646E-143
	HMMA	1.5321E-155	3.0399E-123	6.0807E-125	4.2558E-124	4.4956E-143
F7	MA	35.8184	178.096	92.7297	37.5374	84.5712
	IMA	3.9798	25.8756	10.3546	4.9176	9.9503
	AMMA	25.8689	145.263	60.8912	23.0554	55.2201
	OCMA	0	0.0093	0.0009	0.00214	0
	HMMA	0	0	0	0	0
F15	MA	0.000307486	0.020363339	0.002524212	0.005996743	0.000307486
	IMA	0.000307486	0.020363339	0.003171937	0.006160735	0.000307486
	AMMA	0.000307486	0.020363339	0.001541832	0.004126545	0.000307486
	OCMA	0.000307486	0.020363339	0.002023941	0.005011123	0.000307486
	HMMA	0.000307486	0.020363339	0.002105313	0.004469969	0.000307486

Table 2. Comparison of various ρ in HMMA

	ρ	Best	Worst	Average	Std	Median
F15	0.1	0.000307486	0.020363339	0.002105312	0.004469968	0.000307486
	0.25	0.000307486	0.020363339	0.002278323	0.005426289	0.000307486
	0.5	0.000307486	0.020363339	0.002380993	0.004749712	0.000307486
	1	0.000307486	0.020363339	0.003232381	0.005065012	0.000307486

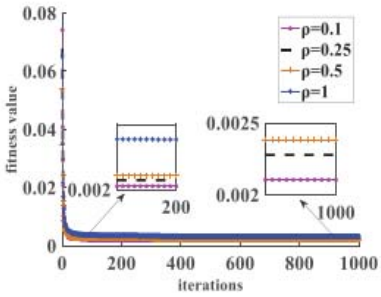

Fig. 2 *Convergence curves of HMMA with different various ρ*

various processes. The improved algorithms are simulated comparatively and demonstrated the features of high accuracy and better convergence in test functions. The proposed MA can be used to capture the global optimal solution in most applications.

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Conflict of interest: The authors declare that there are no conflicts of interest, we do not have any possible conflicts of interest.

Data availability statement: Data is available on request from the authors. The data that support the findings of this study are available from the corresponding author, Hua Zhang, upon reasonable request.

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发表论文：

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GTN损伤参数对DP780钢板成形极限曲线的影响

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摘　要：为研究DP780钢板的成形性能，在室温下对DP780钢板进行了静态拉伸实验，获得了其应力-应变曲线。用ABAQUS有限元仿真软件中的GTN损伤模型对钢板进行了数值模拟，根据最大凸模力和应变突变两个准则获得了成形极限曲线，通过与NAKAZIMA胀形实验和理论预测结果对比，证明了GTN损伤模型预测DP780钢板成形极限的准确性，并且得到了DP780钢的成形极限图理论预测近似公式。分析了形核孔洞体积分数f_N、完全失效体积分数f_F和临界孔洞体积分数f_C这3个损伤参数对成形极限曲线的影响。结果表明，随着f_N的增加，材料提前发生颈缩，成形极限平面主应变FLD_0的值逐渐减小；随f_F和f_C的增加，FLD_0的值逐渐增加，且f_C和f_N对成形极限曲线影响较大。

关键词：DP780钢；成形极限图；GTN损伤模型；损伤参数
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Effect of GTN damage parameters on forming limit curves of DP780 steel sheet

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Abstract：To study the forming properties of DP780 steel sheet，the static tensile experiment was carried out on DP780 steel sheet at room temperature，and its stress-strain curve was obtained. The numerical simulation of steel sheet was carried out by using GTN damage model in ABAQUS finite element simulation software. The forming limit curve was obtained according to the two criteria of the maximum punch force and the sudden change of strain. By comparing the results of NAKAZIMA bulging experiment and theoretical prediction，the

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DP780高强钢U形弯曲回弹影响因素及优化

丁华锋[1,2]，潘俊杰[1]，晏洋[2]，金先志[1]，李红兵[1]，胡泽奇[1]，周昌钰[1]
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摘要：目的 研究DP780高强钢不同参数对其U形弯曲回弹的影响。**方法** 在室温下对DP780钢板材进行拉伸试验，获得其应力应变曲线。采用U形弯曲模具模型，利用ABAQUS有限元仿真软件对U形弯曲回弹进行分析，研究摩擦因数、压边力、冲压速度和凹凸模间隙对U形弯曲回弹的影响规律，并在此基础上设计正交试验以优化影响参数。**结果** 在较小的摩擦因数下，回弹是有微小波动的，继续增大摩擦因数，回弹呈现减小的趋势；回弹随着压边力的增大先增大后减小；冲压速度的改变对回弹的影响不是很大；随着凹凸模间隙的增加，回弹逐渐增大。**结论** 通过正交试验得到4个参数对回弹程度的影响，最佳参数组合为$A_5B_5C_3D_1$，以此参数组合得出的侧壁角θ_1和法兰角θ_2最接近90°，回弹效果最好。

关键词：DP780高强钢；U形弯曲回弹；有限元仿真；正交试验
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Influence Factors and Optimization of U-shaped Bending Springback of DP780 High-strength Steel

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[1] 钱伟, 吴钊, 吴华伟, 等. 上三角肘杆式压力机构间隙动力学特性分析[J]. 锻压技术, 2022, 47(06):214-223.

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上三角肘杆式压力机构间隙动力学特性分析

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摘要：压力机械的运动副常因受到反冲作用力而产生运动间隙，导致机械系统的冲击增大，冲压成形稳定性降低。优选三角肘杆式压力机构运动副间隙动力学的建模及仿真，依据其工作原理分析了上三角型与下三角型肘杆式压力机构执行连杆的运动特性变化规律，得出上三角型相对下三角型在位移、速度和加速度方面分别优化了30%、59%和390%；基于MLSD运动副间隙模型，运用ADMAS虚拟样机技术建立了含运动副间隙上三角型肘杆式压力机构的动力学仿真模型，分析了运动副间隙引起的碰撞和磨损对机构动态特性的影响。结果表明，运动副相对间隙值超20%时，机构运行将伴随较大的冲击，并伴随一定程度的振动和噪声，影响机构工作的稳定性。研究结果为肘杆式压力机构的结构设计提供了理论依据。

关键词：肘杆式压力机构；运动副间隙；动力学特性；运动学特性；执行连杆

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Analysis on dynamic characteristics of upper triangular toggle press mechanism clearance

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Abstract: The moving pair of pressure machine is often prone to produce movement gaps due to the recoil force, which leads to the increase of impact for mechanical system and the decrease of stability for stamping forming. Therefore, the dynamic modeling and simulation of moving pair clearance for triangular toggle press mechanism were optimized. Based on its working principle, the variation rules of motion characteristics for the executive connecting rod of upper triangle type and lower triangle type toggle press mechanisms were analyzed, and the displacement, velocity and acceleration of the upper triangle type were optimized by 30%, 59% and 390%, respectively, compared with the lower triangle type. Then, based on moving pair clearance model MLSD, a dynamic simulation model of upper triangular type toggle press mechanism with moving pair clearance was established by virtual prototype technology ADMAS, and the influences of collision and wear caused by moving pair clearance on dynamic characteristics of the mechanism were analyzed. The results show that when the relative clearance value of moving pair exceeds 20%, the operation of the mechanism is accompanied by great impact, as well as vibration and noise to a certain extent, which affects the stability of the mechanism. Thus, the research results provide theoretical basis for the structural design of toggle press press mechanism.

Key words: toggle press mechanism; moving pair clearance; dynamic characteristics; kinematics characteristics; execution rod

压力机械是一种被广泛应用的冲压装备，为更好地满足实际生产的冲压工艺需求，在传统曲柄滑块压力机机构的基础上，国内外学者提出了多种具有低速锻冲、急回特性的压力机构。其中，以三角肘杆式压力机构执行连杆端的速度变化较为平稳，具备良好的急回特性及显著的回程增力特征，并且其工作行程较大，所需的驱动力矩及动力源的容量相对较小，节约成本、节能降耗，是一种颇具发展前景的压力机构[1]。

国内外学者在肘杆式压力机构的研究领域已经取得了诸多研究成果。王中双等[2]提出相应的向量键合图法来提高肘杆式压力机构动力学建模与分析的效率

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多单点间隙下肘杆压力机运动学特性对比分析

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摘　要：运动副间隙对机构动态特性影响显著。该文提出了一种上三角肘杆式连杆机械压力机结构，采用环形矢量法建立该机构的运动学方程，并根据各杆件间的几何关联，用多体动力学软件依次独立对多个含间隙铰接点进行了运动学仿真分析得到的结果为：机构多铰接点在同一相对间隙值下对应的运动学动态特性曲线。这表明，在同一相对间隙值下，铰接点间隙趋近执行连杆端时，位移、速度及加速度曲线“畸变”显著增强，各间隙点冲击部位存在的差异性较大。

关键词：肘杆机构；铰接间隙；运动学；对比分析

中图分类号：TG385　　**文献标识码**：A　　**文章编号**：1672-545X（2021）10-0015-03

0　引言

压力机是一种统称，它包括冲床、液压机，具有用途广泛、生产效率高的特点，它通过对金属坯件施加强大的压力使金属发生塑性变形和断裂来加工成零件。压力机是最为常见的冲压加工设备。其特性目前主要划分为运动学特性和动力学特性[1]。肘杆式压力机具有显著的强冲击效应和变速高特性。对肘杆式压力机的运动学特性研究是该领域较多学者开展研究之一[2]。但已有的肘杆式压力机研究大部分只是针对单一结构改良或运动形式的分析，对多单点间隙下肘杆式压力机运动学特性研究未有报道[3]。本研究选取上三角肘杆式压力机构进行分析，得出一般性运动规律后，再用仿真技术虚拟样机分别对各铰点间隙进行运动学仿真，观测连杆的运动曲线“畸变”及动力输出波动进行数值化对比，得出：在同一间隙值下各铰点的影响程度与影响区域。该结果为后续更深入进行上三角肘杆机的研究提供参考。

1　数学建模及分析

1.1　数学模型确立

为了增强上三角型肘杆式压力机各铰接点之间的可对比性，提升测试结果的可信度，将其孔径和轴径取值相同，即采用单变量研究法[4]。上三角肘杆式压力机的主结构图如图 1 所示。

通常条件下，结构整体属沿 MN 两点连线对称，任选一侧为主约束结构，另一侧则为副约束结构。本研究围绕主侧结构展开，连杆（AM）为驱动端，可实现上下往复平动，连杆（AB）作为上连杆，负责驱动三角肘杆（BCD）作绕固定点 C 的旋转运动，B、D 两铰接点负责连接上、下两连杆，连杆（DE）为下连杆，负责驱动执行连杆（EN）的杆件，连接三角肘杆与执行连杆。连杆（EN）为执行连杆，是具有执行一定运动特性的往复平动。图 1 所示，铰接点 A-E 均含有铰间隙，且所有连杆均取设有代号。

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通讯作者：钱伟（1997-），男，湖北荆州人，硕士生，机械系统多体动力学仿真方向。

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证书号第4931347号

发明专利证书

发明名称：立体停车装置

发明人：吴钊;钱伟;吴华伟;刘梦迪;赵千

专利号：ZL 2020 1 1375935.X

专利申请日：2020年11月30日

专利权人：湖北文理学院

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证书号第14088157号

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实用新型名称：载车平台及立体停车库

发　明　人：刘梦迪;钱伟;吴钊;吴华伟;李正;雷宇

专　利　号：ZL 2020 2 2828379.9

专利申请日：2020年11月30日

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2021年09月03日

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证书号第14152199号

实用新型专利证书

实用新型名称：车辆搬运平台及立体停车库

发　明　人：钱伟;吴钊;吴华伟;李正;刘梦迪;雷宇

专　利　号：ZL 2020 2 2825757.8

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实用新型名称：一种摩擦式变速结构

发　明　人：钱伟;吴钊;吴华伟;李正;刘梦迪;雷宇;赵千

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[1] 张海军，万少华，张明杰．基于自抗扰控制的轮毂电机驱动电动汽车耦合振动抑制[J]．汽车技术，2023，doi.org/10.19620/j.cnki.1000-3703.20220302．（网络首发）

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[4] Zhang H J，Wan S H，Zhang H J，et al．ADRC Control of Electromagnetic Vi-bration in In-wheel Motor Considering Air Gap Eccentricity[C]．CEFC Twentieth Biennial IEEE Conference on Electromagnetic Field Computation．IEEE，2022：6654-6833．

申请专利：

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发表论文截图

基于自抗扰控制的轮毂电机驱动电动汽车耦合振动抑制*

张海军　万少华　张明杰

（湖北文理学院，纯电动汽车动力系统设计与测试湖北省重点实验室，襄阳 441053）

【摘要】针对路面随机激励和轮毂电机不平衡电磁激励引起的电磁耦合振动对轮毂电机驱动电动汽车的影响，提出一种基于自抗扰的振动抑制方法。建立车辆1/4振动系统数学模型，设计了一种基于自抗扰的控制器，将路面随机激励和电机自身产生的电磁激励视为总扰动进行统一观测补偿控制，并通过MATLAB/Simulink对所提出的控制策略进行仿真验证。结果表明，自抗扰控制对由路面不平度和偏心电磁力引起的电磁耦合振动具有较好的抑制效果。

主题词：轮毂电机　随机激励　耦合振动　自抗扰控制

中图分类号：TM922.71　　文献标识码：A　　DOI: 10.19620/j.cnki.1000-3703.20220302

Coupling Vibration Suppression of In-Wheel Motor Electric Vehicle Based on Active Disturbance Rejection Control

Zhang Haijun, Wan Shaohua, Zhang Mingjie

(Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle, Hubei University of Arts and Science, Xiangyang 441053)

【Abstract】For the influence of electromagnetic coupling vibration caused by random road excitation and unbalanced electromagnetic excitation of in-wheel motor on electric vehicle driven by in-wheel motor, this paper proposed a vibration suppression method based on Active Disturbance Rejection Control(ADRC). Firstly, the mathematical model of a quarter of the vehicle vibration system was established. Secondly, a controller based on ADRC was designed. The road random excitation and the electromagnetic excitation generated by the motor itself were regarded as the total disturbance for unified observation compensation control. Finally, the proposed control strategy was verified by MATLAB/Simulink. The results show that ADRC can suppress the electromagnetic coupling vibration caused by road roughness and eccentric electromagnetic force.

Key words: In-wheel motor, Random excitation, Coupled vibration, Active Disturbance Rejection Control (ADRC)

【引用格式】张海军，万少华，张明杰. 基于自抗扰控制的轮毂电机驱动电动汽车耦合振动抑制[J]. 汽车技术，2023(5)：8-14.

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1　前言

轮毂电机驱动电动汽车动力传输效率高、污染小、控制灵活，尤其可以实现对单个车轮的独立控制，因此具有明显的驱动控制优势[1]。然而，相对传统的动力中置电动汽车而言，轮毂电机省去了机械传动系统，电机更加靠近振动源，使其运行条件更加恶劣，同时电机在运行过程中还存在各类不确定性扰动，如路面的随机扰动和自身电磁激励[2]。工程上采用传统比例积分微分控制方法抑制不确定性扰动，虽然实现简单，但始终存在转速超调与快速跟踪之间的矛盾，在复杂扰动条件下跟踪精度不高，制约了车辆动力性能的提升[3]。自抗扰控

*基金项目：湖北省中央地方科技发展专项(2020ZYYD001)；湖北省自然科学基金项目(2019CFC893)。

随机激励下电动汽车轮毂电机耦合振动特性分析

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摘要：轮毂电机驱动电动汽车受电磁力与路面随机激励双重作用，其振动具有耦合特性。本文将含有径向电磁力的轮毂电机作为自振系统考虑，建立电动汽车的四分之一振动模型。结合电机工作特性并考虑随机路面激励，采用PSD分析方法对不同运行工况下悬架弹簧动挠度、簧载质量加速度等动态响应进行理论分析和仿真计算。结果表明：在内外激励叠加作用下所产生的动态响应也将成倍增加，且1Hz和8Hz附近最容易发生共振现象。

关键词：随机激励；轮毂电机；耦合振动；径向电磁力。

中图分类号：U130.2040　　文献标识码：A

Analysis of coupled vibration characteristics of in-wheel motor of electric vehicle under random excitation

ZHANG Hai-jun, WAN Shao-hua, ZHANG Ming-jie, GUO JI

(Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle, Hubei university of Arts and Science, Xiangyang, 441053)

Abstract: The vibration of electric vehicle driven by in-wheel motor is coupled with electromagnetic force and random excitation of road surface. In this paper, the hub motor with radial electromagnetic force is considered as the natural vibration system to establish a quarter vibration model of electric vehicles. Combining with the working characteristics of the motor and considering the random road excitation, the PSD analysis method is used to carry out theoretical analysis and simulation calculation on the dynamic response of suspension spring dynamic deflection and spring load mass acceleration under different operating conditions. The results show that the dynamic response generated by the superposition of internal and external excitations will also multiply, and the resonance phenomenon is most likely to occur near 1Hz and 8Hz.

Key words: Random excitation; In-wheel motor; Coupled vibration; Radial electromagnetic force

面对节能减排和经济需求的双重压力，新能源电动汽车作为汽车技术新秀，将成为21世纪汽车工业发展的重要支撑[1]。其中，轮毂电机驱动电动汽车具有能效高、环境友好、控制灵活等优点，特别是可以实现对单个汽车车轮的独立控制运行，具有明显的驱控优势[2-3]。然而，相对于传统驱动电机系统，轮毂电机的运行条件尤为恶劣，如振动源复杂性、外部扰动随机性。考虑到省去机械传动系统，轮毂电机径向电磁力和转矩波动会直接作用于驱动轮系统，可能引起悬架共振以及整个轮毂单元的振动[4]。此外除了轮毂电机本体产生的振动噪声外，电动汽车还承受路面不平度引起的随机激励作用，都可能影响车辆行驶平顺性和乘坐舒适性[5-6]。轮毂电机的振动不仅影响电动汽车乘坐的舒适性，其噪声也是一种重要的污染源，制约了轮毂电机在电动汽车上的广泛应用。

已有关于轮毂电机的研究主要集中在电机电磁设计、电动汽车的悬架控制、振动优化等方面[7-8]。文献[9]通过对几种驱动电机进行多维比较，分析了引起振动的振源；文献[10]提出了一种新型轮毂电机式电动汽车主动悬架构型，通过采用二次型进行控制，对不同路面激励具有较好的减振性。文献[11]提出了一种主动悬架多目标优化控制方法并初步分析了电磁激励特性；文献[12]研究了随机路面和脉冲路面对车辆垂向振动的影响，通过粒子群算法对综合减振系统进行了优化；文献[13]和[14]分别研究了电磁力与路面激励对开关磁阻电机气隙偏心，并提出混合控制方法以降低气隙偏心带来的电磁振动；文献[15]分析了随着路面不平度和车速增大工况下，电磁激励将会引起电动汽车的阶次振动。在实际运行过程中，受不同工况影响引起轮毂电机电流和转矩频繁变化以及径向电磁力的波动。考虑

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Analysis of Electromagnetic Vibration of Electric Vehicle Drive Motor Considering the Influence of Random Excitation

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Abstract— In order to improve the ride comfort of electric vehicles driven by in-wheel motors, this paper intends to analyze the changes in the electromagnetic characteristics of the electric vehicle in-wheel motors from the perspective of vibration mechanics due to random excitations caused by uneven road surfaces. The spring dynamic deflection and its limit stroke are produced by the uneven road surface and the dynamic load between the wheel and the road. The influence of random excitations to motor is considered by the eccentricity between the stator and the rotor, where an unbalanced electromagnetic field is analyzed. Based on the air gap magnetic field generated when the stator and rotor of the hub motor are eccentric, a mathematical model of the radial electromagnetic force is established. Also, the random vibration acceleration transfer function of the motor is constructed. Finally, a simulation model of the electromagnetic vibration acceleration of the hub motor considering random excitation is established based on MATLAB/Simulink software. The electromagnetic vibration of the in-wheel motor under random excitation is analyzed through the simulation results.

I. Introduction

Electric vehicles driven by in-wheel motors have a series of advantages such as short power transmission distance, low transmission loss, high transmission efficiency and controllable power. It is one of the hot spots in the development of the electric vehicle industry. However, in practical applications, in-wheel motors the influence of random excitation in the running process aggravates the vibration of the body and the motor, and reduces the ride comfort and ride comfort of the vehicle.

Based on quarter-vehicle model, wheel vertical dynamics performance is investigated for the proposed suspension system by numerical modeling and simulation method [1]. The design of a synchronous motor with a distributed winding and an outer rotor as an in-wheel electric motor for vehicles is proposed [2]. A novel flux weakening method is reported for in-wheel motor drives of electric vehicles [3]. However, it can be seen that the current research on electromagnetic vibration of in-wheel motors is still rare, and the electromagnetic vibration caused by random excitation is even rarer.

In this paper, the perspective of vibration mechanics and the random excitation generated by the in-wheel motor during operation are considered, such as the body acceleration, dynamic deflection of suspension spring β and its limit stroke $[\beta]$, and the dynamic load between the wheel and the road surface. The eccentricity between the stator and the rotor of the in-wheel motor may produce an unbalanced electromagnetic force under the action of the electromagnetic field. Based on the air gap magnetic field generated under the eccentric, the mathematical model of radial electromagnetic force is established, and the random vibration transfer function of the motor is constructed.

II. Random Model of In-Wheel Motor

The vibration caused by the unevenness of the road surface will act on the drive motor of the electric vehicle. This section first analyzes the vibration of the road surface to varying degrees and introduces the fitting formula of the road surface power spectrum density:

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-\omega} \tag{1}$$

For a single-mass wheel system, the random excitation generated by the road surface and the dynamic wheel load F_d are determined by the inertial force of the body mass. As shown in Figure 1, from the equilibrium position of the body, the change caused by random excitation is the limit stroke[β].

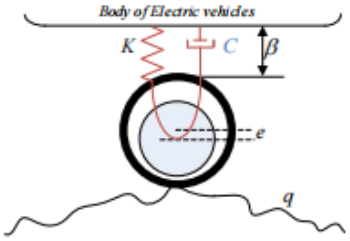

Fig. 1. in-wheel motors fixed rotor eccentric diagram

The complex amplitude of the suspension spring is $\beta = z - q$, so the frequency response function of random excitation to uneven road surface is:

$$\beta = \frac{\lambda^2 q}{1 - \lambda^2 + 2\zeta j\lambda} \tag{2}$$

III. In-Wheel Motor Vibration Model

During the operation of the in-wheel motor, due to the influence of random factors on the road surface, eccentricity will occur between the stator and the rotor of the in-wheel motor, and an unbalanced electromagnetic force will be generated under the action of the electromagnetic field. When

ADRC Control of Electromagnetic Vibration in In-wheel Motor Considering Air Gap Eccentricity

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***Abstract*—In view of the influence of electromagnetic vibration caused by road random excitation and unbalanced electromagnetic excitation on in-wheel motor, a vibration suppression method based on active disturbance rejection control (ADRC) is proposed. The road random excitation and electromagnetic excitation generated by the motor itself are regarded as total disturbances for unified observation compensation control. The results show, that the proposed control strategy has a better inhibitory effect on the eccentric electromagnetic vibration generated during the operation of the in-wheel motor.**

***Keywords*—In-wheel motor, Electromagnetic vibration, ADRC**

I. Introduction

Due to the advantages of high power transmission efficiency, low pollution and flexible control, in-wheel motor has become an important direction of future automobile development. Because the in-wheel motor eliminates the mechanical transmission system, the road excitation will cause the in-wheel motor stator and rotor air gap asymmetry, so that the motor air gap magnetic field distribution is not uniform, resulting in electromagnetic vibration of the motor. Active disturbance rejection control has the ability of disturbance estimation and compensation on the basis of absorbing modern control theory and methods. It has good control effect and does not require accurate mathematical model, which can greatly improve the motor control performance [1].

Many scholars have studied the application of ADRC in electric vehicles. Reference [2] reviewed the design of permanent magnet synchronous motor based on active disturbance rejection control, and gave the future research direction. References [3] and [4] studied the vehicle braking performance based on active disturbance rejection control and the constant-speed cruise control strategy of electric respectively. Reference [5] designed an active disturbance rejection controller to realize the traction control of electric vehicles. At present, the application of active disturbance rejection control in electric vehicles is mostly concentrated in traction braking and constant speed cruise, and there is no research on the application of active disturbance rejection control in the electromagnetic vibration of in-wheel motor.

In this paper, the influence of in-wheel motor electromagnetic vibration caused by air gap eccentricity on vehicle ride comfort is studied, and an electromagnetic vibration suppression method based on active disturbance rejection is proposed. The random excitation of road surface and the electromagnetic vibration generated by in-wheel motor itself are regarded as the total disturbance for unified observation, so as to carry out real-time compensation and control of in-wheel motor electromagnetic vibration.

II. Electromagnetic Vibration Modeling of In-wheel Motor

A. Stochastic road modeling

Establish a quarter vehicle vibration model as shown in Figure 1:

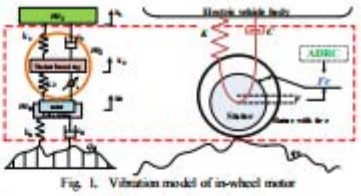

Fig. 1. Vibration model of in-wheel motor

The power spectral density of road roughness expressed by time frequency is white noise in the whole time frequency range. The white manic sound under certain conditions can be expressed as:

$$\dot{q}_0(t) = -2\pi f_0 q_0(t) + 2\pi n_0 \sqrt{G_q(n_0)v}\cdot\omega(t) \tag{1}$$

In the formula, n_0=0.1m^{-1} is the reference space frequency; $G_q(n_0)$ is the road power spectrum value at the reference spatial frequency; v speed; f_0 = 0.01Hz is the lower limit cutoff frequency; $q_0(t)$ is the amplitude of random road roughness changing with time; $\omega(t)$for the average of 0, the intensity of 1 unit white noise road interference.

$$\begin{cases} m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_2) = 0 \\ m_0\ddot{x}_0 + c_0(\dot{x}_0 - \dot{q}_0) + k_0(x_0 - q_0) + k_2(x_0 - x_2) = -F_r \\ m_2\ddot{x}_2 + + c_0(\dot{x}_2 - \dot{x}_1) + k_1(x_2 - x_1) + k_2(x_2 - x_0) = F_r \end{cases} \tag{2}$$

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发表论文：

[1] 聂金泉，王敖，魏长银，等．燃料电池汽车工况自适应的模糊能量管理策略[J]．重庆理工大学学报（自然科学）（已录用）.

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[2] 聂金泉，王敖，陈晨，等．复合电源系统及其能量管理方法[P]．中国，发明专利，CN114228566A，2022-03-25（实质审查）.

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发明专利申请公布及进入实质审查阶段通知书

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[1]温云,马强,杨桃桃.基于无源观测器的永磁同步电机无传感器控制[J].湖北文理学院学报,2023,44(05):5-11.

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基于无源观测器的永磁同步电机无传感器控制

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摘要: 针对永磁同步电机使用滑模观测器产生抖振引起转速和转矩波动问题,设计一种无源观测器用于降低观测器速度和角度误差,实现永磁同步电机的无传感器控制策略。利用李雅普诺夫函数证明了该无源观测器的稳定性。仿真结果表明,无源观测器较传统滑模观测器对抑制转矩波动性能有较大提高,速度估计误差和角度估计误差接近零,且对电机运行中引起的参数变化具有良好的鲁棒性。

关键词: 永磁同步电机; 无源观测器; 无传感器控制; 滑模观测器
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永磁同步电机(Permanent magnet synchronous motor,简称 PMSM) 具有体积小、高功率密度、功耗小与温升低等优点,在新能源电动汽车、轨道交通、航天航空等领域得到广泛应用[1-2]。高性能 PMSM 常用矢量控制方法,该方法采用机械式传感器获取精确的转子角度和转速信息,对恶劣环境适应不强,增加系统成本,同时降低系统可靠性。而采用观测器无传感器技术可以精简电机控制系统,提高电机在不同应用场景中的控制精度和稳定性[3-4]。

目前,PMSM 高速状态使用较多的观测器有龙伯格观测器[5](Luenberger Observer, LO) 、扩展卡尔曼滤波器[6](Extended Kalman Filter, EKF) 、滑模观测器(Sliding Mode Observer, SMO) 。SMO 由于响应迅速、稳定性好,对参数扰动不敏感[7],是常用的观测器,但存在抖振及控制精度较低现象。为了降低抖振,通常使用新型趋近率 SMO。张强等[8]通过扩展滑模电流设计了一种新型变趋近律滑模观测器,提高转子位置及转速估算准确性,降低系统的抖振。谭光兴等[9]通过引入新型趋近率,设计积分变结构与扰动观测器复合新型滑模观测器,有效削弱了滑模控制的抖振。高性能矢量控制须要精确的转速和角度信号,除选择合适的

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谢东升（1997-），男，四川巴中人，中共党员，汽车与交通工程学院2020级机械（新能源汽车动力测控系统方向）专业研究生，导师是工学博士刘祯教授。科研方面：研究生期间主要从事流体机械优化设计与性能仿真，参与项目研究4项，学科竞赛3项，发表SCI论文1篇，核心1篇，国际会议论文1篇，申请专利6项，授权2项，受审4项，授权实用新型专利2项。学业获奖：2020年学业奖学金二等；2021年学业奖学金一等；2022年学业奖学金三等。

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[1] Xie Dongsheng, Liu Zhen, Li Zheng, et al. Effect of tooth head modification on the performance of a scroll expander for ORC waste heat recovery system [J]. Frontiers in Energy Research, 2023(10): 1951.

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Characteristics of Scroll Expander for Vehicle Waste Heat Recovery [C]. the 14th International Conference on Applied Energy - ICAE2022, Aug. 8-11, 2022, Bochum, Germany.

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Effect of tooth head modification on the performance of a scroll expander for ORC waste heat recovery system

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In order to cope with the energy crisis and improve energy efficiency, the use of organic Rankine cycle (ORC) to convert low-quality heat energy into electricity and use it is an effective method. Based on the ORC waste heat recovery system of vehicle engine, this paper explores the flow heat transfer and deformation law of the core component scroll expander under different tooth head corrections. Deformation has a significant impact on the performance of the expander. In this study, several flow-thermal-solid coupling models based on double circular arc correction and double circular arc plus straight-line correction are established. The effects of tooth head correction on the strength and stiffness of tooth head, flow field distribution of suction chamber and deformation characteristics of tooth head are studied. Finally, the deformation law of scroll tooth head with different correction angles was discussed. The results show that the EA-SAL correction makes the wall curvature of the tooth head change greatly, and the flow field in the center of the tooth head becomes more uneven and complicated. The tooth head area under EA-SAL modification is larger, and the tooth head strength and stiffness are improved by about 6%. Within a certain angle range, the tooth head deformation after EA-SAL correction is slightly larger than that after PMP correction, but the difference between them decreases and even reverses with the increase of angle. The maximum deformation of the EA-SAL modified tooth head under internal pressure is about 20% smaller than that of PMP. With a given initial correction angle Ø, the deformation of the corrected tooth head caused by a pressure or temperature load reduces when the correction angle γ is reduced, Therefore, reducing the correction angle properly is helpful to reduce the deformation of the tooth head.

KEYWORDS

ORC waste heat recovery, scroll expander, PMP (dual-arc correction), EA-SAL (dual-arc plus straight-line correction), flow field and deformation distribution

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Study on Fluid-Solid Coupling Characteristics of Scroll Expander for Vehicle Waste Heat Recovery#

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ABSTRACT

In this work, the scroll expander in the organic Rankine heat recovery system of vehicle engine was taken as the research object. The fluid-solid coupling method was used to numerically simulate the scroll expander, and the temperature, pressure and velocity distributions at different spindle angles of the expander were obtained. The distribution law of the internal flow field of the expander and the deformation characteristics of the scroll disk under the flow field results were studied. The results show that the shielding of the orbiting scroll tooth affects the opening of the suction port, so that the working fluid is inhaled in the working chamber in the form of swirl and flows rapidly, resulting in turbulence. The large curvature variation on the wall of scroll tooth results in swirling flow and flow separation inside and outside the scroll tooth; temperature load is the main cause of scroll tooth deformation; with the rotation of the spindle, the overall deformation of the scroll decreases first and then increases locally.

Keywords: heat recovery, scroll expander, flow field distribution, deformation characteristics

NONMENCLATURE

Abbreviations	
ORC	Organic Rankine Cycles
CFD	Computational Fluid Dynamics
NIST	National Institute of Standards and Technology
Symbols	
R_b	Radius of basic circle(mm)
R_{or}	Orbiting radius of orbiting scroll(mm)
h	Height of scroll wrap(mm)
t	Tooth thickness(mm)
R_c	Radius of corrected circle(mm)
U	Voltage (V)
I	Current (A)
W	Output power (W)
n	Rotating speed (r/min)
T	Time period (s)
M_d	Driving gas moment (N m)
P_i	Inlet pressure (kPa)
P_o	Outlet pressure (kPa)
T_i	Inlet temperature (K)

1. INTRODUCTION

In recent years, energy and environment problems have become increasingly prominent, and how to improve energy utilization has become one of the main topics. People pay more attention to energy saving technology. For the automobile industry, improving the effective utilization rate of automobile fuel has strategic significance for automobile energy saving and reducing automobile energy consumption. Effective recycling of automobile waste heat is one of the effective ways to achieve this goal. Scroll expander is widely used in compressed air energy storage system, organic Rankine cycle, low-grade heat recovery and other aspects due to its advantages of high efficiency, high performance and high expansion ratio [1]. In the vehicle heat recovery system, scroll expander is used as the key work components, and its working characteristics have an important impact on the efficiency and output power of the whole system. Therefore, many scholars have studied the internal flow characteristics and structural performance of scroll expander.

At present, the research on the scroll expander mainly focuses on the analysis of the working process of the scroll expander and the numerical simulation of the internal unsteady flow field. Morini et al. [2] carried out two-dimensional unsteady numerical simulation on the basis of obtaining the actual coordination gap between the scroll disks, and studied the internal flow

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车用余热回收系统涡旋膨胀机涡旋盘应力变形分析

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摘 要:以车用发动机有机朗肯余热回收系统中的某型涡旋膨胀机为研究对象,通过对比分析施加基于线性分布的温度载荷和基于流场的热边界载荷下涡旋盘的热应力和热变形的分布差异,以及对比分析热力学模型下和基于流场结果下涡旋盘所受气体力作用造成的变形情况及应力分布,研究涡旋膨胀机涡旋盘应力变形情况及分布规律,并探究了载荷耦合作用下和载荷单独施加下涡旋盘形变的不同和变化规律。结果显示:温度载荷是影响涡旋盘变形的主要因素;基于流场下的涡旋膨胀机运行参数更符合其实际工况,温度分布更合理;膨胀腔压差越大,波动越大,形变量越大,且与吸气腔相连的第一膨胀腔形变最明显。载荷单独施加和载荷耦合下的形变规律相似,最大应力和变形均出现在涡旋齿始端且随展开角的增加应力与变形量逐渐减小,耦合作用下的应力变形大于单独施加下的应力变形且不是简单的线性叠加。

关 键 词:涡旋膨胀机;应力变形;气体力作用;耦合作用
中图分类号:TK421.5 **文献标识码**:A **文章编号**:1674-8425(2022)02-0093-08

随着膨胀机应用范围越来越广和应用要求不断提高,就透平式膨胀机和活塞式膨胀机而言,涡旋膨胀机作为一种新型容积式膨胀机,具有结构紧凑、体积小、重量轻、能量转换效率高以及可处理小气量膨胀工质等优点[1-2],更能满足人们对其更高的要求,因此近年来在空调制冷、压缩空气储能技术、有机朗肯循环、低温余热回收等方面得到广泛应用[3-6]。在涡旋膨胀机工作过程中,高温高压气体经吸气口进入推动涡旋盘运动,不断增大进气腔与膨胀腔的体积,从而实现气体体积的膨胀,并将气体的压力能转化为机械能[7],在实现整个吸气、膨胀、排气的周期性运作中,膨胀机动静涡旋盘工作环境复杂,不仅受到 2 个涡旋盘之间的摩擦,还承受着较高的热负荷和气体力,这使得涡旋盘尤其是涡旋齿极易发生变形。变形会使轴向间隙变大,也会对 2 个涡旋齿的啮合效果以及径向间隙的密封产生影响,从而影响膨胀机的工作性能和可靠性,因此,涡旋膨胀机涡旋盘的变形研究十分重要。

目前,关于涡旋盘的变形研究大都集中在对涡旋盘进行气体力载荷和热载荷分析,得到相应的应力和变形,且研究对象多为涡旋压缩机。郭

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申请专利部分截图

[中国发明] CN202111584666.2　发动机能量回收系统及控制方法　审中-实质审查

专利公开详情　法律信息　同族专利　引证文献　专利价值度　缴费信息　审查信息　发文信息　相关专利

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主分类号	F02B41/00	分类号	F02B41/00 F01N5/02 F01N13/00 F01K23/06
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摘要

本发明公开一种发动机能量回收系统及控制方法，所述发动机能量回收系统包括废气管路、第一切换装置、第一温度传感器、第一工质循环回路、第二工质循环回路及发电装置。所述废气管路包括用于输送高温废气的第一换热段及用于输送低温废气的第二换热段，所述第一工质循环回路用以与所述第一换热段换热，所述第二工质循环回路用于与所述第二换热段换热，而所述发电装置用于将所述第一工质循环回路及所述第二工质循环回路吸收的热能转化为电能，从而回收发动机废气的能量。所述第一换热段与所述第二换热段连接，如此所述废气在所述第一换热段内完成换热后还能继续在所述第二换热段内再次换热，使得对所述废气的换热更加充分，回收能量的效果更好。

证书号第14806478号

实用新型专利证书

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发　明　人：刘祯;谢东升;李正;马飞

专　利　号：ZL 2021 2 0679061.0

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摘要

本实用新型公开涡旋压缩膨胀一体机，包括形成有安装腔的壳体、定涡旋部件及动涡旋部件，定涡旋部件安装于安装腔内，包括沿前后向间隔布设的第一定涡旋盘和第二定涡旋盘，第一定涡旋盘和第二定涡旋盘相邻近的侧面分别对应设置有第一定涡旋齿和第二定涡旋齿，动涡旋部件沿前后向的轴线转动安装于安装腔内，包括动涡旋盘，动涡旋盘位于第一定涡旋盘和第二定涡旋盘之间，以对应分别与第一定涡旋齿和第二定涡旋齿相配合，分别限定出压缩腔和限定膨胀腔，以在动涡旋盘转动时，压缩腔压缩工作流体，膨胀腔膨胀工作流体，使得定涡旋部件与动涡旋部件结构紧凑，缩小了涡旋压缩膨胀一体机的体积，且易于加工。

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发表论文：

[1] Zhang H J，Zhang M J，Wang X．Fracture Failure Analysis of Insulation With Initial Crack Defect for Stator End-winding in Induction Motor by Using Magnetic-structural Coupling Model[J]，Engineering Failure Analysis，2023，Volume 149．ISSN 1350-6307, https://doi.org/10.1016/j.engfailanal.2023.107239.

[2] 张海军，张明杰，陈小勇，等．复杂电磁力作用下10 kV交流电机端部绕组绝缘损伤应力强度分析[J]．绝缘材料，2023，56(01)：45-50．

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Magnetic-structural FEM[C]，2022 IEEE 20th Biennial Conference on Electromagnetic Field Computation (CEFC)，Denver，CO，USA，2022，1-2．

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Fracture failure analysis of insulation with initial crack defect for stator end-winding in induction motor by using magnetic-structural coupling model

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ABSTRACT

The insulation mechanic failure in stator end-winding of induction motor is usually an early and serious cause to weaken the residual breakdown electrical field strength and produce the short-circuit fault, especially subjecting to the combination of dynamical electromagnetic forces, mechanical stress and vibration. In this paper, the fracture behavior of insulation layer with considering the initial crack defects and end-hoop support failures in end-windings were analyzed by using magnetic-structural coupling model and finite element method (FEM). Firstly, the distributions of magnetic flux density and electromagnetic force around the stator end region were determined by injecting three-phase alternating current. Secondly, the dynamic characteristics of deformation, stress and strain in winding insulation were respectively calculated by coupling the transient electromagnetic and structural analysis. Furthermore, the weak points of the concentrated stress and strain were located. Thirdly, the crack model mounted in winding insulation is defined and simulated by employing three-dimensional (3-D) semi-elliptical crack element. To evaluate the fracture mechanism and the degree of crack expansion quantitatively, the stress intensity factor (SIF) was introduced. Finally, the influence of crack location, direction, depth and end-hoop support failure on SIF and crack propagation were investigated. Results show that the concentrated stress at knuckle part of the coil insulation is lager quite larger than that of other parts. The SIF of transverse crack is larger than that of longitudinal cracks. The larger the initial crack depth in the stator end-winding insulation, the more serious the tendency and degree of crack fracture. Local end-hoop support failure also has an important influence on the crack propagation. Results in this study may contribute to the understanding of fracture failure behaviors in insulation under dynamical electromagnetic vibration and provide necessary theoretical reference for fault diagnosis and prediction of stator winding in induction motors.

1. Introduction

Induction motor is the major drive of industry and the most common electromagnetic–mechanical equipment. Due to its advantage of high efficiency, high reliability, low cost, easy and proper operation, many applications have been widely used [1,2]. It is vital to keep the health of this motor for well performance and life span. Statistically, the insulation failure or damage is still one of the main causes for electric machine accidents [3–5]. The stator winding is always suffered to the combined stress coupling of electromagnet

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复杂电磁力作用下10 kV交流电机端部绕组绝缘损伤应力强度分析

张海军[1,2]，张明杰[1]，陈小勇[2]，万少华[1]，郭 季[1]

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2. 新昇电气有限公司，湖北 襄阳 441899）

摘 要：针对10 kV大功率牵引电机端部绕组绝缘层的早期故障问题，基于断裂力学理论分析了绝缘层裂纹损伤在复杂电磁力、机械力作用下的破坏机理。利用有限元方法建立三维分析模型，并通过分段加载电磁力对不同位置的绝缘层裂纹应力应变状态进行数值计算，同时引入应力强度因子对裂纹损伤扩展的程度进行评估。结果表明：与鼻端位置绝缘层裂纹损伤相比，线棒关节处裂纹扩展的速度更快、断裂程度更大；裂纹的初始损伤状态对断裂及扩展程度也有重要影响，横向裂纹更容易扩展。

关键词：电机端部绕组；断裂损伤；有限元分析；裂纹扩张；故障机理

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Stress intensity analysis on insulation damage of 10 kV AC motor end winding under complex electromagnetic force

ZHANG Haijun[1,2], ZHANG Mingjie[1], CHEN Xiaoyong[2], WAN Shaohua[1], GUO Ji[1]

(1. Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle, Hubei University of Arts and Science, Xiangyang 441053, China; 2. NRE Electric Co., Ltd., Xiangyang 441899, China)

Abstract: Aimed at the early fault of 10 kV high power traction motor end winding insulation layer, the failure mechanism of insulation layer crack damage under complex electromagnetic and mechanical forces was analyzed on the basis of fracture mechanics theory. A three-dimensional analysis model was established by using the finite element method, and the stress-strain states of the insulating layer crack at different positions were calculated numerically by piecewise loading electromagnetic force. At the same time, the stress intensity factor was introduced to evaluate the degree of crack damage expansion. The results show that compared with the insulating layer crack damage at the nose end, the crack expansion speed at the rod joint is faster and the fracture degree is greater. The initial damage state of the crack also has an important influence on the fracture and expansion degree, and the transverse crack is easier to expand.

Key words: motor end winding; fracture damage; finite element analysis; crack expansion; fault mechanism

0 引言

牵引电机作为交流电力机车的核心设备之一，其健康状态关系到整个列车的安全与稳定运行。一旦发生事故，除了电机本体检修周期比较长，还可能造成巨大经济损失，甚至带来严重的社会影响。统计表明，端部绕组故障是直接或间接导致牵引电机事故的主要原因之一[1-2]。随着机车牵引速度与功率的增大，受复杂、恶劣工作环境因素（高温、负载波动大、高频振动）影响，牵引电机绕组将长期工作在以强电磁力为主要力，辅以机械应力和热应力等综合力的作用下，导致电机端部绕组故障概率显著提高[3-4]。端部绕组绝缘层破坏是典型的电机故障之一，如图1所示。

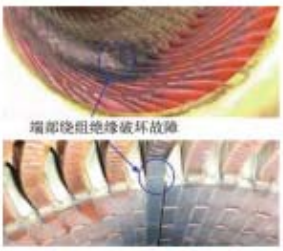

图1 电机端部绕组故障

Fig.1 Fault of motor end winding

目前关于端部绕组的研究主要集中在绕组电磁力计算、电磁力引起的动态变形以及振动分析方面，文献[5]基于有限元法分析了发电机定子端部绕

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Effects of Dynamic Constraint on Stator End-Winding Stress for Large Traction Motor Based on 3-D Magnetic-Structural FEM

First A. Haijun Zhang, Second B.Mingjie Zhang, *Senior Member, IEEE*, Third Shaohua Wan, and Fourth Zhenan Jian, *IEEE*.

Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle,
Hubei university of Arts and Science,
Hubei, China.

The operating environment of traction motor is quite different from that of traditional motor, which may affect the dynamic response of vibration and stress caused by the complex coupling electromagnetic force and mechanical constraints at the end of stator winding. In this paper, the influence of dynamic constraints on the end stress of stator winding is studied for a large traction motor with 2.8 MW rated power. The magnetic-structure model was established, and the stress response of the end winding was determined by three-dimensional finite element method. Set winding asymmetric constraints to simulate the impact of dynamic constraints. The results show that when the end winding is asymmetrically constrained, the maximum displacement value of the winding is twice as large as that of the complete constraint, and the maximum position appears at the winding nose. Under asymmetric constraints, the radial displacement is much larger than the circumferential displacement, about 3.6 times. This is beneficial to the research and understanding of fault mechanism of large traction motor end winding.

Index Terms—AC machine, end winding, electromagnetic force, asymmetric constraints, FEM.

I. Introduction

AC motor: AC motor as one of the core equipment of locomotive, its performance directly affects the performance of locomotive. During the operation of AC motor, the end winding is affected by electromagnetic force and thermal, mechanical and other stresses, and the vibration problem is the most prominent. The vibration of stator end winding has become an important reason for generator failure. The main source of vibration is the current that generates electromagnetic force between coils, especially the strong impact and vibration of electromagnetic force when the AC motor starts and shorts, and may be amplified due to mechanical resonance[1-2]. The vibration caused by periodic electromagnetic force is also the main reason for winding fracture and insulation integrity degradation, so it is necessary to analyze the stress and displacement of the end winding when it is partially loose under the action of electromagnetic force[3-4].

In this paper, a large traction motor with a rated power of 2.8 MW is taken as an example. As shown in Fig. 1, a three-dimensional finite element model of its end winding is established. The electromagnetic force of end winding is analyzed by finite element method. On this basis, the directional displacement and stress of the end winding under unstable state are calculated. Based on the combination of theory and practice, the displacement and stress of the whole winding structure under the local instability of the end hoop are explored.

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Fig.1. Motor end winding fault diagram.

II. END WINDING FORCE ANALYSIS THEORY

A. Electromagnetic Force Analysis Theory

According to the Maxwell equations, the solved governing equation of electromagnetic field with magnetic vector potential A is described as follows:

$$\nabla \times (\frac{1}{\mu} \nabla \times A) = \frac{i(t)}{s} \quad (1)$$

where μ represents permeability, s denotes the cross section area of the conductor, $i(t)$ is the transient current applied to the stator winding. Then, the magnetic flux density is calculated by using the results of magnetic vector potential. Based on Lorentz force, the electromagnetic force in end-winding is expressed as follows:

$$\boldsymbol{F} = \boldsymbol{J} \times \boldsymbol{B} \quad (2)$$

where $\boldsymbol{F}$ is electromagnetic force; $\boldsymbol{J}$ is current density; $\boldsymbol{B}$ is the flux density.

B. Theoretical analysis of asymmetric support

Based on the principle of structural stability, it can be obtained that:

$$EIy'' + Py = \frac{M_0 x}{l} \quad (3)$$

Where E is internal force; I is the moment of inertia of the whole section to the centroid axis; P is external force; y is the displacement distance; M_0 is the reaction bending moment; l is

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赵千（1998-），男，安徽合肥人，汽车与交通工程学院2020级车辆工程专业研究生，导师是工学博士吴华伟教授。科研方面：研究生期间主要从事新能源汽车电池热管理方面研究，参与项目3项，发表SCI论文1篇，中文核心论文1篇，会议论文1篇；申请发明专利5项，授权1项，实审4项，授权实用新型专利1项；获得国家级学科竞赛荣誉3项。学业获奖：2021年三等学业奖学金；2022年二等学业奖学金；2023年一等学业奖学金；校级优秀硕士学位论文获得者；湖北文理学院2023届优秀毕业研究生。目前已签约卧龙电气驱动集团股份有限公司。

发表论文：

[1] Zhao Q, Wu H, Wang Z, et al. Numerical Research on Lithium-ion Battery Thermal Management Utilizing a Novel Cobweb-like Channel Cooling Plate Exchanger[J]. Frontiers in Energy

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[2] 柴油机 U 型后处理系统数值模拟及混合器结构优化. 重庆交通大学学报（自然科学版）(已录用，同题长摘要收录于 2022 世界交通运输大会 WTC 摘要集并做汇报）

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Numerical research on lithium-ion battery thermal management utilizing a novel cobweb-like channel cooling plate exchanger

Qian Zhao[1,2], Huawei Wu[1,2]*, Zhaohui Wang[3], Yiwei Fan[3] and Wei Cheng[4]

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As a key component of a pure electric vehicle, the battery in an overheated state will have a direct impact on battery life and vehicle safety. To promote battery heat dissipation, a novel cobweb-like type (C-type) channel cooling plate with asymmetric inlet and outlet is designed. The C-type channel cooling plate is numerically simulated in two coolant flow directions ($\mathbf{I}_{fd}$ and $\mathbf{II}_{fd}$), using the computational fluid dynamics software STAR-CCM+, and compared to the conventional serpentine type (S-type) channel. Meanwhile, the effects of three structural parameters (channel diameter, spacing, and cooling plate thickness) on maximum temperature and temperature difference of the C-type cooling plate, and pressure drop are investigated. Based on this, the C-type channel is optimized by orthogonal test. The results show that the C-type with $\mathbf{II}_{fd}$ coolant flow direction has a better heat dissipation effect on the battery module than the C-type with $\mathbf{I}_{fd}$ and S-type under the same conditions, and the maximum temperature and temperature difference are respectively reduced by 0.2% and 17.8%, while the pressure drop is increased by 17.3%. In addition, increasing channel diameter can obtain good battery temperature distribution and smaller pressure drop, while the increase of cooling plate thickness and channel spacing has a greater effect on the battery temperature difference compared to the change of maximum temperature. Finally, the results of the orthogonal tests show that the cooling effect is best when the diameter of the cobweb-like channel cooling plate is 7 mm, the thickness of the cooling plate is 12 mm, and the channel spacing is 16 mm, and the maximum temperature and temperature difference are reduced by 0.7% and 6.8%, respectively, and the pressure drop is reduced by 37.6% compared to the initial cobweb-like channel scheme. This offers a fresh perspective on cooling plate channel design in liquid-cooled battery thermal management.

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