附件 2　　浙江水利水电学院“南浔青年学者”申请表

<table>
<tr><td>姓　名</td><td>冯燕</td><td>出生年月年龄（年龄）</td><td>1985年 1 月（38 岁）</td><td>参加工作时间</td><td>2009 年 9 月</td></tr>
<tr><td>现所在单位（部门）</td><td>机械与汽车工程学院</td><td>最高学历/学位</td><td>博士研究生/博士</td><td>专业技术职务</td><td>讲师</td></tr>
<tr><td>符合条款</td><td colspan="5">符合科研类：立项III类项目 1 项，发表 5 类论文 4 篇、6 类论文 1 篇，绩点 165</td></tr>
<tr><td rowspan="6">所涉业绩</td><td>教学类
绩点：_____</td><td colspan="4"></td></tr>
<tr><td rowspan="2">科研类
绩点：165</td><td colspan="4">科研-科研项目-立项III类项目 1 项-75 点：
冯燕，热力机械泛形界面微/宏尺度接触特性参数高精度预测理论、方法及试验研究，国家自然科学基金（青年基金），2024.01.01-2026.12.31</td></tr>
<tr><td colspan="4">科研-科研成果-5 类论文 4 篇-80 点；科研-科研成果-6 类论文 1 篇-10 点：
（1）FENG Yan; YANG Peng; ZHANG Yan-yan; SHI Li-qiu; HANG Zhou-ming; FENG Yi-xiong ; Fractal model of thermal elasto-plastic contact of rough surfaces, Journal of Central South University, 2022 （SCI，5 类论文）
（2）冯燕; 俞小莉; 刘震涛 ; 基于热弹塑性理论的内燃机结合部法向负荷，内燃机学报, 2018 （一级期刊，5 类论文）
（3）冯燕; 俞小莉; 尹旭; 陈晓强; 刘震涛 ; 缸盖-缸垫-机体热弹性接触问题研究，内燃机工程, 2017 （一级期刊，5 类论文）
（4）冯燕; 俞小莉; 刘震涛 ; 基于热弹塑性理论的法向接触刚度分形模型，浙江大学学报（工学版）, 2015 （一级期刊，5 类论文）
（5）冯燕; 俞小莉; 刘震涛 ; 应用热弹塑性理论的结合部法向载荷分形模型，西安交通大学学报, 2015 （EI，6 类论文）</td></tr>
<tr><td rowspan="2">人才称号类
绩点：_____</td><td colspan="4"></td></tr>
<tr><td>总绩点</td><td colspan="4">165</td></tr>
<tr><td colspan="5">备注：请严格按照《浙江水利水电学院“南浔青年学者”实施办法（试行）》（浙水院〔2022〕114 号）附件《业绩成果绩点赋值项目库》的类目、分类、等级（等次）、绩点填写。</td></tr>
<tr><td>个人承诺</td><td colspan="5">本人承诺上述所填内容真实、准确；如有不实，本人承担相应责任。
签名：冯燕　时间：</td></tr>
<tr><td colspan="6">以上部分由申请人填写，所在单位审核。以下由单位（部门）和学校填写。</td></tr>
<tr><td>所在单位（部门）意见</td><td colspan="5">1.经审核，申请人所填内容：☐属实　☐不属实；
2.是否符合所申请的类别：☐符合　☐不符合；
3.是否同意推荐：☐同意　☐不同意。
负责人签名：　（部门盖章）
____年____月____日</td></tr>
</table>

科技处 审核意见	负责人签名：　　（部门盖章） ____年____月____日	教务处 审核意见	负责人签名：　　（部门盖章） ____年____月____日
其他相关职能 部门审核意见	负责人签名：　　（部门盖章） ____年____月____日		
学校意见	（学校盖章） ____年____月____日		

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国家自然科学基金资助项目批准通知

（包干制项目）

冯燕　先生/女士：

根据《国家自然科学基金条例》、相关项目管理办法规定和专家评审意见，国家自然科学基金委员会（以下简称自然科学基金委）决定资助您申请的项目。项目批准号：52305291，项目名称：热力机械泛形界面微/宏尺度接触特性参数高精度预测理论、方法及试验研究，资助经费：30.00万元，项目起止年月：2024年01月至2026年12月，有关项目的评审意见及修改意见附后。

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Fractal model of thermal elasto-plastic contact of rough surfaces

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SHI Li-qiu(史立秋)[1], HANG Zhou-ming(杭州明)[1], FENG Yi-xiong(冯毅雄)[4]

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Hangzhou 310027, China

Abstract: Without considering the influence of heat, existing fractal contact models are not applicable to analyze the contacts when the temperature changes. For this problem, the normal load model and the normal stiffness model of thermal elasto-plastic contact of rough surfaces are developed respectively in this paper. The proposed model is based on the normal contact mechanics model of fractal theory of anisotropic and thermal elasto-plastic contact theory which can be used to characterize the rough surface thermodynamic properties. Then the validity of the model is verified. Finally, the influence of main parameters on the total normal load and the whole normal stiffness of thermal elasto-plastic contact at the interface is analyzed by contact simulation. The results show that the total normal load of thermal elasto-plastic contact increases with the increases of temperature. The whole normal stiffness of thermal elasto-plastic contact increases with increasing coefficient of linear expansion, scale factor, temperature difference or fractal dimension, but decreases with increasing fractal roughness. This model expands basic theory and applications of traditional models, and can be used to calculate and analyze the contacts when the temperature changes.

Key words: rough surfaces; thermal elasto-plastic; asperity; fractal model

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1 Introduction

The surfaces of the mechanical parts manufactured cannot be completely smooth and flat. They are rough surfaces composed of many irregularly shaped protrusions and depressions at the microscopic scale. The essence of the mechanical joint problem is the contact problem between two rough surfaces with different roughness. Normal contact stiffness of rough surfaces, such as that in adjacent engine parts, plays an important part in matching design and structural components analysis. The acquisition of accurate load and

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《SCI-EXPANDED》收录及《JCR》期刊影响因子、分区情况证明

经检索《Web of Science》和《Journal Citation Reports（JCR）》数据库，《Science Citation Index Expanded (SCI-EXPANDED)》收录论文及其期刊影响因子、分区情况如下。（检索时间：2022 年 9 月 19 日）

第 1 条，共 1 条

标题: Fractal model of thermal elasto-plastic contact of rough surfaces

作者: Feng, Y(Feng Yan);Yang, P(Yang Peng);Zhang, YY(Zhang Yan-yan);Shi, LQ(Shi Li-qiu);Hang, ZM(Hang Zhou-ming);Feng, YX(Feng Yi-xiong);

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SCI	METALLURGY & METALLURGICAL ENGINEERING	**27/79**	**Q2**

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教育部科技查新工作站（Z09）

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2022 年 9 月 19 日

Z09

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基于热弹塑性理论的内燃机结合部法向负荷

冯　燕[1,2]，俞小莉[1]，刘震涛[1]

（1. 浙江大学 动力机械及车辆工程研究所，浙江 杭州 310027；
2. 浙江水利水电学院 机械与汽车工程学院，浙江 杭州 310018）

摘要：针对目前机械零部件接触关系建模普遍采用光滑表面，而没有考虑表面粗糙度影响的问题，基于各向异性分形几何理论的热弹塑性法向接触力学模型，以多参数为自变量，建立了粗糙表面热弹塑性接触扩展分形模型．从常物性和变物性两方面，分别计算得到内燃机缸盖-缸垫结合部法向负荷理论值，并与缸盖-缸垫-机体-螺栓四体三维热弹性接触有限元简化模型计算得到的仿真值进行比较和分析．结果表明：在靠近两排气门间的缸口处，是否考虑材料变物性对计算结果有较大影响；零部件接触表面粗糙度对法向负荷等接触状态具有影响，目前常用的光滑表面有限元建模计算所得结果与实际情况存在偏差．

关键词：内燃机；热弹塑性；分形理论；法向负荷

中图分类号：TK402　　**文献标志码**：A　　**文章编号**：1000-0909(2018)03-0267-07

Normal Load of Internal Combustion Engine Junction Based on Fractal Theory of Thermal Elasto-Plastic Contact

Feng Yan[1,2]，Yu Xiaoli[1]，Liu Zhentao[1]

（1. Power Machinery & Vehicular Engineering Institute，Zhejiang University，Hangzhou 310027，China；
2. School of Mechanical and Automotive Engineering，Zhejiang University of Water Resources and Electric Power，Hangzhou 310018，China）

Abstract：Based on normal mechanics model of thermal elasto-plastic contact adopting anisotropic fractal geometrical theory，three parameters were used as argument，then the extended fractal model of thermal elasto-plastic contact of rough surfaces was established for the problem of ignoring the effect of surface roughness in mechanical parts modeling. The theoretical values of normal load in the internal combustion engine cylinder head-cylinder head gasket joints were calculated with constant properties and variable properties，respectively. Then，these theoretical values were analyzed and compared with simulation values which resulted from the four-body contact simplified model composed of cylinder head-cylinder head gasket-engine block-bolts. The results clearly show that in the cylinder ring near the two exhaust valves，whether considering the variable properties or not has a significant impact on the results. Contact surface roughness has an impact on the normal contact load. The results calculated from smooth surface finite element modeling has great deviation from the actual situation.

Keywords：internal combustion engine；thermal elasto-plastic；fractal theory；normal load

接触问题对零部件密封、机械产品动力学传递等具有重要影响[1-4]．实际加工表面不可能完全光滑、平整，接触问题从本质上来说是两个粗糙表面间的接触[5]．针对粗糙表面的弹塑性接触问题，近年来，Gonzalez、Buczkowski、田红亮和 Jiang 等[1-2,5-7]通过解析、数值和试验等方法分别展开了研究，取得了一些成果，但是这些研究存在的不足是：①大都局限于纯机械领域，未考虑结合部温度情况及热力学因素的影响，因而其结论不适用于内燃机等工作环境温度或结合部温度变化的问题；②可直接应用于工程实践的

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作者简介：冯　燕，博士，讲师，E-mail：fengyan111e@126.com.

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380016

缸盖-缸垫-机体热弹性接触问题研究

冯 燕[1,2]，俞小莉[1]，尹 旭[1]，陈晓强[1]，刘震涛[1]
(1. 浙江大学 动力机械及车辆工程研究所，杭州 310027；2. 浙江同济科技职业学院 机电系，杭州 311231)

Study on Thermoelastic Contact of Cylinder Head-Cylinder Head Gasket-Engine Block

FENG Yan[1,2], YU Xiaoli[1], YIN Xu[1], CHEN Xiaoqiang[1], LIU Zhentao[1]
(1. Power Machinery & Vehicle Engineering Institute, Zhejiang University, Hangzhou 310027, China;
2. Department of Mechanical and Electrical Engineering, Zhejiang Tongji Vocational College of Science and Technology, Hangzhou 311231, China)

Abstract: In order to study the influence of mechanical constraints and thermal state on thermoelastic contact nonlinear problem that between cylinder head and cylinder head gasket, a four-body contact simplified model of cylinder head-cylinder head gasket-engine block-bolts was built based on a four-valve diesel engine. Under different bolt preload and thermal state, contact state and deformation of cylinder head plate were calculated by using Augmented Lagrange multipliers as the contact algorithm. Then the influence of contact stresses and nodal displacements of mechanical constraints on some parts of the cylinder head plate were revealed in rated thermal state condition. Moreover the effect of different thermal state on the results was similarly revealed. The study makes clear that, when preload maintains the rated value and burst pressure is exerted, contact stresses in rated thermal state condition of the parts on cylinder head plate that against the cylinder ring and around the screw, which is on exhaust valve side, are similar with those values in cold state, while nodal displacements are reduced, and in different thermal states, the rates of change among the nodal displacements around the screw and both contact stresses and nodal displacements that against the cylinder ring are all less than 2%; with few exceptions, contact stresses and nodal displacements of these parts of the cylinder head plate increase with the increases of the bolt preload. The results also show that cylinder head gasket sealing tests in normal temperature condition is roughly adequate to practical state.

摘要：为研究机械约束和热状态对缸盖与缸垫间热弹性接触非线性问题的影响规律，以某 4 气门柴油机为研究对象，建立了缸盖-缸垫-机体-螺栓的四体接触关系简化模型。采用增广拉格朗日乘子法作为接触算法，在不同的螺栓预紧力和热状态下，计算了缸盖底板的受力变形，揭示了标定工况热态下机械约束对缸盖底板相关部位接触应力和节点位移的影响规律，及标定预紧力时不同热状态对结果的影响。研究表明：当预紧力为标定值时，施加最高燃烧压力后，标定工况热态下缸盖底板正对缸圈处及排气门侧螺孔处的接触应力与冷态时相近，节点位移有所减小，不同热状态下螺孔处节点位移及正对缸圈处接触应力和节点位移的变化幅值均小于 2%；除少数情况外，缸盖底板各相关部位的接触应力和节点位移随预紧力增大而增大。上述研究结果也说明：目前采用常温条件进行缸垫密封性试验基本上能够代表实用状态。

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作者简介：冯 燕(1985—)，女，博士生，主要研究方向为内燃机零部件接触问题，E-mail：fengyan111e@126.com；
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DOI: 10.3785/j.issn.1008-973X.2015.08.021

基于热弹塑性理论的法向接触刚度分形模型

冯 燕[1,2], 俞小莉[1], 刘震涛[1]
(1. 浙江大学 动力机械及车辆工程研究所,浙江 杭州 310027; 2. 浙江同济科技职业学院 机电系,浙江 杭州 311231)

摘 要: 针对现有法向接触刚度分形模型没有考虑热应力影响、不适用于分析结合部温度变化的问题,基于各向异性分形几何理论的法向接触力学模型,引入表征粗糙表面热力学特性的热弹塑性接触理论,建立了粗糙表面热弹塑性接触法向刚度模型. 该模型是传统法向接触刚度分形模型在基础理论和应用范围的拓展,可用于计算和分析工程实际中大量存在的结合部温度发生改变的接触情况. 通过数字仿真,分析了典型参数对结合部热弹塑性接触法向刚度的影响规律. 结果表明:热弹塑性接触法向刚度随线膨胀系数、比例系数、温差、分形维数的增大而增大,随表面粗糙度的增大而减小.

关键词: 热弹塑性;分形理论;微凸体;法向接触刚度
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Fractal model of normal contact stiffness based on thermal elasto-plastic theory

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Abstract: Without considering the influence of thermal stress, the existing fractal models of normal contact stiffness are not applicable to analyze the contact issues when the temperature changes. Based on normal contact mechanics model adopting anisotropic fractal geometrical theory, thermal elasto-plastic contact theory that characterize thermodynamic properties of rough surface was introduced, then the fractal model of thermal elasto-plastic contact of rough surfaces was established in order to analyze the real contact conditions between fixed contact surfaces when the temperature changes. This model expands basic theory and applications of traditional models. The effects of main parameters on the normal contact stiffness of thermal elasto-plastic contact of joint interface was analyzed through digital simulation. The results make clear that the normal contact stiffness of thermal elasto-plastic contact increases with the coefficient of linear expansion, scale factor, temperature difference, fractal dimension, and decreases with fractal roughness.

Key words: thermal elasto-plastic, fractal theory, asperity, normal contact stiffness

建立粗糙表面热弹塑性接触问题的理论模型,并计算、分析结合部的接触力学特征,能够有效指导内燃机等热力机械产品的零部件结构匹配设计. 应用分形理论对粗糙表面接触行为进行研究,粗糙表面的分形特征具有尺寸独立性,可以提供存在于分形表面上所有尺度范围内的全部表面形貌信息[1-3].

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应用热弹塑性理论的结合部法向载荷分形模型

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摘要：针对现有法向接触载荷分形模型没有考虑热应力的影响、不适用于结合部温度变化的问题，基于热弹塑性理论和接触分形理论，建立了热弹塑性接触法向载荷分形模型。该模型是对传统模型在基础理论和应用范围上的拓展，综合考虑了温差、线膨胀系数、机械载荷比例系数等参数的影响，从而可用于计算和分析工程实际中大量存在的结合部温度发生改变的接触情况，其结果更符合客观规律。此外，针对考虑热应力的接触问题，引入机械载荷比例系数，给出了模型的另一种表达形式。通过特例验证了模型的有效性，并与前人的模型进行了对比分析，结果显示：模型间的计算结果差距随结合部温差的增大而增大。最后，通过数字仿真揭示了结合部温差对热弹塑性接触法向载荷的影响规律----热弹塑性接触法向载荷随结合部温差的增大而增大。

关键词：热弹塑性；法向接触载荷；结合部；比例系数；分形模型

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A Normal Load Fractal Model of Joint Interface Based on Thermal Elasto-Plastic Theory

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Abstract: Without considering the influence of heat, the existing fractal contact models are not applicable to analyze the contact issues when the temperature changes. Based on thermal elasto-plastic theory and contact fractal theory, a new fractal model of normal contact load is established in this study. This model expands the basic theory and applications of traditional models, and comprehensively considers the effects of such parameters as temperature difference, linear expansion coefficient, mechanical load scale factor, etc. Therefore this model can help calculate and analyze the real contact conditions between fixed contact surfaces when the temperature changes, and it shows better conformity with objective laws. Besides, another expression of the model is proposed by introducing mechanical load scale factor. Then the model is validated through a special case, and comparative study and analysis are conducted between this model and TZQ model. The results show that the difference between the model calculations increases with the junction temperature difference. In addition, the effect of temperature difference on the normal contact load is also analyzed. The results reveal that the normal contact load of thermal elastoplastic contact increases with the temperature difference at joint interface.

Keywords: thermal elastoplastic; normal contact load; joint interface; scaling factor; fractal model

粗糙表面接触特性参数是影响机械产品静、动态特性的关键因素，而法向接触刚度与法向接触载荷是机械结构静态特性研究的重要内容，且法向载荷对接触刚度具有明显影响[1]。早先基于实验统计学参数建立的接触模型，由于基础数据受测试仪器和样本限制，其计算结果具有不确定性[2]。工程表

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