Pisco Med Publishing

Fretting Fatigue Life of connecting rod under multi-axial variable amplitude Stress

Lingyan Hang

Hebei University, Shijiazhuang 050000, Hebei, China

Abstract: Summary:A fatigue life calculation model for multi-axial variable-amplitude fatigue stress is proposed.ParisThe fatigue crack propagation rate formula is suitable for multi-axial variable amplitude stress.ParisThe life-span calculation model is obtained by introducing the modified short crack size into the formula, the life of the dangerous nodes on the mating surface is calculated. The results show that the model can be used to calculate the life of structural surface cracks from any initial size to any design size under complex conditions, which is of great significance to guide the life design of key components and to determine the maintenance time.

Keywords: fracture mechanics; multi-axial variable-amplitude stress; life-span model; Tooth Profile mating surface of Connecting Rod

1. Introduction

Fretting (Fretting) Refers to nominal relative static of two solid its each other contact of surface in method to pressure role under each other extrusion and produce reciprocating relative sliding of Phenomenon[1-3]. Fretting Fatigue as an fretting damage of Main Mode in engineering actual in widely there and harm big[4]. Connecting Rod as an diesel engine moving parts of important composition part structure shape and the loading status of the all compare the complex its main failure form for connecting rod body and connecting rod cap with surface between of Fretting Fatigue Damage, serious influence connecting rod "with life[5]. Some heavy-duty mechanical equipment

In the connecting rod parts need to by overseas import price expensive maintenance time Don't strict easy to cause connecting rod can't repair and scrapped in advance take up a lot of "with maintenance cost. Because conventional life design methods can't meet the key parts of safety and economy requirements so need to continue to explore can effective prediction Fretting Fatigue Life, accurate determine component maintenance cycle of theory methods.

Home for the first time in the connecting rod tooth profile with the surface failure and Fretting Fatigue Damage contact up study of is southwest traffic University tribological Institute of weeks secondary honor[6]Professor.SONSuch.[7/]For Diesel Engine Connecting Rod Tooth Profile with Surface Problems of Fretting Wear damage the connecting rod multi-body dynamics analysis and finite element analysis and useRuizGuidelines on Fretting Fatigue Crack the location and material point cracking possibility size the pre-

Test.HESuch.[8]The connecting rod Tooth Profile with surface material composition, mechanical performance and damage morphology and the test analysis combined with quasi-dynamic finite element technology analysis connecting rod Tooth Profile with surface appear Fretting Fatigue Crack of fundamental reason, and put forward improvement measures. Cui hai tao and[9]For arc end tooth structure of three-dimensional micro-motion fatigue test difficulty big, cost higher problem put forward a kind of two-dimensional equivalent load programme design and implementation the Fretting Fatigue Test Loading Device, for fretting damage mechanism analysis and Fretting Fatigue Life Prediction

provide test data support.

At present Fretting Fatigue of multi-axis fatigue characteristics its Life Calculation Methods main based on multi-axis fatigue critical surface Criterion[10]. Zhu as Mr and[11]The Fretting Fatigue in Mechanical Parameters Analysis Based on Micro-motion injury comprehensive parameters andRuizCriteria. A kind of low weeks and level weeks composite Fretting Fatigue Life Prediction Model. Ancient far-paper and[12]Combined with fracture mechanical theory put forward the kind of based on micro-motion comprehensive parameters and fracture mechanical theory of mixed life prediction model the crack size and life between the relationship.

Based on fracture mechanics theory of damage tolerance method is calculation fatigue crack extension life of effective methods its theory foundation isPARISSuch.[13]Given the in constant amplitude loading conditions under describe macro-crack extension rateParisFormula.TANAKA[14]For multi-axis fatigue crack problem put forward effective stress strength factor concept and willParisFormula in stress strength factor picture with effective stress strength factor picture alternative.HADDADSuch.[15]Proposed nature Crack LengthA'Get short crack cutting-edge stress strength factor amplitude calculation expression.NEW‐MANSuch.[16‐17]Use small crack Theory verify crack closed model describe crack initiation and early short crack extension rate and prediction fatigue life of ability to the fracture mechanical methods can be the Fatigue Crack Formation Life Analysis Calculation of conclusion.PugnoSuch.[18]In study in promotionParisFormula to short crack extension stage for "with fracture mechanical theory the structure all life Analysis Development the new ideas. In domestic Yin of equality[19]Based onPugnoTheory use existing material stress life curve test data and defined a crackLength Influencing FactorsASTo correctionParisFormula integral get available constant amplitude loading conditions under structure all life analysisSN‐ParisComprehensive model.

However nearly five years about connecting rod Fretting Fatigue of study show that, most scholars will energy on connecting rod fretting on the causes of damage research, connecting rod with surface tooth profile structure improvement, Fretting Fatigue Test Research and effective slow down connecting rod with surface micro injury measures of on the exploration of, very few scholars attention connecting rod Fretting Fatigue Life Calculation Methods of research. In addition in Fretting Fatigue Life of calculation methods on multi-axis fatigue critical surface method due to the many difficult to determine the material constant and to life prediction bring difficult. Based onRuizParameters of life calculation methods rely on in research object and a large number of Fretting Fatigue test time-consuming effort and not universal. Damage tolerance method can given crack size and fatigue life between the relationship and the injury Start and Stop of boundaries

It is clearly stated that the initial defect size depends on the nondestructive testing technology and must be limited to the fatigue crack macro-propagation stage to accurately calculate the life. For some important parts, once the crack initiation or size is very small, it is considered as unqualified. It needs regular maintenance and repair, therefore, a general method that can predict the crack initiation and propagation life at the same time and is convenient for engineering application is urgently needed.Sn★‐ParisThe damage tolerance theory is extended to the fatigue crack initiation stage by the life-span comprehensive model, which can calculate the whole life of the structure from crack initiation to failure fracture. The parameters used depend on the common fatigue and fracture material constants.[19]However, due to the complex geometry of most mechanical structures, most of them are in multi-axial stress state, and this model is only applicable to uniaxial constant amplitude stress state, so it is still limited in engineering application.

Based on the more general structural stress state, a fatigue life calculation model is proposed for multi-axial variable amplitude stress state.

2. FixParisFormula

Average increment is the amplitude of Stress Intensity FactorKFunction;CP,MThey do not vary with the shape and load properties of the member, but only with the material type and stress ratio.RRelated.

Type (1.) It shows that the growth rate of fatigue crack is related to the amplitude of Stress Intensity Factor, which is a physical quantity reflecting the strength of stress field at the crack tip.

The fatigue crack growth rate under variable amplitude fatigue stress depends on the stress variation, not only on the difference between the maximum stress and the minimum stress. Research suggests[21.]For Stable Random AmplitudeLoad can be used with the root mean square value of the stress intensity factor rangeKRMSTo describe the growth rate of fatigue cracks:

Type,SigmaRMSThe root mean square value of the stress range;IAfter the rain flow counting methodICascade Loop;NTotal number of cycles;Sigma-1IStress Ratio is★ -1.Time firstIStress Amplitude of stage Circulation;YFor the coefficient related to the crack condition, the value can be determined by querying the stress intensity factor manual;UIt shows the effect of compressive stress under cyclic loading on fatigue crack growth rate.

The influence factors of crack closure are mainly related to the stress ratio.Stress Ratio satisfied-1 <RLess than 0.7Available whenElber[22.]The formula obtained from the experiments of thin and thick plates is calculated:
ForI,IIComposite Crack Problem, reference [J [14.Amplitude theory of effective stress intensity factor in Medium (2.) The root mean square value of effective stress intensity factor amplitude andIType andIIThe root mean square value of the stress range isKEffrms= (KIRMS4.4 DeltaKIirms4.)1.,4=[(YIU σIRMS \ / PiA)4. (YIIU σIirms \ / PiA)4.]1.,4= [5 (U\/PiA)4.]1.,4.·(YISigmaIRMS)4.4 (YIISigmaIirms)4.]1.,4.= 51.,4.U σEffrms\/PiA(5.)

Type,SigmaIRMSAndSigmaIirmsFor respectivelyIType andIIRoot mean square value of stress range;YIAndYIIForIType andIIImpact factor of shape of Crack;δσEffrmsForI,IIRoot mean square value of the effective stress range under the combined action.

EventuallyParisThe amplitude of the Stress Intensity Factor in the formula is further modified, and the correction for Fatigue Crack Propagation Life Calculation in multi-axial variable amplitude stress state is obtained.ParisFormula and Integral Formula:

If the initial crack size is knownA0And critical crack sizeACCan be changed by multi-axial variable amplitude StressParisThe Formula for Calculating Fatigue Crack Propagation Life is obtained by integral formula.

Critical Crack sizeACCompliance with linear elastic fracture mechanicsKCriteria that represent Stress Intensity FactorsKReach material fracture toughness

ICThe critical crack size can be calculated as follows:

Type,KICFracture Toughness;Sigma-1BFatigue Strength limit.

Similarly, for the initial crack sizeA0, Stress Intensity Factor

Reaching fatigue crack growth thresholdKThWhen there is

3. UtilizationS -NLife curve estimationParisMaterial Parameters in Formula

Material ParametersCP,MWith material type, crack condition and Stress RatioRRelated. Literature [23.] ShowIStress plays a major role in controlling the fatigue crack growth stage.IFatigue Crack Growth Rate parameters under multi-axial stress state can be estimated conservatively.CP,MValue. So, (1.) Deformation gets
$Sigma^{M}N=._{A}{}^{A}{}_{0}{}^{C}CP^{-1}(Yu\sqrt{}PiA)^{-M}DA=C1.(9.)$

Type,δσFor constant amplitude stress amplitude;C1.It can be considered as a constant when the structural form, material type and load application are determined.

Type,NPFor traditionParisThe number of load cycles in the formula;NSForS★ -NThe number of load cycles in the life Curve Fitting Formula.

In terms of physical meaning, the former describes the period of macroscopic crack propagation, and the latter describes the whole process of crack evolution from initiation to unstable fracture.Two-way equivalence isCP,MThe evaluation expression

$P= 2\ (2-M)^{-1}Pi^{-0.5M}Y^{-M.}$

$(0.5-0.5R)^{-M}(A^{1.}C^{-0.5M}-A^{1.}0^{-0.5M})C2.^{-1}(12)$

Thus, the material constants can be determined.CP,MThe key is getting material or partsS★ -NCurve to getS★ -NCoefficient of power exponent form fitting formula of life curveC2.And IndexNThe value.

Fatigue Life Model under multi-axial variable amplitude Stress

Reference [17] And literature [18] Theory, introducing shortModified crack sizeADTo further amendParisFormula,Get

$$DA/DN = CP(K^M) = CP[Yu\ \sigma\sqrt{\ }Pi\ (AAD)]^M(13.)$$

It is suitable for the description of the fatigue crack growth rate at the short crack stage, and the life formula is obtained by integrating:

$P= 2\ (2-M)^{-1}CP^{-1}(Pi^{0.5}Yu\ \sigma)^{-M}\cdot$

$ACAD)^{1-0.5M}-(A0AD)^{1-0.5M}=$

$(1-0.5M)CPC2(Pi^{0.5}YU)^M(16)$

BecauseADIs a very small so whenA0Infinite approach in0When income life approximate equivalent in structure from no crack to fracture failure of all life has andS-NLife curve same of physical significance the meet

$PA_0\rightarrow 0=NS$. Based on such-Relationship between simultaneous (14) And formula (15) Solving can get Stress RatioR=-1OfADOf expression. (16) Show that short crack correction sizeADAnd load it independent on the State.

Final get for use with multi-axis under variable amplitude stress state under Fatigue the crack life model of General Form

Main consider two of Tangential Force role: A is by contact normal stress caused by of with surface between friction shear stress role caused by parallel in with surface of Crack Initiation and Propagation lead to delamination failure; another a kind of is vertical in the crack surface tangential stress role tangential stress is parallel in closely with surface and in material unit before and after, about two each other vertical orientation on the pull stress of force, it Induced Crack in depth orientation on the vertical in with surface extension. According to stress role effect friction shear stress as Ⅱ Style stress, tangential stress asIStyle stress was applied to all life model the structure Fretting Fatigue Life Study.

4. Connecting Rod count Cases

4.1 Connecting Rod flaw detection test

For a marine platform diesel generator set Connecting Rod Failure problem table1Is connecting rod work24 000 h(About2.7Years) after the incision Meshing

Tooth Part inspection record it said crack the most easy to initiation location concentrated in of the connecting rod big end short arm Tooth Profile with on the second tooth root and bolt hole intersection of location (figure1a) And detection to the service crack size in1 ~ 1.5mmBetween.

Table1Connecting Rod work24 000 hAfter the incision meshing tooth part inspection record

Tab.1Dectection record. con-Rod Mating Surfaces

24 000 working hours

According to the fracture mechanics theory, the crack type can be divided into open type (IType), sliding type (IIType) and tear type (IIIType) three types.IThe tensile stress of the crack growth mode is perpendicular to the crack surface.IType expansion is the most dangerous, fracture toughness is poor, the most likely to cause brittle fracture.

In order to get the tooth profile of the short arm of the connecting rod1aIt is necessary to cut the specimen in the graph by wire cutting to get the long strip area containing the crack, and load the transverse tension slowly and smoothly on the testing machine until the fracture is separated, such

As shown in Fig.2.The early crack propagation direction is not entirely perpendicular to the mating surface as shown in the medium fatigue crack propagation direction. This is becauseIIThe stress intensity factor plays a major role in controlling the crack initiation and Early Propagation. To sum up, the connecting rod damage problem belongsI IIFretting Fatigue Crack Initiation and Propagation under normal stress.

4.2Fracture Toughness Test of Connecting Rod Materials

Fracture ToughnessKICIt is an important basic parameter in contemporary engineering design to measure the material's ability to resist crack instability and propagation. In this method, A notched specimen with pre-fatigue crack is used to open the crack tip under tensile or three-point bending loading.VAnd loadPThe test results are automatically recorded and generated.P★ -VCurve; by standard[24]Prescribed methods inP★ -VThe apparent propagation of the crack length on the curve is2%And then substituting it into the fracture toughness of the corresponding specimen.KICExpression to evaluateKICConditional ValueKQIf the test results meet the validity criteria prescribed by this methodKQ=KICOtherwise, the test result is invalid.

According to literature [8.] Through the chemical composition analysis test of Connecting Rod Material, the Connecting Rod Material35 CrMo. According to the national standard of fracture toughness test, the size of fracture toughness test specimen and the entity of fracture toughness test specimen are shown in Fig.3.. Test equipment and test process see chart4..

ICTest of test report see table2. By table2In data shows that sample2Fracture Toughness minimum sample3Maximum sample1Crack Extension

Maximum. So sample3Resistance crack extension of ability strongest. Final will Experimental Results Average27.9 MPa in $m^{1/2}$As an Connecting Rod Material fracture toughness.

4.3Risk node fatigue should be spectrum of get and Processing

According to literature [8] The connecting rod three-dimensional finite element analysis get connecting rod finite element Global Model of analysis results. Due to Tooth Profile Surface StressAnalysis results of correctness related to Life Prediction of accuracy so in order to get more accurate of Tooth Profile Surface regional stress results in accordance with finite element analysis softwareABAQUSSub-model function of operation methods will Global Model Segmentation only keep connecting rod Short Arm Tooth Profile with surface part; Modify Boundary Conditions Delete sub-model outside of all constraint and contact relationship; finally will grid quantity by the original182 523Improve356 394. Figure5For Connecting Rod run a work cycle after its big endian Short Arm Tooth Profile with face modelMisesEquivalent Stress cloud. Cloud said stress concentration Regional Main is located in the second tooth root and bolt hole intersection of location and by Arrow shown in tooth to in the second tooth root uniform take point number12...101.

Use finite element analysis results can get connecting rod run a cycle the node tangential should be and friction shear stress change situation respectively asIStyle and Ⅱ Style fatigue should be spectrum for connecting rod Tooth Profile with surface of All-Life-span Theory Calculation in.

6Shown in is connecting rod big end short arm Tooth Profile with on the second tooth root the nodeMisesEquivalent stress,IStyle should be and Ⅱ Style stress of statistical results. Results show that,MisesAnd Effect andIStyle stress maximum were happened in node38The, Ⅱ Style stress change situation complex but also in node38Near stress amplitude to maximum. This node is located in the second tooth root and bolt hole interchange and connecting rod flaw detection test in the record the location consistent. So to risk Node38For calculation object extraction the node stress state to get the node a cycle inIStyle and Ⅱ Style stress variable process. With rain Flow Count technology will under variable amplitude stress variable process transformation for contains a few all cycle and half cycle of constant amplitude stress get table3Shown in the count results. Results show that a cycle

Load block inIStyle and Ⅱ Style stress variable process curve can be transformation into a full cycle and two-and-a-half-cycle of constant amplitude fatigue stress.

For convenient Stress results service in the whole life calculation process the rain Flow Count resultsGoodmanCorrection will stress ratio unified-1Correction results see table4. Will the cycle part of stress amplitude in accordance (3) TransformationIStyle, Ⅱ Style stress amplitude of root mean square value (Table4) Into all life formula in the can the life calculation.

Threshold Value5.642 7 MPa in $m^{1/2}$. According to literature [8] The provide of Connecting Rod Material

mechanical characteristics test results shows that strength limit and yield limit respectively876.47 MPaAnd715.57 MPaCan estimation get Connecting RodS-NFatigue Life curve (figure7/) AndN=5.874C2= 5.495 4×10^{19}. According to this results by the first2SectionParisFormula in material parameters of expression calculation get

= 5.874CP= 4.630 4 × 10^{-19}. Reference literature [21] For material35 CrMoOf cylindrical smooth sample its fatigue strength limitSigma-1bAnd strength limitSigmaBMeetSigma-1b/SigmaB= 0.467To Assessment

A get fatigue strength limit409.311 MPa. Will connecting rod Tooth Profile with surface structure crack approximate for rectangular plate hole edge crack by literature [26] Where are we on crack shape Influencing FactorsYIAbout1.09,Y_{II}About0.3. In accordance (4) Calculation get Stress Ratio

=-1When the crack closed influencing factors0.8. Based on

Described results according (16) Calculation get short crack extension of correctionSizeAD= 4.504 × 10^{-3}Mm. Final according to multi-axis Variable Amplitude load role under the compound fatigue the crack life calculation formula (17) To define the initial crack sizeA0= 0According to even

24 000 hMaintenance Cycle the measured crack size set critical crackWith sizeAC= 1.0Mm. Calculation results show thatWhen crack size1mmWhen work cycle number8.13×10^{8}

Times used time about3.0Years and injury statistical results compared error about12.82%Error main from fatigue crack extension parameters of estimation error and analysis research process in calculation error in the accuracy requirements high fatigue extended parameters can be through fatigue test calculation. For the high cycle fatigue damage, surface state good of Connecting Rod thing crack initiation life in its fatigue life in accounted for leading0.01mm(A grain scale) as an crack initiation size calculation of the crack initiation life7.30×10^{8}Times (2.78Years) about total life89.79%. If crack initial organization defects0.001mm"With life is about2.1Years and with initial defects size of increase and reduce.

5. Conclusion

(1) This paper put forward a kind of can be used for multi-axis variable amplitude fatigue stress role under StructureI, Ⅱ Compound fatigue the crack life calculation analysis model. The model for use with multi-axis under variable amplitude stress load conditions under the Fatigue Life Calculation and contained material parameters can be by existing material fatigue performance data estimation get can degradation into conventionalParisFormula for uniaxial constant amplitude stress conditions image intuitive and application scope widely.

(2) All life model consider the crack shape and structure configuration and pressure stress under crack cutting-edge closed the fatigue crack extension rate of influence to simplified the complex structure crack cutting-edge stress strength

Factor of solving process calculation efficiency to improve convenient engineering application.

(3) All life model can in accordance with the set of crack state the life prediction not only can consider initial defects of influence also can according to engineering actual of important parts safety, reliability requirements, the critical crack size definition into life design need to meet the size can the structure crack from any initial crack size extended to any critical crack size of life calculation.

(4) All life calculation results and connecting rod flaw detection test statistical results agreement is good can effective prediction connecting rod life to Engineering in strict of maintenance and scrap processing plan, avoid for maintenance time Don't accurate of a series of security and economic problem.

References

1. WATERHOUSE R BForoulis twig u & z a. fretting Cor-Rosion [J]. Proceedings. institution. Mechanical Engineers1973169(4): 1157-1172.
2. Waterhouse r B. fretting Fatigue[J]. Materials Science & Engineering197625(1):201-206.
3. Fu guo such as Zhang Zheng.Failure Analysis Technology [J].Physical and chemical test: physical volume,200541(4):212-216. FU guoru[[. Failure analysis Technol-Ogy[J]. Physical Testing, Chemical analysis Part A:Physical Testing200541(4):212-216.

4. What tyranny..Mechanical component of Fretting Fatigue [M].Beijing: national defense industrial press,1994:31-140.
5. Yan Deshun chang shi only. 16V280ZJType Diesel Engine Connecting Rod Fault Analysis and Processing measures [J].Internal combustion engine car,2000(9): 31-33
6. Weeks secondary Rong Zhu Min Hao.Composite fretting wear [M].Shanghai: Shanghai Traffic University Press,2004:221-234.
7. SON J HAHN S CBAE J GEt al. fretting Damage Prediction. Connecting Rod. Marine Diesel Engine[J]. Journal. Mechanical Science & technology201125(2):441-447.
8. HE baiyanSHI PhasedSUN jibingEt al. Crack analysis. Toothed Mating Surfaces. A Diesel Engine Connecting Rod[J].
9. Cui hai tao Li Ai-min temperature Weidong.Arc end tooth structure Fretting Fatigue Test Loading Device of design and implementation [J]., China Mechanical Engineering,201627(22): 3020-3024.CUI haitaoLI AiminWEN weidong. Design, implementation. fretting Fatigue Test System. curvie couplings[J].; Mechanical Engineering201627(22):3020-3024.
10. Yong zhong Yin East Zhao Jie Jiang and.Fretting Wear and Fretting Fatigue Life of calculation and analysis methods [J].Chinese quarterly of Mechanics,201536(2):165-178.
11. Zhu as Mr Pan l Material.Level weeks Composite Load role under Fretting Fatigue Life Prediction Study [J].Mechanical Strength,199618(3):37-40. ZHU rupengPAN shengcai. study. Prediction. fretting-Fatigue Life under High-Low Cycle Complex Loading[J]. Journal. Mechanical199618(3):37-40.
12. Ancient far-paper temperature Weidong cui hai tao.Level weeks load role under dovetail joint structure of Fretting Fatigue Life Prediction [J].Promote technology,2008(2):240-243.
13. PARIS P CGOMEZ M PAnderson w e. a Rational Analytic theory. Fatigue[J]. Trend. Engineering196113(1):9-14.
14. Tanaka k. Fatigue Crack Propagation from a Crack Incline. Cyclic tensile Axis[J]. Engi-Neering fracture KRW Mln)19746(3):493-507.
15. EI HADDAD M HTOPPER T HSmith k n. Prediction. Non propagating Cracks[J]. Engi-Neering fracture KRW Mln)197911(3):573-584.
16. NEWMAN J CPHILLIPS E PSwain m h. Fa-Tigue-Life Prediction methodology Using Small-Crack Theory[J]. International Journal. Fatigue199921(2):109-119.
17. NEWMAN J CBROTMatias c. Crack-Growth calculations. 7075-T7351 Aluminum Al-Loy under Various Load Spectra Using an improved Crack-Closure Model[J]. Engineering fracture Me-Chanics200471(16):2347-2363.
18. Pugno NCIAVARELLA MCornetti PEt al. A Generalized Paris '"Fatigue Crack growth[J]. Journal. KRW Mln, Physics. Solids200654(7/):1333-1349.
19. Yin of the plane yellow its green. SN-ParisAll life comprehensive model [J].Northwest Industrial University Journal,200725(3):327-330.