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# Fatigue Life Analysis of Electrical Connector Contacts Part Based on ABAQUS/FE-SAFE

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*Abstract*—**The reliability of the fatigue life of the contacts part of the electrical connector is an important aspect of the mechanical equipment reliability. Aiming at the reliability problem of fatigue life of 450 series multi-purpose spring electrical connector contacts part, A fatigue life calculation method based on ABAQUS/FE-SAFE for the contacts part of the electrical connector is proposed. By establishing a three-dimensional model of the contacts part of the electrical connector, the finite element software ABAQUS can be used to calculate the contact performance during the single insertion and removal of contacts. According to the stress state of the contact, the physical model of fatigue failure of the contact is established. Then the joint fatigue analysis software FE-SAFE is used to establish the simulation calculation model of the fatigue life of the contact, and the fatigue life of the contact can be inferred. The paper proposes a reliability calculation method for contacts part to prevent major safety accidents caused by contact failure. It is of great practical significance to guide the design, processing and inspection of electrical connector contacts part.**

***Keywords-Electrical Connector; Contacts Part; Fatigue Life; Simulation***

## I. INTRODUCTION

As an electromechanical component, electrical connectors are important basic components for electrical connection and signal transmission. It is widely used to ranging from civilian mobile phones to military equipment. For example, a certain type of ground equipment uses more than 3,400 electrical connectors. Electrical connectors are used in a large number of types of equipment; its reliability determines the success or failure of equipment system tasks. The common failure modes of electrical connectors are three types: contact failure, insulation failure and mechanical connection failure. According to incomplete statistics, the above three failure modes for low-frequency connectors account for 45.1%, 22.3% and 19.8% of the total failures. It can be seen that the proportion of failure of electrical contact performance is the highest.

At present, the research on the reliability of electrical connectors mostly focuses on the exploration of the contact reliability of electrical connectors. The reliability of the contact element depends on the design, process, manufacturing, management, raw material properties and working environment of the contact[1]. Horn J, Egenolf B[2-3] and Sawchyn I, Sproles E J through theoretical analysis and experiment.the effects of different shapes of the pin head on the insertion and extraction force of the contract were studied, and the pinhead was partially optimized. Beloufa A, Mastorakis N E, Martin O[4-5] use a combination of finite element simulation and experiment. the influence of the contact surface roughness on the contact resistance of the copper alloy electrical connector contacts part for automobiles was investigated. Hsu Yeh-Liang, Hsu Yuan-Chan, Hsu Ming-Shao[6] simulated the asymmetrically shaped contact reed structure in the electrical connector and obtained the distribution of the root stress. And the structure optimization is carried out with the minimum root stress as the objective function.

Fatigue failure of contacts is one of the important reasons for the failure of electrical connectors[7-8]. Huang B, Li X, ZengZ[9] proposed a three-dimensional finite element model of electrical connectors to research the mechanical properties and contact properties of fretting wear. And gave a calculation method to evaluate their fatigue life. Chen Tianhai[10] used miniature electrical connectors as the research object, and predicted fatigue life of dangerous parts of electrical connectors based on fatigue life prediction theory and S-N curve. Li Q, Gao J, XieG[11] designed an accelerated life test method. And based on this, a reliability prediction model for the fatigue life of the electrical connector contacts part is established. QianPing[12] researched the failure mechanism and failure mode of electrical connectors under combined temperature and vibration stress. Establishing a reliability statistical model, optimized design of integrated stress and constant stress accelerated life test schemes. Finally, the reliability of the electrical connector was evaluated. Considering that the accelerated life test is spend too much time for product with high reliability and long life. In order to fully utilize the performance degradation data, DuanK, Zhu F, Li Y[13] researched the relationship between contact stress shrinkage range and contact resistance based on ANSYS. Li Y, Zhu F, Chen Y[14] used ANSYS software to model the insertion force between the contacts, specific measures to improve the contact reliability of electrical connectors. Shao G, Dong Q, Hong J[15] calculated the mechanical stress and electromagnetic stress of the vehicle electrical connector, provides an important reference for the design of electrical connectors. Liu Juan[16] researched the effect of electrical connector contact on the degradation life, and gave an optimization method for accelerated degradation life test. Wang Tao researched the positive pressure and separation force of the round slotted jack. Based on simplified jack structure and stress conditions, Establishing the mathematical model relationship under the ideal state of closing and positive pressure[17]. Analyze the dangerous area of a contact of a certain type of electrical connector based on simulation technology and calculate its fatigue life. For the prevention of major safety accidents caused by the failure of contacts part, it is of great practical significance to guide the design, processing and inspection of the contacts part of the electrical connector.

## II. SIMULATION ANALYSIS

### A. *Establishment of 3D CAD Model of Electrical Connector Contacts*

Taking the 450 series multi-purpose spring electrical connector universal contact pin jack as the research object, using the UG 3D modeling software. the parameterization model of the pin jack is established as shown in Figure1 and Figure2:

Figure 1. Overall model of the contact

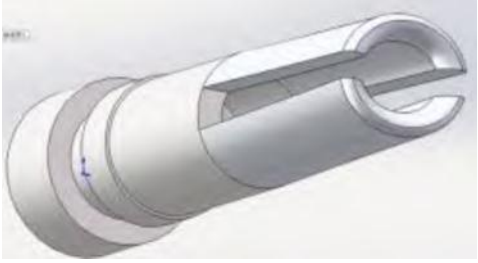


Figure 2. Jack model

Among them, the diameter of the pin is 0.762 mm, and the opening size of the end of the jack is 0.65 mm.

### B. *Analysis of Contact Performance During Single Insertion and Removal*

The pin jack three-dimensional fit model was imported into ABAQUS for finite element analysis. The material properties of the pins and sockets are as defined in Table I for the material properties of the electrical connector contacts part. For finite element simulation analysis, the C3D10M tetrahedral element is selected for meshing. Due to the shrinkage of the end of the jack, the type of contact between the contacts when the pins are inserted into the jack is a face contact. In the absence of lubrication. the coefficient of friction between the contacts was set to 0.13. Finally, the ABAQUS software was used to simulate the contact performance of the contacts during a single insertion and removal process. Stress and cloud diagram, as shown in Figure 3.

It can be seen in Figure3, when the pin head is just in contact with the end of the jack. The position where the equivalent stress and the equivalent strain are large is mainly concentrated at the position where the contact is in contact and the root of the jack reed. According to the analysis of the research report of Pan Jun et al., stress concentration occurs at the groove of the root of the reed. This situation should be avoided as much as possible during the design process.

TABLE I. MATERIAL PROPERTIES OF THE CONTACTS PART

| **Contact** | **Material** | **Elastic Modulus /MPa** | **Poisson's ratio** | **Density / （kg / m$^3$）** |
|---|---|---|---|---|
| Jack | Tin bronze | $1.1\times10^5$ | 0.340 | $8.9\times10^3$ |
| Pin | brass | $1.06\times10^5$ | 0.324 | $8.8\times10^3$ |

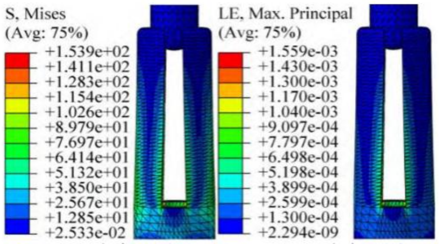


Figure 3. Stress and strain cloud diagram when the pin head is just inserted into the jack

During the insertion of the pin into the jack, the amount of deformation of the jack reed is constantly increasing. The stress on the reed is also increasing. When the pin head is fully inserted into the jack, the positions of the maximum equivalent stress and the maximum equivalent strain are concentrated at the root of the jack reed. as shown in Figure4.

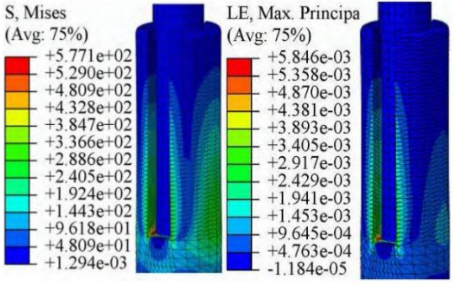


Figure 4. Stress and strain clouds when the pin is fully inserted into the jack

The stress distribution at the root of the spring piece is shown as Figure5. The maximum stress is 299 MPa, which exceeds the yield limit of the material by 280 MPa. Therefore, during the working of the contact member, the root of the jack reed is firstly plastically deformed. When the plastic deformation accumulates to a certain amount, cracks may occur in some parts of the root of the plug reed. At this time, as the number of insertions and removals increases, the cracks expand continuously. When the reed stretch reaches a certain length, the jack reeds are prone to overall fracture, which seriously affects the reliability of the entire system.

In order to observe the change of stress and strain at the maximum stress and strain at the root of the reed during the single insertion and extraction of the contacts part. In the ABAQUS software output, the stress strain curve of the dangerous node during the simulation is output as shown in Figure 6(a) and Figure 6(b). In the two figures, 0s to 2s indicate the insertion of the pin into the jack process, 2s Up to 3s indicates the process of removing the jack from the jack. The change of the insertion and extraction force of the contact is shown in Figure 7.

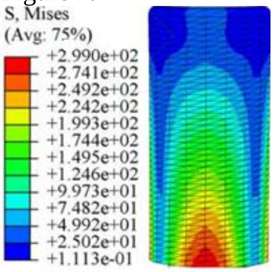
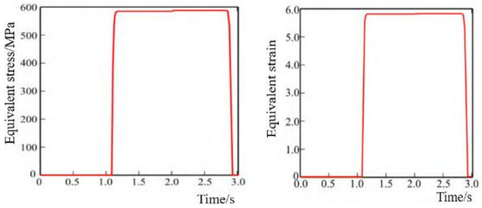


Figure 5. Reed root stress distribution



(a) Equivalent stress curve (b) Equivalent strain curve

Figure 6. Curve of the maximum position of equivalent stress strain

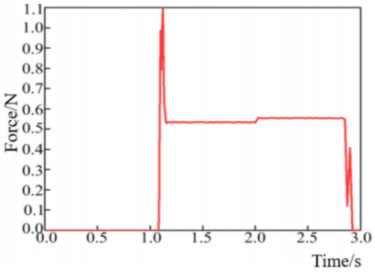


Figure 7. Insertion force between the jack and the pin

## III. CONTACTING FATIGUE LIFE ANALYSIS

### A. Establishment of Contact Strain-Life Equation

Before using the FE-SAFE software for fatigue analysis, Establish a life assessment model for the contacts is needed. Considering that the 450 series multi-purpose spring electrical connector contact material tin bronze is a metal material with better toughness, Therefore, the fatigue life assessment model was established by Brown-Miller [18] critical plane method, which is suitable for solving the fatigue life of ductile materials. Taking the left side of the traditional strain-life equation as the shear strain amplitude and the normal strain amplitude, the Brown-Miller strain life equation can be obtained as shown in the following equation (1):

$$\frac{\Delta\gamma_{\mathrm{max}}}{2}+\frac{\Delta\varepsilon_{\mathrm{n}}}{2}=C_1\frac{\sigma_f}{E}(2\mathrm{N_f})^b+C_2\varepsilon_f(2\mathrm{N_f})^c \qquad (1)$$

In the formula, $E$—Elastic Modulus, $\Delta\gamma_{max}$—Maximum shear strain range, $\Delta\varepsilon_n$ —Normal strain range on the maximum shear strain plane, $\sigma_f$ —Fatigue strength coefficient, $\varepsilon_f$ —Fatigue ductility coefficient, $b$—Fatigue strength index, $c$—Fatigue ductility index, $N_f$—Fatigue life with cycle number, $C_1$ —Real constant under elastic conditions, $C_2$—Real constant in the case of plasticity.

For the issue of elasticity, Poisson's ratio of material v=0.34, $\Delta\gamma_{max}$ = （1+v） $\Delta\varepsilon_1$ =1.34 $\Delta\varepsilon_1$ , $\Delta\varepsilon_n$ =(1-v)$\Delta\varepsilon_1$/2=0.33$\Delta\varepsilon_1$ , then $C_1$=1.34+0.33=1.67, $\Delta\varepsilon_1$ is Main strain. For the plastic problem, Poisson's ratio v=0.5. The same reason, Calculated as $C_2$=1.75.

Substituting the above parameter values into equation (1) gives the Brown-Miller strain-life equation as:

$$\frac{\Delta\gamma_{\mathrm{max}}}{2}+\frac{\Delta\varepsilon_{\mathrm{n}}}{2}=1.67\frac{\sigma_f}{E}(2\mathrm{N_f})^b+1.75\varepsilon_f(2\mathrm{N_f})^c \qquad (2)$$

Considering the unevenness of the stress experienced by the jack during the insertion and removal process, The Morrow average stress correction method is required to correct the stress. Set the average normal stress to$\sigma_{m,n}$, Then the modified Brown-Miller strain-life equation is:

$$\frac{\Delta\gamma_{\mathrm{max}}}{2}+\frac{\Delta\varepsilon_{\mathrm{n}}}{2}=1.67\frac{\sigma_{\mathrm{f}}-\sigma_{\mathrm{m,n}}}{E}(2\mathrm{N_f})^b 1.75\varepsilon_f(2\mathrm{N_f})^c \qquad (3)$$

Yield stress according to tin bronze material $\sigma_s$ =280MPaand elastic modulus $E$=*110000*MPa. Fatigue performance data was obtained by Seeger estimation. The specific data is$b$=*-0.087*, $c$=*-0.58*, $\sigma_f$ =*420*MPa, $\varepsilon_f$ =*0.59*. Finally, FE-SAFE software was used to fit the strain life curve of the contact material.

### B. Calculation method of fatigue life of contacts part

After importing the result file of the ABAQUS software finite element analysis into the FE-SAFE software. the fatigue life of the contact is calculated by the contact performance as a boundary condition during the single insertion and removal of the contact. According to the contact performance analysis during a single plugging process, it can be known that: Under the cyclic load, the jack receives a large stress due to its special structure with respect to the pin, most likely to be the first to experience fatigue failure. Therefore, in order to reduce the amount of calculation and save the calculation time, it is only necessary to solve the fatigue life of the contact jack. The fatigue life analysis process of the contact is shown in Figure8.

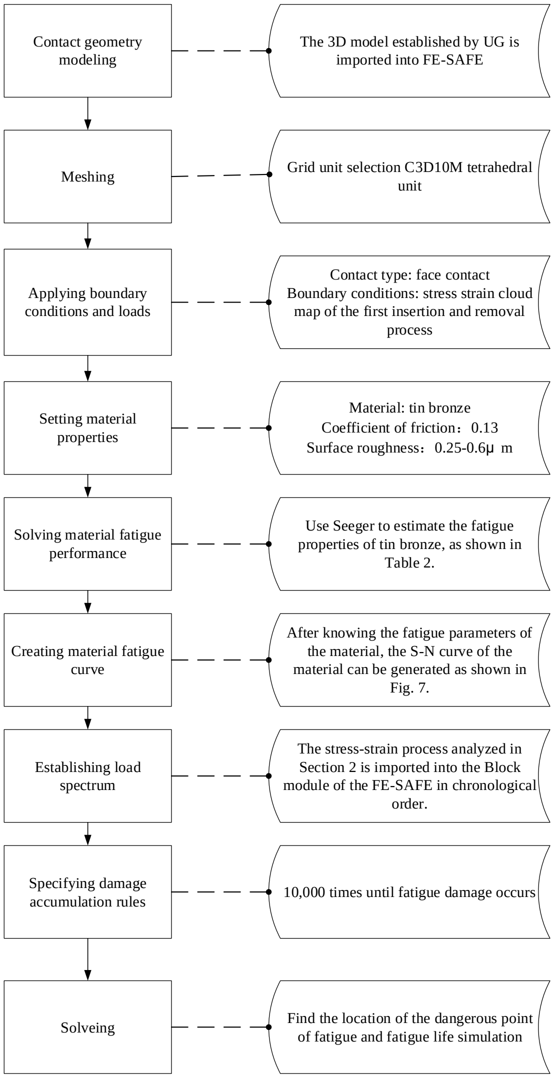


Figure 8. Process of simulation analysis of contact fatigue life

*1) Material definition and fatigue algorithm selection of contacts part*

The Seeger algorithm is used to approximate the fatigue performance of the contact tin bronze material. The Seeger algorithm generates fatigue data based on the tensile strength and elastic modulus of the material. The tensile strength of the material is 280 MPa and the elastic modulus is 1.1×105 MPa. When $\sigma_s$=280MPa, $E=1.1\times10^5$MPa input, FE-SAFE will automatically obtain the fatigue performance parameters of tin bronze material. As shown in Table II

According to the analysis of Section III.A, Select the Brown Miller-Morrow algorithm as the fatigue algorithm for the contact.

*2) Calculation and Analysis of Contact Fatigue Life*

Based on the initiation criteria of material cracks in the contact jack, the parameter settings of the FE-SAFE software calculation process are shown in table III. The simulation results of the fatigue life of the contact are: the fatigue life simulation value of the 450 series multi-purpose spring electrical connector contact jack is 20276.82 times, and the theoretical value is 10000 times. The FE-SAFE software calculation result file is imported into the ABAQUS software, and the fatigue life cloud map of the contact is displayed in the ABAQUS software as shown in Figure 9. After multiple insertions and removals, significant fatigue damage occurs at the root of the contact plug reed, resulting in minimal fatigue life at this location. Comparing Figure9 with Figure3, it can be seen that the simulation analysis results of stress and strain of ABAQUS software are consistent with the fatigue damage simulation results of FE-SAFE software. The dangerous position appears in the root of the reed of the jack during the entire insertion and removal process.

TABLE II. FATIGUE PERFORMANCE PARAMETER VALUES OF TIN BRONZE

| Fatigue performance parameter | Seeger Algorithm | Tin Bronze |
|---|---|---|
| Fatigue strength coefficient (MPa) | $1.5\sigma_b$ | 420 |
| Fatigue strength index | -0.087 | -0.087 |
| Fatigue ductility coefficient | 0.59α | 1.056 |
| Fatigue ductility index | -0.58 | -0.58 |
| Cyclic strain hardening coefficient (MPa) | $1.65\sigma_b$ | 462 |
| Cyclic strain hardening index | 0.15 | 0.15 |

TABLE III. PARAMETER SETTINGS FOR THE FE-SAFE CALCULATION PROCESS

| Algorithm | (shear+direct) Stress -Morrow [SN] |
|---|---|
| Material | Tin bronze |
| Surface | $0.25<Ra\leq0.6\mu m$ |
| KT | 1.05 |
| UTS | 280MPa |
| FEA Units | S=MPa e=strain T=deg.c |
| Loading | Loading is equivalent to 1 Repeats Elastic FEA |

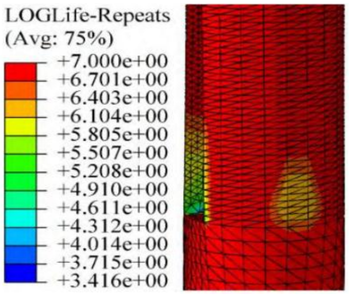


Figure 9. Logarithmic cloud map of the fatigue life of the jack

## IV. CONCLUSION

Fatigue life analysis was performed by applying ABAQUS/FE-SAFE to the 450 series multi-purpose spring the contacts part of the electrical connector, and the following conclusions were drawn:

*1)* Based on the finite element software ABAQUS simulation analysis, the simulation calculation model of contact performance analysis in the contact process of 450 series multi-purpose spring electrical connector contacts part was established, and the maximum stress during the whole plugging process was 662.3Mpa. The maximum stress occurs at the position where the pin and the jack are in contact when the pin head is fully inserted into the jack. The maximum stress at the root of the plug reed is 588.8 MPa when the pin is fully inserted into the jack. Through the pin and jack contact position and the root stress curve with time, the root of the reed is the dangerous position of the jack during the entire insertion and removal process. In this paper, the research on the stress range applied to the contact is used for reference when conducting the contact life verification test of the electrical connector.

*2)* Using the established FE-SAFE software based on contact fatigue life simulation calculation model, the fatigue life of the 450 series multi-purpose spring electrical connector series universal contact jack is 20276.82 times, which meets the 10000 requirements specified in GB599A-1993.

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## REFERENCES

[1] Compilation Committee of Reliability Design Encyclopedia. Reliability Design Encyclopedia [M]. Beijing: China Standard Press, 2006.

[2] Horn J, Egenolf B. Shape Optimization of Contacts part for Reduced Wear and Reduced Insertion Force[J]. AMP Journal of Technology, 1992,2:42-46.

[3] Sawchyn I, Sproles E J. Optimizing Force and Geometry Parameters in Design of Reduced Insertion Force Connectors[J].IEEETransactionson Components, Hybrids,and Manufacturing Technology,1992,15(6):1025-1033.

[4] Beloufa A, Mastorakis N E, Martin O. Influence of Shapes, Contact Forces and High Copper Alloys on the Contact Resistance and Temperature[C]//the 2nd WSEAS International Conference on Engineering Mechanics, Structures and Engineering Geology. Rodos, Greece: EMESEG, 2010:139-144.

[5] Beloufa A. Numerical and Experimental Optimization of Mechanical Stress, Contact Temperature and Electrical Contact Resistance of Power Auto-motive Connector[J]. International Journal of Mechanics,2010,4(4):94-104.

[6] Hsu Yeh-Liang, Hsu Yuan-Chan, Hsu Ming-Shao. Shape Optimal Design of Contact Springs of Electronic Connectors[J].JournalofElectronicPackaging,2002,124:178-183.

[7] Yang Fenwei. Application and Development of Military ElectricalConnectors[J].Electromechanical Components, 2007, 27(3): 42-49.

[8] Pan Jun, Liu Hongjie, Chen Wenhua, et al. Contact reliability evaluation of aerospace electrical connectors based on step-acceleration degradation test[J]. China Mechanical Engineering, 2011, 22(10): 1197-1200.

[9] Huang B, Li X, Zeng Z, et al. Mechanical behavior and fatigue life estimation on fretting wear for micro rectangular electrical connector[J]. Microelectronics Reliability, 2016, 66: págs. 106-112.

[10] Chen Tianhai. Research on fatigue life prediction of miniature connectors based on nominal legislation[J]. Electromechanical Components,2009,29(04):20-24.

[11] Li Q, Gao J, Xie G, et al. Lifetime prediction of electrical connectors under multiple environment stresses of temperature and particulate contamination [J]. Journal of Chinese Post and Telecommunications University: English edition, 2016, 23(5):61-67.

[12] Qian Ping. Research on comprehensive stress accelerated life test and statistical analysis of aerospace electrical connectors [D]. Zhejiang University, Hangzhou, 2010.

[13] Duan K,Zhu F,Li Y. Contact resistance investigation of electrical connectorwith different shrink range ［C］// International Conference on Electronic Packaging Technology,2014:1146-1149.

[14] Li Y,Zhu F,Chen Y. Analysis of insertion force of electric connector based on FEM ［J］.IEEE International Symposium on the Physical & Failure Analysis of Integrated Circuits，2014：195-198.

[15] Shao G,Dong Q,Hong J. Finite Element Analysis of Mechanical and Electric Properties of Electric Connector in Electric Vehicle ［C］ //Sixth International Conference on Electromagnetic Field Problems and Applications. IEEE, 2012:1-4.

[16] Liu Juan. Modeling and statistical analysis of step-stress accelerated degradation test of electrical connector[A]. Reliability Engineering Branch of China Mechanical Engineering Society, School of Mechanical Science and Engineering of Jilin University. 2012 National Machinery Industry Reliability Technology Academic Exchange Conference Proceedings of the 4th All-Members Conference of the 4th Reliability Engineering Branch [C]. Reliability Engineering Branch of China Mechanical Engineering Society, School of Mechanical Science and Engineering of Jilin University: Reliability Engineering Branch of China Mechanical Engineering Society, 2012: 4.

[17] Wang Tao.Study on Positive Pressure and Separation Force of Circular Grooved Jacks[J].Electromechanical Components,2012,32(03):16-19+23.

[18] Ramezanipour F, Greedan J E, Grosvenor A P, et al. Intralayer Cation Ordering in a Brownmillerite Superstructure: Synthesis, Crystal, and Magnetic Structures of Ca2FeCoO5[J]. Cheminform, 2011, 42(2):6008-602.