МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
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КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

ДОПУСТИТИ ДО ЗАХИСТУ
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«__ »_________2021р.

ДИПЛОМНА РОБОТА

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Монокристалічний індикатор втомного пошкодження»

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Київ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
The head of the Department
Dr. of .Sc., professor
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«___ »___________2021.

MASTER DEGREE THESIS
ON SPECIALITY
"AVIATION AND ROCKET-SPACE ENGINEERING"

Topic: « Single-Crystal as Fatigue Damage Indicator »

Fulfilled by: ____________ **Shupei WANG**

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Kyiv 2021

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

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Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
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«___» ___________2021 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

ШУПЕЙ ВАН

1. Тема роботи «Монокристалічний індикатор втомного пошкодження», затверджена наказом ректора від 08 жовтня 2021 року №2173/ст..

2. Термін виконання роботи: з 11.10. 2021р. по 31.12 2021 р.

3. Вихідні дані до проекту: інформація стосовно проблеми втоми авіаційних конструкцій та сучасних систем моніторингу втомного пошкодження, результати досліджень, проведених в національному авіаційному університеті.

4. Зміст пояснювальної записки: аналіз проблеми втоми авіаційних конструкцій та сучасних концепцій забезпечення ресурсу, порівняльний аналіз методів діагностики технічного стану, оптимізація чутливості монокристалічних індикаторів втомного пошкодження, рекомендації по застосуванню монокристалічних індикаторів втоми.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: PowerPoint презентація результатів дослівдження.

6. Календарний план-графік

№ пор.	Завдання	Термін Виконання	Відмітка про виконання
1	Аналіз проблеми втоми авіаційних конструкцій.	8.10.2021−12.10.2021	
2	Аналіз сучасних концепцій забезпечення ресурсу.	13.10.2021−16.10.2021	
3	Порівняльний аналіз методів діагностики технічного стану.	17.10.2021−22.10.2021	
4	Оптимізація чутливості монокристалічних індикаторів втомного пошкодження, рекомендації по застосуванню монокристалічних індикаторів втоми.	16.11.2021−30.11.2021	
5	Вирішення задач охорони праці	30.11.2021- 7.12.2021	
6	Вирішення задач охорони навколишнього середовища	7.12.2021- 15.12.2021	
7	Заключне редагування тексту та графічного матеріалу	15.12.2021-20.12.2021	

7. Консультанти з окремих розділів

Розділ	Консультанти	Дата, підпис	
		Завдання Видав	Завдання Прийняв
Охорона праці	к. біол. н., доцент Вікторія КОВАЛЕНКО		
Охорона навколишнього середовища	д. т. н, професор Тамара ДУДАР		

8. Дата видачі завдання: 11.10. 2021 р.

Керівник дипломної роботи ____________ Михайло КАРУСКЕВИЧ

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Educational Professional program «Aircraft equipment»

APPROVED BY
Head of department
Dr. of Sc., professor
_________ Sergiy IGNATOVYCH
«___» ___________2021 р.

TASK

For the master degree thesis

SHUPEI WANG

1. Topic: **«**Single-Crystal as Fatigue Damage Indicator**»**, approved by the Rector's order №2173/ст. 8 October 2021.

2. Period of work: 11.10. 2021р. - 31.12.2021

3. Initial data: information regarding the problem of aircraf, analysis of contemporary methods of fatigue monitoring, results of the research and developments at National Aviation University.

4. Content: analysis of the contemporary aircraft fatigue problem and aircraft design concepts, comparative analysis of methods for technical state diagnostic, optimization of the single crystal indicators sensitivity, recommendation on the application of single crystal indicators.

5. Required material: Text of the Master's work, PowerPoint presentation of the work results.

6.Thesis schedule:

№	Task	Time limits	Done
1	Aircraft fatigue problem analysis	8.10.2021−12.10.2021	
2	Contemporary concepts of aircraft design.	13.10.2021−16.10.2021	
3	Comparative analysis of the methods for technical state monitoring	17.10.2021−22.10.2021	
4	Optimization of single crystal fatigue indicator, recommendation on fatigue sensor application.	16.11.2021 − 30.11.2021	
5	Labor protection tasks.	30.11.2021- 7.12.2021	
6	Environment protection tasks	7.12.2021- 15.12.2021	
7	Final revising of the text and presentation.	15.12.2021-20.12.2021	

7. Special chapters advisers

Chapter	Consultants	Date, signature	
		Task Issued	Task Received
Labor protection	PhD, associate professor Victoria KOVALENKO		
Environmental protection	Dr. of Sc. professor Tamara DUDAR		

8. Date of the issue of the task: 11 October 2021.

Supervisor ______________ Mykhailo KARUSKEVYCH
Student ______________ Shupei WANG

РЕФЕРАТ

Пояснювальна записка дипломної роботи магістра «Монокристалічний індикатор втомного пошкодження»:

70 с., 20 рис., 3 табл., 19 джерел

Дана дипломна робота присвячена розробці монокристалічного індикатора втомного пошкодження з рекомендаціями по його застосуванню для моніторингу вичерпання втомного ресурсу літаків цивільної авіації.

В роботі було використано методи втомних випробувань елементів авіаційних конструкцій, металографічні методи дослідження стану поверхні металів при їх циклічному навантажуванні, методи кореляційного та регресійного аналізу результатів експериментів.

Практичне значення результату дипломної роботи магістра полягає в підвищенні надійності авіаційної техніки, оптимізації технічного обслуговування завдяки індивідуальному моніторингу накопиченого втомного пошкодження повітряних суден.

Матеріали дипломної роботи магістра можуть бути використані в навчальному процесі та в практичній діяльності конструкторів спеціалізованих проєктних установ.

Дипломна робота, конструкція літака, втомне пошкодження, деформаційний рельєф, монокристалічний індикатор втомного пошкодження

ABSTRACT

Master degree thesis "Single-Crystal as Fatigue Damage Indicator"

70 p., 20 fig., 3 tables, 19 references

Object of study is a process of aircraft fatigue damage accumulation.

Subject of study is Single-Crystal fatigue damage indicator.

Aim of master degree thesis is to develop recommendations on the single crystals fatigue indicators application for the Chinese aviation industry.

Research and development methods: analysis of the aircraft fatigue problem; analysis of the single-crystal behavior under aircraft operational loads; metallographic analysis, crystallography.

Novelty of the results. It is first time proposed to use single crystal indicators in Chinese aviation industry.

Practical value. The presented information can be used for the aircraft fatigue monitoring and for the University's study of the metal fatigue nature.

AIRCRAFT, LOADS ON AIRCRAFT, FATIGUE DAMAGE, SINGLE CRYSTALS.

ABBREVIATIONS

FD – Fatigue Damage

NDI - Non-destructive testing

SHM – Structural Health Monitoring

SS – Slip System

PSB – Persistent Slip Bands

CRSS- Critical resolved shear stress

RSS- Resolved shear stress

FCC – Face Centered Cubic

ARL – Aircraft Remaining Life

INTRODUCTION

The Master's work deals with the problem of aircraft fatigue monitoring by application of Single-Crystal fatigue damage indicator.

As the aircraft belongs to the structures of very high requirements to the safety, the problem of the fatigue analysis is a crucial.

Contemporary analytical methods for the assessment of accumulated metal fatigue damage are not able to predict residual service life of engineering structures subjected to the action of irregular fluctuating loads with required level of accuracy. Therefore, experimental methods of the fatigue damage estimation are considered as helpful approach for the fatigue analysis.

Many tool methods have been developed to the moment in the different research aviation centers, but biggest portion of them do not reflect the fundamental nature of the fatigue phenomenon, thus further search of reliable and scientifically based method is actual.

Significant efforts were made at National Aviation University in the field of Structural Health Monitoring methods. Unfortunately, these methods are not well known in China.

The aim of the Master's work is to develop recommendations on the single crystals fatigue indicators application for the Chinese aviation industry.

To gain this purpose the following task must be solved:

- To analyze the problem of aircraft fatigue;
- To analyze contemporary concepts of aircraft design;
- To compare direct investigations of metal state and application of the attachable indicators;
- To substantiate the ways for the sensitivity optimization of the fatigue indicator;
- To develop the recommendation of the single crystal fatigue indicator implementation into the Chinese aviation industry.

The results of the work can be implemented into the research and development activity.

CONTENT

PART 1
AIRCRAFT FATIGUE ASSESSMENT

Aircraft structure has to balance functionality and economy, requiring light weight, long life, high reliability, good safety and other characteristics, which makes the aircraft structure design increasingly complex, fatigue problems more prominent, and the use of maintenance difficulties. The fatigue problem is one of the key factors affecting the performance of aircraft under development/in service, and it seriously affects the mobility, reliability and safety of aircraft. In order to meet the harsh requirements of aircraft in service environment and the requirements of high preformance technical indexes in the development of new models, the study of aviation fatigue problem needs to run through the whole life cycle of aircraft development and operation, and should be given priority consideration and attention. Study of aviation fatigue needs to be considered and paid attention to throughout the whole life cycle of aircraft development and operation.

1.1 Aircraft fatigue problem

When the aircraft is in service, the process of take-off-flight-landing is repeated continuously, and the structure of the aircraft will bear various repeated fatigue loads. These fatigue loads mainly include:

(1) Aerodynamic alternating loads borne by the aircraft in maneuvering flight.

(2) The gust of wind when the aircraft is flying in unstable air currents.

(3) The ground-air-ground cyclic load borne by the wings during aircraft parking, taxiing, take-off, and landing.

(4) After the aircraft touches down, the elasticity of the landing gear causes the load on the aircraft structure caused by the turbulence of the aircraft.

(5) Repeated loads added to the aircraft due to turbulence caused by uneven runway or due to various operations such as turning when the aircraft is taxiing on the ground.

(6) The repeated load applied to the components around the cockpit due to the pressurization and depressurization of the cockpit during the flight cycle of the aircraft.

Under the action of these external cyclic loads, the stress inside the aircraft structure will also be a "cyclic stress" that changes periodically. In the service environment, the aircraft structure is prone to fatigue damage, causing catastrophic accidents.

Judging from the numerous air accidents, there are many parts of the aircraft structure where fatigue damage may occur, such as wings fuselage, etc., and complex service environments, such as corrosion, high temperature, and low temperature, may accelerate the development of fatigue damage. In order to ensure the safety of aircraft structures, studies are generally carried out on the fatigue failure of different typical structures in different environments. Usually divided into three categories:

The landing gear is a key component for the safe flight of an aircraft. Its structure is complex, and it will withstand large impact loads during take-off and landing. It is severely stressed and may be affected by accidental factors. Therefore, the failure rate of the landing gear Higher. According to statistics, accidents caused by landing gear structures account for about 40% of aircraft structural damage accidents. In view of this, numerous studies have been gradually carried out, discussing the fatigue damage of the landing gear from different aspects.

The aircraft fuselage structure mainly includes beams, skins, stiffeners, etc. There are extensive defects such as R angles, rivet holes, etc., which make the aircraft structure discontinuous due to manufacturing, which makes the stress concentration of the fuselage structure complicated and therefore possible the fatigue failure situation is also very complicated.

As the "heart" of the aircraft, the engine provides power for the flight of the aircraft, and its reliability will directly affect the safety of the aircraft. During the service of the engine, due to frequent starting-accelerating-stopping, the various parts of the engine will be subjected to alternating loads, and the engine will be subjected to high-temperature environments during operation. Therefore, the problem of fatigue damage of the engine becomes very complicated.

1.2 Contemporary aircraft design principles

Durability and damage tolerance are structural properties that must be met in the design of modern aircraft structures. The meaning is simply: durability is the ability of a structure to prevent and resist damage (including fatigue, corrosion, stress corrosion, thermal degradation, peeling, delamination, wear and foreign object damage)[1]. Damage tolerance is the ability of a structure to prevent damage from growing to catastrophic damage. For this reason non-destructive testing (NDI) remains an important tool to meet all requirements. We must consider new design principles and create new methods of fatigue detection based on an understanding of the nature of fatigue.

Safe life design principles were applied to aircraft design until 1960. The F-111 incident directly led to the current concept of Damage Tolerance design. In July 1974, the U.S. Air Force issued a military specification, Airplane Damage Tolerance Requirements (MIL-A-83444), which mandated the use of "damage tolerance" design for all future military aircraft development. The so-called slow-growth design means that the initial crack in the structure will not grow to a critical value within a certain period of time. A single load path structure must be designed in this way, such as the longitudinal beam of a fighter aircraft, where the preexisting crack growth life needs to be greater than the design service life of the aircraft. A structure designed for safe life contains only a single load path, and the crack length to be inspected may be within the critical crack length. Therefore, it is not possible to define inspection intervals for the monitored structure.

Failure of one of these structural elements would result in complete failure of the safe life structure and could have significant consequences for the aircraft. The "damage tolerance" design is divided into:(1) Multiple load path structures, e.g., the wing and fuselage of a fighter jet are often joined by multiple joints, and if any one joint is damaged, the load will be shared by the other joints. (2) Crack Arrest structure, such as: large aircraft fuselage along the circumference, will be in the inside of the skin every 50 centimeters to add a Crack Arrest strip, can be blocked along the fuselage direction of the extension of the skin cracks. The multiple load path structure is subdivided into 3 groups: multiple load paths - external inspection only; multiple load paths - no inspection of less than one complete load path failure; multiple load paths - inspection of less than one complete load path.

1.3 Methods of fatigue damage diagnostic

Fatigue diagnostic may be conducted by two main ways: a) by direct inspection of materials state; b) by the use of so called specimen-witness.

1.3.1 Direct inspection of materials state

Materials in the transport and service process, due to external forces, fatigue, high temperature creep and other factors, will produce damage, Damage, on the other, can lead to a decrease in the strength and stiffness of the material. During the course of material service, the production of micro-damage is often difficult to detect, along with micro-injury the expansion of the material is very easy to fail, thus causing difficult to estimate the consequences. Therefore, in the actual engineering should be used, the material into damage detection, real-time understanding. The service of the material, the evaluation of the remaining life of the material has a very important meaning. Non-destructive testing (NDT) refers to the detection of damage to materials without damaging or affecting the material's mechanics. The emergence of non-destructive testing techniques provides important for the evaluation of material service and the evaluation of the remaining life means. The level of development of non-destructive detection techniques has been developed as a measure of a country's developed level one of the criteria. At present, the aerospace field has been used a variety of mature non-destructive detection techniques, such as acoustic vibration technology Ultrasonic detection techniques, optical detection techniques, electrical magnetism Detection techniques, as well as line detection techniques, etc.

Sound vibration detection technology Acoustic vibration detection technology refers to the vibration of the test piece by applying stimulation to it to produce mechanical vibration, through the vibration state of the test piece and its response signal containing the characteristic parameters of damage information, and then analyze the detected characteristic parameters, and evaluate the damage situation of the test piece. Acoustic vibration detection technology is one of the most widely used non-destructive detection technologies in the early stage of damage detection industry, and its required detection device is simple and easy to operate, so the economic cost is low. In addition, since acoustic vibration detection usually does not require contact with the test piece under test, no coupling agent is required. The reason why acoustic vibration detection technology is less popular so far is that the frequency of sound waves used in detection is generally low, resulting in low sensitivity and resolution of acoustic vibration detection, so it is difficult to identify small damage, with greater limitations. Of course, with the development of science and technology, acoustic vibration detection technology has also been developed. For example, by using piezoelectric sensors to collect the vibration characteristics and response signals of the test pieces, the signal can be analyzed and processed more accurately, and the accuracy of the test results can be improved.

Optical detection technology Optical detection technology refers to the use of pure optical methods to check test pieces, we can usually see in other detection technologies using optical methods to assist detection, but these detection techniques are not optical detection technology. Optical detection can usually be divided into three categories, namely: visual detection technology, laser hologram detection technology and laser misplaced spot interference detection technology[2].

Visual detection technology Visual detection technology refers to the human eye or the use of optical amplification device to enlarge and then through the human eye to observe the test piece, evaluation of the damage of the test piece, which is the oldest one of the damage detection technology. Visual inspection technology is widely used in material bonding components and material service inspection. The advantages of visual detection technology are convenient operation and high efficiency, and can observe the distortion, fracture, scratching, foaming and other macro-damage of the material surface. Because the core of this detection technology is the human eye, it also has great limitations. For example, the human eye is often difficult to identify small damage, and only the surface of the material or near the surface of the damage can be detected, difficult to identify the damage inside the material. In addition, for some of the more complex damage, visual detection technology is difficult to identify the type of damage. Therefore, the sensitivity and accuracy of visual detection technology are less than other detection technologies.

Laser holographic detection technology Laser holographic detection technology refers to the use of light interference principle, the detection of the specific light waves containing damage information in the form of holograms recorded, and processed and analyzed. Generally speaking, laser hologram detection technology usually needs to take two photographs of the detected parts, first extract the holograms of the detected pieces in a non-damaged state, then extract the holograms of the detected parts after loading the damage, and then compare the holograms in two different states to analyze the damage of the detected parts. The technology is not limited by the shape and volume of the test piece in practice, so it can realize the damage detection of the more complex test piece. However, it is difficult to make an accurate evaluation of the size and depth of damage.

Laser misplaced scattered spot interference detection technology Laser misplaced scattered spot interference detection technology refers to the principle of laser misplaced scattered spot interference to detect test pieces, which is derived from the end of the last century an optical detection technology. Its testing device is simple, the external environment has less impact on the test results, so it is widely used in the production line testing of test pieces. In addition, laser misplaced scattered spot interference detection technology does not need to be in contact with the detected parts, so it does not need coupling agents, is also widely used in aerospace, marine, metallurgy and other fields of large structural parts damage detection. For example, the technology has been successfully applied to the production of composite components on B-2 stealth bombers and F-22 fighter jets in the United States, which greatly improves productivity due to its high detection speed. In addition, the technology has been successfully used in damage detection of complex composite structural parts on aircraft such as the A380 and A350xwb, Airbus's next-generation jumbo aircraft.

Electromagnetic detection technology Electromagnetic detection technology refers to the application of electromagnetic field to the test piece, by detecting changes in its electromagnetic performance to evaluate the damage. In general, electromagnetic detection technology can be divided into eddy current detection, dielectric properties detection and microwave detection.

Vortex detection Vortex detection refers to the electromagnetic induction effect based on materials, by measuring changes in the amount of induction to evaluate the damage to its surface or near surface. The application scope of this technology is limited, can only detect the electromagnetic induction effect of the material, mostly metal or alloy materials, and it is difficult to detect the deep defects of the test piece. The advantage of this technology is that it is not affected by temperature and can detect damage to the test pieces at high temperatures. In addition, the damage detection of the test piece surface or near surface has a high sensitivity.

Dielectric properties detection Dielectric properties detection refers to the measurement of the material's dielectric constant loss angle of the tangent value to evaluate its mechanical properties and physical properties, thereby evaluating the damage of the material. Objects from the point of view of conductivity can be divided into conductors and dielectrics, dielectrics are generally non-conductive, so it is also called insulators. Dielectric properties detection has high detection accuracy, but there are multi-value problems, and it is difficult to detect very thin materials.

Microwave detection Microwave detection refers to the high-frequency electromagnetic waves as the medium, through the analysis and processing of echo signals, damage detection of materials. Microwave detection has a wide range of applications and high prospects for development. Microwave detection is fast, highly pointed and penetrating. At present, the technology is widely used in ceramics, concrete and composite materials and other non-metallic materials damage detection. However, due to the skinning effect of electromagnetic waves, it is difficult to accurately judge the damage inside the material.

Ray detection technology Ray detection technology refers to the use of ray as a medium, the use of ray penetration and linearity, rays and materials will interact, such as absorption, scattering and ionization, and then by comparing the absorption of rays through non-damaged materials and damage materials, to evaluate the damage of materials. Commonly used rays are X-rays and γ rays.

X-rays X-rays are highly penetrating, and the lower the material density, the higher the penetration rate of X-rays. When an X-ray irradiates a material containing damage inside, the density of the damaged part changes, causing the penetration rate of the X-ray to change, so that it can be determined whether the material is damaged. It is worth noting that X-rays can produce ionizing radiation and are biologically dangerous.

γ rays γ rays are electromagnetic radiation with a higher frequency than X-rays. γ ray detection technology and X-ray detection technology are not much different in nature, both are mainly used to detect the volume damage of materials. The detection results of ray detection are more intuitive and applicable, but they can't detect stratification damage and deep damage, and radiation safety protection needs to be considered in practical application （Fig.1.1）

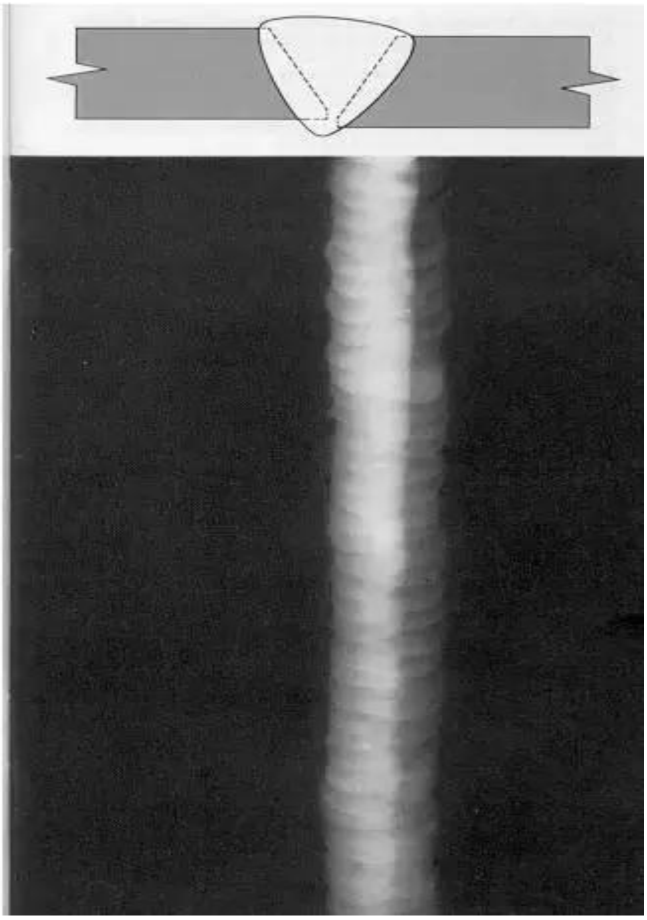

Fig.1.1 - Transmission image of weld defect

Ultrasonic detection technology Ultrasonic detection technology refers to the use of ultrasonic as a detection signal to apply an excitation signal to the material, the signal will interact with the material, so that it carries the material damage information, and then the response signal is analyzed and processed, converted into a frequency domain map or image. Ultrasonic waves are divided into longitudinal waves, transverse waves, surface waves and guide waves according to the relationship between the polarization direction of the wave during propagation and the type of propagation medium, and Table 1.2 is the characteristics of each type of ultrasonic wave. Ultrasonic detection can be divided into traditional linear ultrasound detection and nonlinear ultrasound detection.

Table 1.2 - Features of ultrasound

Types of ultrasound	Features
Longitudinal wave	The direction of vibration of the mass is the same as the direction of wave propagation
Transverse wave	The direction of vibration of the mass is perpendicular to the direction of wave propagation
Surface waves	Propagation along the surface of a solid in the interface between a semi-infinite solid and other media
Guided waves	Propagation enclosed in a specific finite space

Traditional linear ultrasound detection Traditional linear ultrasound detection generally believes that the signals generated by ultrasonic propagation in the material are linear, regardless of the generation of high harmonics. In linear ultrasound detection, the properties of materials are characterized by ultrasonic linear parameters such as attenuation and propagation speed. When the internal structure of the material changes, it causes the ultrasonic wave to be absorbed by the material during propagation, resulting in a change in the amount of attenuation. In general, material misalignment, boundary and other information can be obtained by the change of attenuation. The propagation speed of ultrasonic waves is generally related to the density and elastic modulus of the material, and the change of propagation speed can reflect the pores and cracks of the material. However, for the early deformation, micro-cracking and other minor damage caused by the material service process, ultrasonic linear parameters are not sensitive to such damage, and the detection effect is not ideal. Therefore, linear ultrasound detection is mainly used for material macro cracks and macro defect detection.

Nonlinear ultrasound detection Nonlinear ultrasound detection is mainly used for the detection of material micro-damage. When ultrasonic waves are slightly damaged, nonlinear acoustic phenomena such as harmonics, waveform distortion and beam stacking occur. Micro-damage usually occurs in the early stages of material service, if not paid attention to, micro-damage will expand rapidly, resulting in material failure, so the detection of material micro-injury is particularly important. By analyzing the nonlinear parameters of ultrasonics, such as secondary harmonics and high harmonics, it is possible to evaluate the fatigue damage, high temperature creep and closed cracks of materials.

1.3.2 Methods of inspection with specimen-witness

The application of specimen witness may be an effective detection method: it allows a series of physical methods to be applied to study the state of the material, in addition to obtaining advance information about the structural failure process. Fatigue life analysis and monitoring technology mainly refers to the use of fatigue life meter, fatigue sensor and other strain data real-time collection, through the load under the effect of the cumulative size of resistance value changes, the establishment of the corresponding fatigue response model, so as to achieve automatic monitoring of structural fatigue health status and assessment of fatigue life purposes.

Resistance-Strain response is real-time, continuous, high resolution and automatically memory of resistance change values under accumulated cycle loads, and testing and data analysis are easy to operate and are not susceptible to environmental and other factors. However, this fatigue life estimation method requires long-term real-time continuous monitoring, so it is necessary to use equipment with large storage, high stability and high durability, and also needs to have a high sampling frequency to ensure the accuracy of detection, which is complex and expensive. When the degree of change of resistance value accumulation is obtained by equipment such as fatigue life meter and fatigue life sensor, it is also necessary to select the appropriate model that meets the load conditions, otherwise it is difficult to estimate the life accurately. At present, fatigue life analysis and monitoring technology is mainly used in aerospace.

The authors of the literature have done a lot of work to develop a strain multiplier with reliable performance, high magnification and good linearity, and to solve the fatigue meter by improving the structural shape of the fatigue meter. The key technical problems used in the monitoring of fatigue damage in large bridges. The bow structure of the multiplier is integrated with the horizontal arm, where a rubber elastomer is placed at the opening, and the fatigue gauge sensitive gate is attached to the rubber elastomer so that the strain on the rubber elastomer is felt on the sensitive gate, which is a fatigue sensor that can be used directly for bridge fatigue damage monitoring (fig. 1.3).

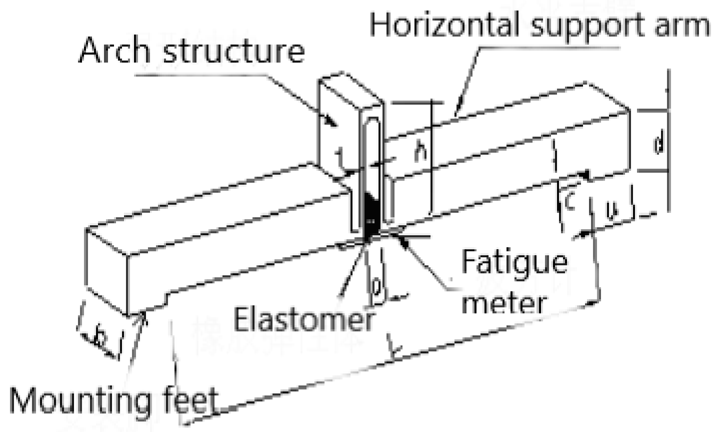

Fig.1.3 - Strain multiplier structure

Lee D C et al uses Intensity-based Optical Fiber sensors (IOFS) to monitor crack expansion of steel structures under fatigue loads[3]. According to the sensing principle of IOFS and the fracture mechanics theory of crack structure, IOFS is installed on the center crack rebar test piece to monitor the expansion of crack, and compares the results obtained with strain gauge and finite elements model. The experimental results show that IOFS can detect stiffness changes caused by crack expansion of steel structures, demonstrating the potential of IOFS in practical applications.

The Huang Hongmei uses Fiber-optic Bragg Grating (FBG) sensors to monitor the crack expansion of pre-cracked Al alloy specimens under circular loads[4]. Based on the strain field distribution analyzed by the finite part model at the crack, the reflection spectrum of FBG is calculated when the crack is extended to different lengths, and the results are basically consistent with the test results. The results show that FBG sensors can not only be used to monitor the expansion of fatigue cracks, but also to some extent to determine the location of cracks.

Summarizing the accumulated research and development experience and analyzing all kinds of modern fatigue injury sensors, we can work out the requirements that must be considered in the development process of fatigue sensors.

- The opportunity to use both meters to estimate the level of disposable loads and cumulative fatigue damage.
- The sensor can operate independently for a long period of time for all life periods of the design.
- No complex data processing equipment is permanently installed on structural and communication lines.
- Quantify the chance of cumulative damage at any operating time.
- Easy to receive information about parameters.
- Measure the reliability and accuracy of the system.

In the past few years, a large number of experimental and theoretical materials have accumulated in the evolution of metal substructures and surface deformations under various mechanical loads. Quantitative methods have been shown to be possible for describing these changes.

The results show that there is a close correlation between the consumption of metal carrying capacity and the parameters of the lower structure and the fluctuation of deformation. The national aeronautical university's research cycle on the damage accumulation process in monocrystalline and polycrystalline crystals allows the development of a new method based on the registration and calculation of continuous slip zone density on the surface of metal crystals to monitor deformation damage.

In this paper, the use of single crystal is considered to indicate accumulated fatigue damage and static loads.

Conclusion to part 1

Despite the achievements in material science, new methods of the stress-strain analysis, development of the analytical and experimental methods for assessment of the accumulated fatigue damage, the problems of the calculation accuracy remains to be very much actual.

The researches of the Aircraft design department at National Aviation University have proved the possibility to use surface deformation relief as an indicator of accumulated fatigue damage. One of the subcomponent of this concept is to use single crystal indicator, where the informative parameter of the accumulated fatigue damage is density of persistent slip bands.

The aim of the Master's work is to develop recommendations on the single crystals fatigue indicators application for the Chinese aviation industry.

To gain this purpose the following tasks must be solved:

- To analyze the problem of aircraft fatigue;
- To analyze contemporary concepts of aircraft design;
- To compare direct investigations of metal state and application of the attachable indicators;
- To substantiate the ways for the sensitivity optimization of the fatigue indicator;
- To develop the recommendation of the single crystal fatigue indicator implementation into the Chinese aviation industry.

PART 2.
SINGLE-CRYSTAL INDICATOR OF FATIGUE DAMAGE

The control over formation and development of persistent slip bands can be one of the ways for diagnostic of a damage rate of a material under cyclic and static loadings. Realization of this approach may be conducted by the attachment of the single-crystal foil sensor on a surface of a detail of a researched product.

Such indicator must be periodically inspected for quantitative estimation of the persistent slip bands density and consequently for the prediction of residual life of the investigated element.

For the single-crystal indicator manufacturing it is necessary to use a material satisfying the following requirements: a) first attributes of occurrence of a deformation relief should come to light after rather small amount of load cycles or at small levels of static strain; b) intensity of a deformation relief should be function of number of load cycles or a level of static strain.

The developed indicator of deformation damage represents the plate of a single-crystal pasted on a surface of a deformable element of a design.

In the present work single-crystals of Al (99.99% weight of Al), brought up by the Bridgment method in Metal-physics Institute of the National Academy of sciences of Ukraine were used.

Previous researches have shown that the deformation process of face centered cube crystals, f.c.c. (for example, crystals of aluminium and its alloys) essentially depends on crystallographic orientation.

Disks of 20 mm diameter have been cut out with the method of the electro-spark device to avoid additional deformation.

The 0.2 mm thickness of the indicator has been obtained by electrolytic polishing.

Electrolytic polishing was made in a solution: 100 ml H_3PO_4; 80 ml H_2SO_4 and 20 ml H_2O.

Mode of polishing:

- A current - I=6 A;
- A voltage - U=15 V;
- Temperature of electrolyte - t=80 C;
- Time Electrolytic polishing - 10 min.

Fastening of the indicator to a sample for tests is made by the glue on the base of cyanocrylat.

The control of a surface state of a single-crystal indicator is carried out with the help of optical metallographic microscope with enlargement 200-400.

2.1 Single-crystal indicators sensitivity control and recommendation for optimum crystallographic orientations

The analysis of physical-mechanical properties of single-crystals showed that it is possible to control the sensitivity of single-crystals indicators. Some ways have been investigated:

- Application for sensors manufacturing materials with various physical-mechanical characteristics;
- Application of devices for proportional changing of indicator deformation level (amplifiers of deformation);
- A variation of crystals crystallographic orientations;

The physical-mechanical characteristics of the material for the indicator with necessary sensitivity must be chosen to synchronize the processes of damages accumulation for materials of corresponding element of design and the indicator. In cases of necessity of control the state of wing's construction, fuselage, tail empennage of the plane which is made of the aluminium alloys, it is desirably to use single-crystals of aluminium or its alloys.

Changing of the composition of used material is apparently, the most complex technology for control of the sensitivity of the indicators.

At application of sensors of exhausting of resource in many cases use the magnification of deformation. Such devices considerably complicate the display system of deformations damages.

In a considered method, sensitivity of the indicator is planned to change by application of single-crystals of various crystallographic orientations.

The analysis of the data about orientation dependences of mechanical characteristics of crystals with f.c.c. - structure, experimental definition of the basic orientation parameters , researches of a deformation relief of single-crystals of some orientations have allowed to make some conclusions: a) sensitivity of the crystal depends on the stress level in primary slip plane; b) sensitivity of the crystal depends on the factor Q, that may be calculated as Shmid Factor of the secondary slip plane , divided by Schmid factor value of primary slip plane; c) sensitivity of the crystal depends on mutual position of the crystal slip planes and internal surface of the crystal.

Critical resolved shear stress (CRSS) is the component of shear stress, resolved in the direction of slip, necessary to initiate slip in a grain. Resolved shear stress (RSS) is the shear component of an applied tensile or compressive stress resolved along a slip plane that is other than perpendicular or parallel to the stress axis[5]. The RSS is related to the applied stress by a geometrical factor, m, typically the Schmid factor.

$\tau = \sigma \cos\varphi \cos\lambda$,

where σ is the magnitude of the applied tensile stress, φ is the angle between the normal of the slip plane and the direction of the applied force, and λ is the angle between the slip direction and the direction of the applied force. The Schmid Factor is most applicable to FCC single crystal metals, but for polycrystal metals the Taylor factor has been shown to be more accurate. The CRSS is the value of resolved shear stress at which yielding of the grain occurs, marking the onset of plastic deformation. CRSS, therefore, is a material property and is not dependent on the applied load or grain orientation. The CRSS is related to the observed yield strength of the material by the maximum value of the Schmid factor:

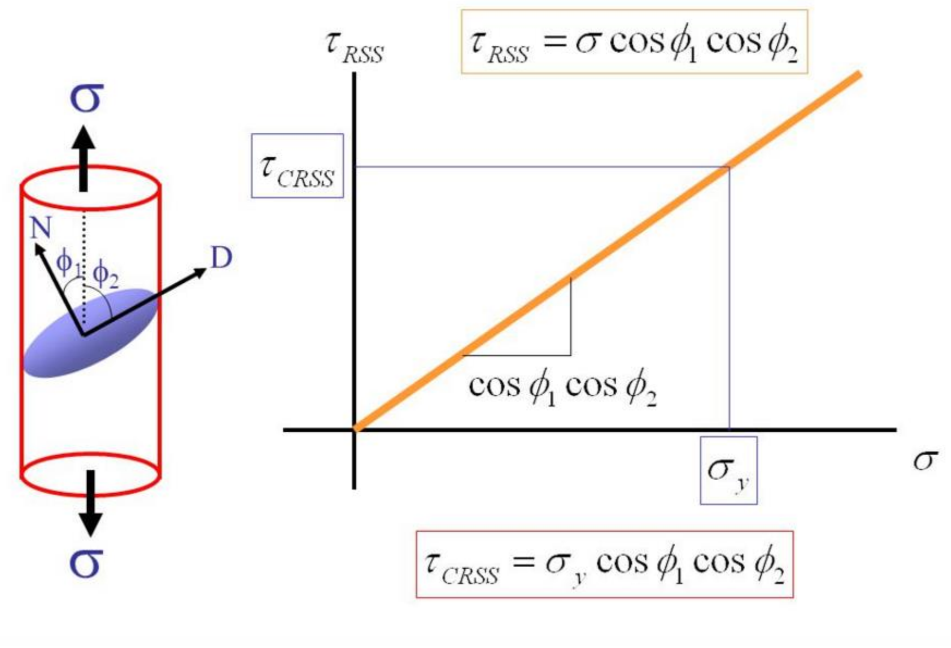

Fig. 2.1 – Critical resolved shear stress

Slip process depends on the crystallographic orientation (fig.2.1).

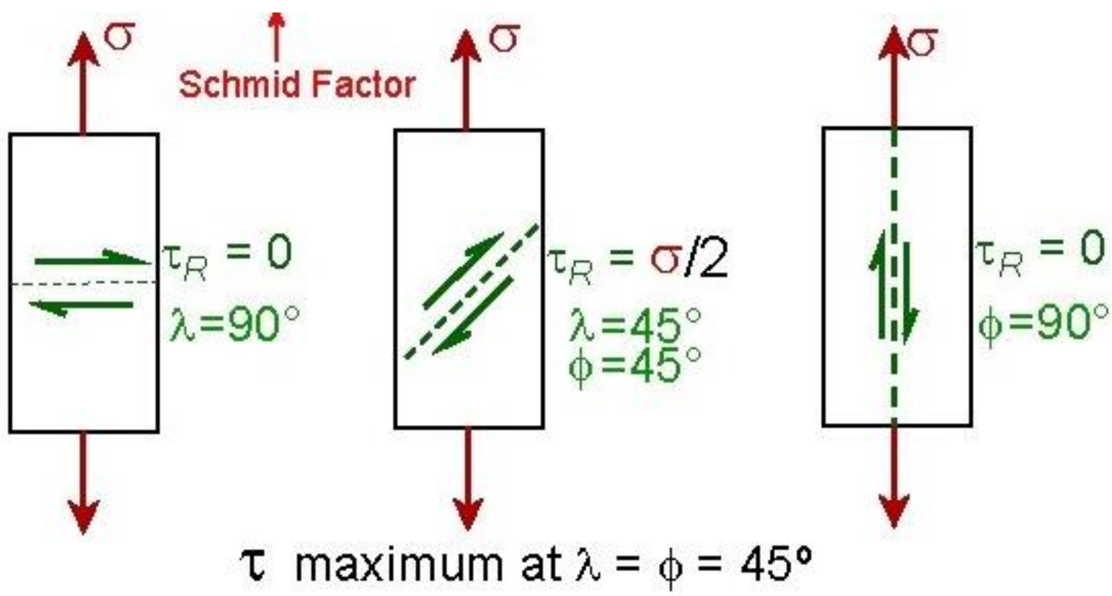

Fig.2.2 - Conditions for the slip for different orientations

There are twelve slip systems in FCC single crystals: Slip occurs on four similar

{111} planes (close packed planes) along, each process goes in the <110> similar directions (close packed directions).

The stereographic projection is used to find angular relations between directions and planes in a crystal (fig.2.3).

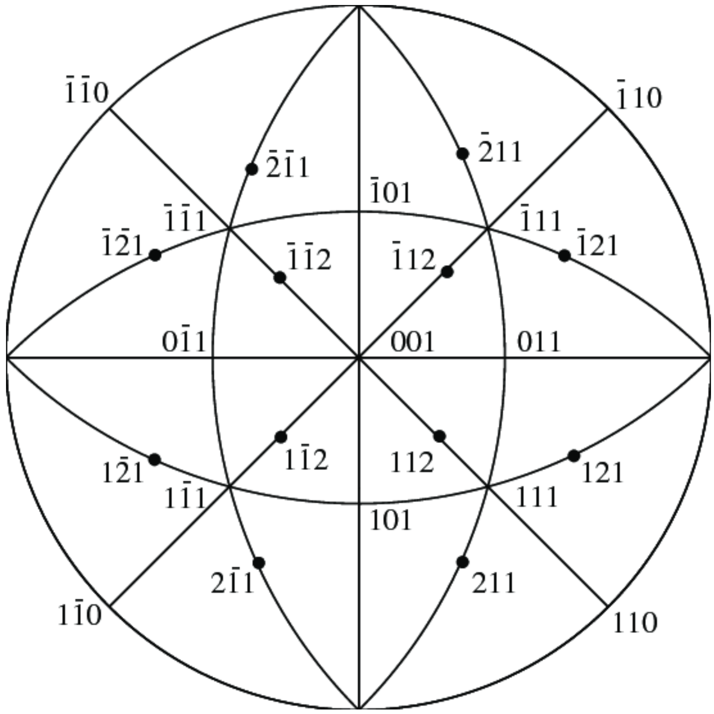

Fig.2.3 - Stereographic projection of the FCC crystal

Twelve possible slip systems are shown in table 2.1.

Table 2.1 - Slip systems in FCC single crystals

Slip system	Slip plane ⟨110⟩{111}	Slip direction
1	(111)	$[10\bar{1}]$
2	(111)	$[0\bar{1}1]$
3	(111)	$[1\bar{1}0]$
4	$(\bar{1}1\bar{1})$	$[10\bar{1}]$
5	$(\bar{1}1\bar{1})$	[110]
6	$(\bar{1}1\bar{1})$	[011]
7	$(1\bar{1}\bar{1})$	[110]
8	$(1\bar{1}\bar{1})$	$[0\bar{1}1]$
9	$(1\bar{1}\bar{1})$	[101]
10	$(\bar{1}\bar{1}1)$	[011]
11	$(\bar{1}\bar{1}1)$	[101]
12	$(\bar{1}\bar{1}1)$	$[1\bar{1}0]$

The resolved shear stresses are different in these 12 slip systems. The maximum stress depends on the crystallographic orientation (fig.2.4).

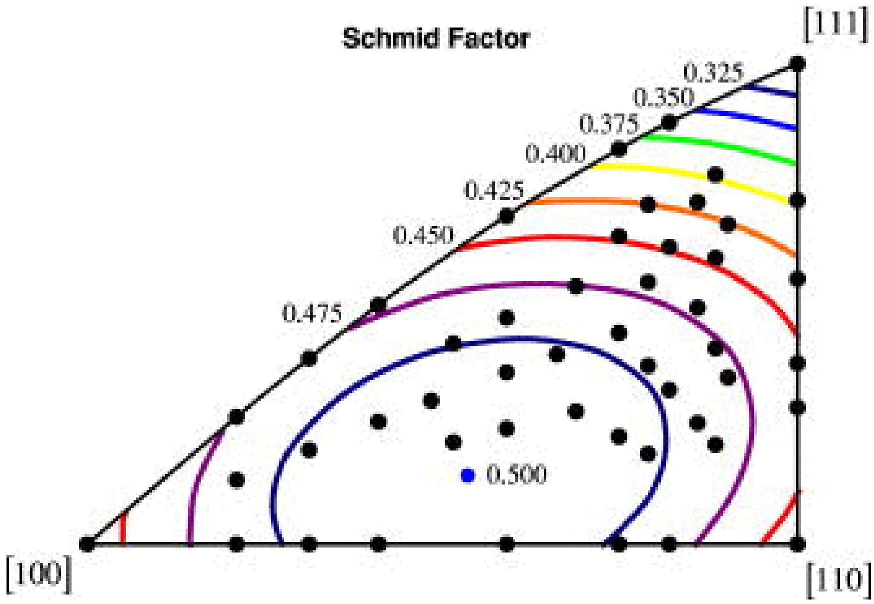

Fig.2.4 - Stereographic triangle and maximum Schmid factor distribution

At the same time the number of the actuated simultaneously slip systems depends on the crystallographic orientation. The tendency for the slipping actuating is illustrated by the position in the crystallographic triangle (fig.2.5 – 2.6). This number reflects also the intensity of the strain hardening.

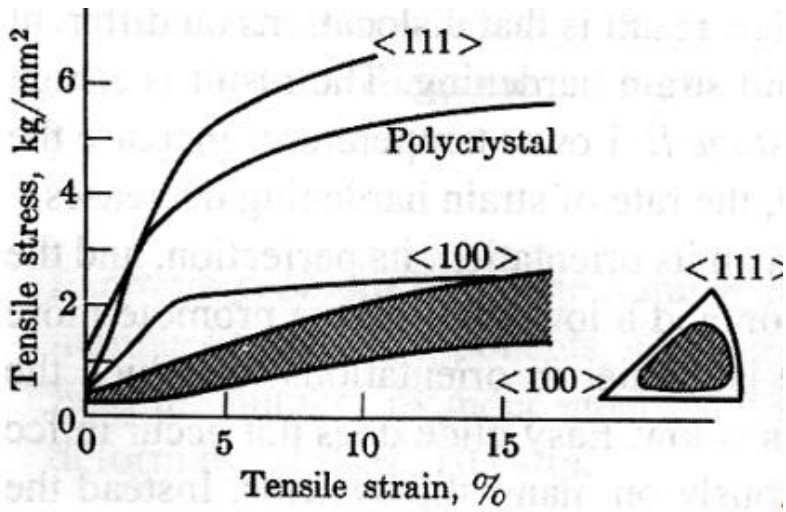

Fig.2.5 - Strain hardening orientation dependence of the FCC single crystals: The

shaded region indicates strain hardening in orientations with only a single slip system.

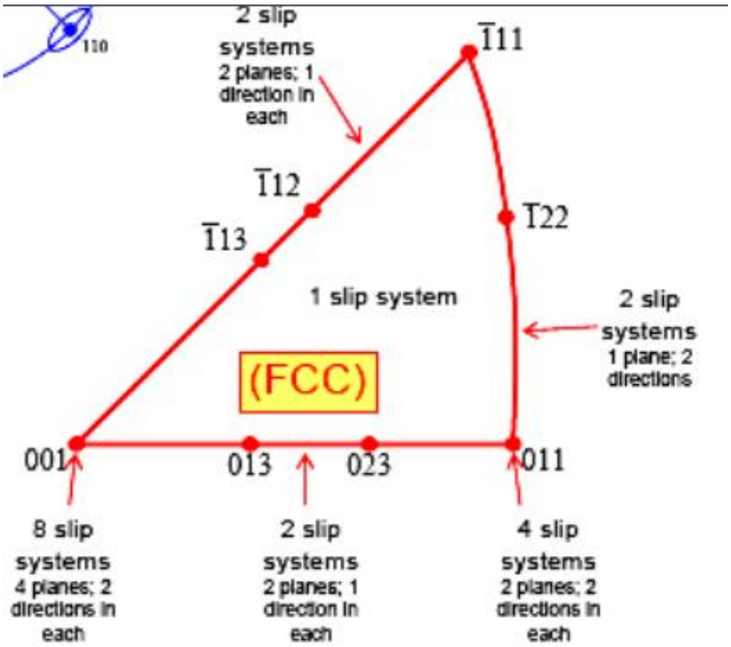

Fig.2.6 – The number of slip systems actuating simultaneously in FCC crystal

2.2 Test result of constructive elements with the single-crystal indicators

The design damage level is connected with damage created by a spectrum of repeated loads and probable overloads. The proposed method gives the opportunity to make the estimation of a level of the deformation caused by a overload and cyclic operational loads as well.

In presented research the following combinations of loads have been considered:

- Regular cyclic loading, simulating loadings from pressure in fuselage cabin;
- Loadings of the wing by air gusts;
- Irregular ("block") loading, simulating damaging action of a spectrum of operational loadings.

In all cases after the applying of the certain number of preliminary loading cycles to a constructive element the loading (overload) causing plastic deformation of a constructive element with the single-crystal indicator unitary was put.

2.2.1 The test program.

Single-crystal indicators fastened with the help of cyanocrylat glue to the samples simulating a smooth element of skin - the constructive elements. Constructive elements were cut out from a sheet of aluminium alloy D16ATB, so that the direction of load corresponded to a longitudinal axis of a sample. The general view of a constructive element and the geometrical sizes are presented on Fig. 2.6.

Cyclic loading of the constructive elements was made on the hydro-pulsating machine MUP-20. Periodically constructive elements were removed from the test machine, the state control of the surface of single-crystal indicator and calculation of quantity of persistent slip bands over the definite base of measurement have been conducted with the help of metallographic optical microscope MMP-4.

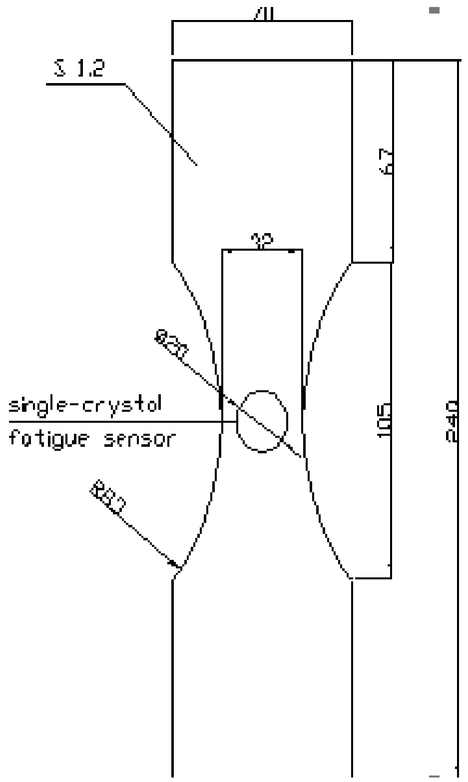

Fig.2.6 - Specimen for fatigue test with single-crystal indicator

2.2.2 Control over the deformations, caused by a static overload in case of preliminary regular cyclic loading

The program for the Single Crystal Fatigue Indicator in the simplest form of the regular regime of loading must contain investigation of the deformation relief under the a) loadings from pressure in fuselage cabin (Fig. 2.7); b) loadings of the wing by lift (Fig. 2.8).

The pressurization load varies from 0 to maximum; the load on the wing lower panel has asymmetry, i.e. the minimum stress is bigger than 0.

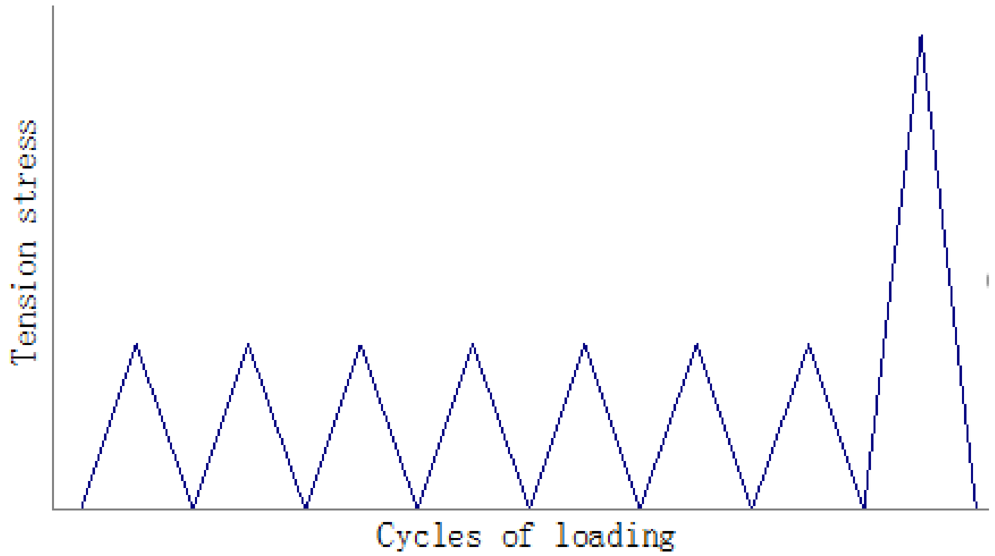

Fig.2.7 – Test program for simulating fuselage loading by pressurization ($\sigma_{max} = 140 MPa$) and single overload ($\sigma_{max} = 400 MPa$)

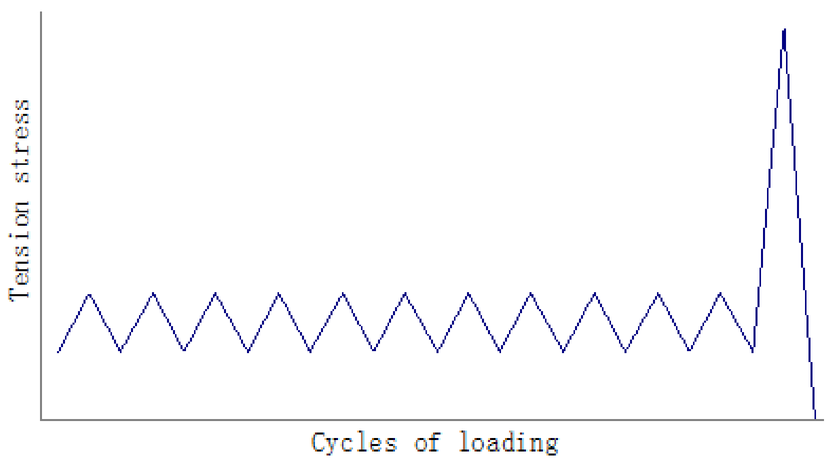

Fig. 2.8 - Test program for simulating wing loading by flight cycle ($\sigma_{max} = 130 MPa$; $\sigma_{max} = 70 MPa$) and single overload ($\sigma_{max} = 400 MPa$)

On each graphs the values received at test of five samples are pointed out and straight lines which equations were obtained by statistical processing are presented. In the same place the values of secondary slip lines density of the deformation relief pointed out, specified as a result of the overload with stress level of 400 MPa.

2.2.3 Control over the deformations, caused by a static overload in case of preliminary irregular loading

As it has been shown in the first section, most frequently the operational loadings work on various units of the plane and their separate elements have irregular characters. Exact imitation of a spectrum of the real operational loadings at carrying out of resource tests needs the expensive test equipment.

Therefore in the practice operational spectrum of loads frequently is replaced by so-called "block" loading. In this case the certain number of "blocks" is put to a sample, a constructional element, unit or a design as a whole. The level of loadings in each of "blocks" is determined from a need of realization of all real spectrum operational damaging loads.

The elementary circuit of program tests is a two-level loading, i.e. tests at which loadings of two levels are put to the sample consistently: after working off the certain number of cycles (N1) at a cyclic tension (G1) transition to other level (G2) is made and fulfilled (N2) cycles loading. Such simple kind of program loading is rather informative as thus there are phenomena of the hardening known from numerous researches, with the transitions of "low - high" and "high - low" tension (Fig. 2.9-2.10).

In our case it is important to find out the specified possible changes of the mechanical properties of materials of the indicator that will affect character of a deformation relief of the indicator at the subsequent, after irregular cyclic loading an overload. The circuit of the carried out program tests is shown on the figures. Processing of results was carried out by a technique considered above.

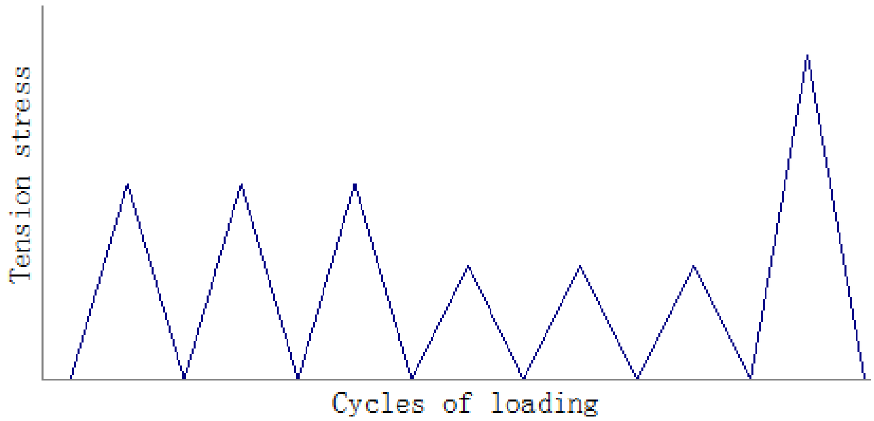

Fig.2.9 - Loading program “High-Low-Overload”

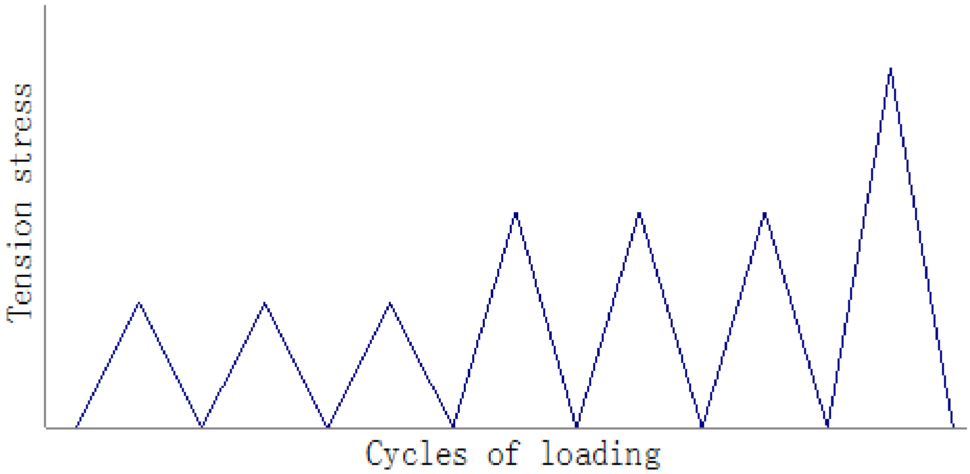

Fig.2.10 - Loading program “Low-High-Overload”

At the process of cyclic loading the density of the slip lines was calculated. The number of the persistent slip lines was determined as average value of three measurements. Results were represented by diagrams (Fig. 2.11 - 2.15) in coordinate’s ln K - ln N, where:

K - density of persistent slip lines;

N – Number of cycles (in thousands of cycles).

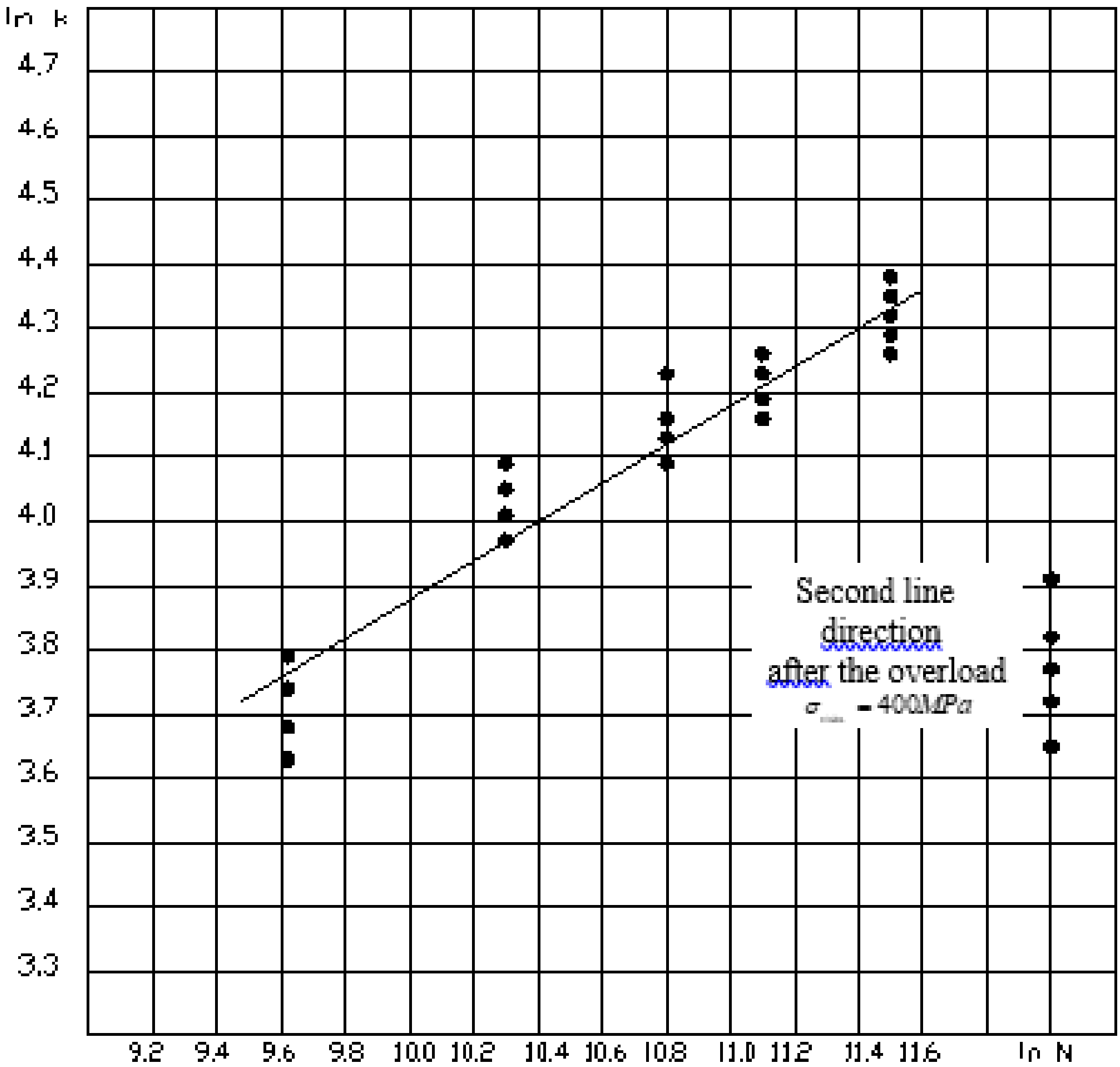

Fig. 2.11 - Slip lines density at the regular modes of cyclic loadings with max stress 140 MPa and overload

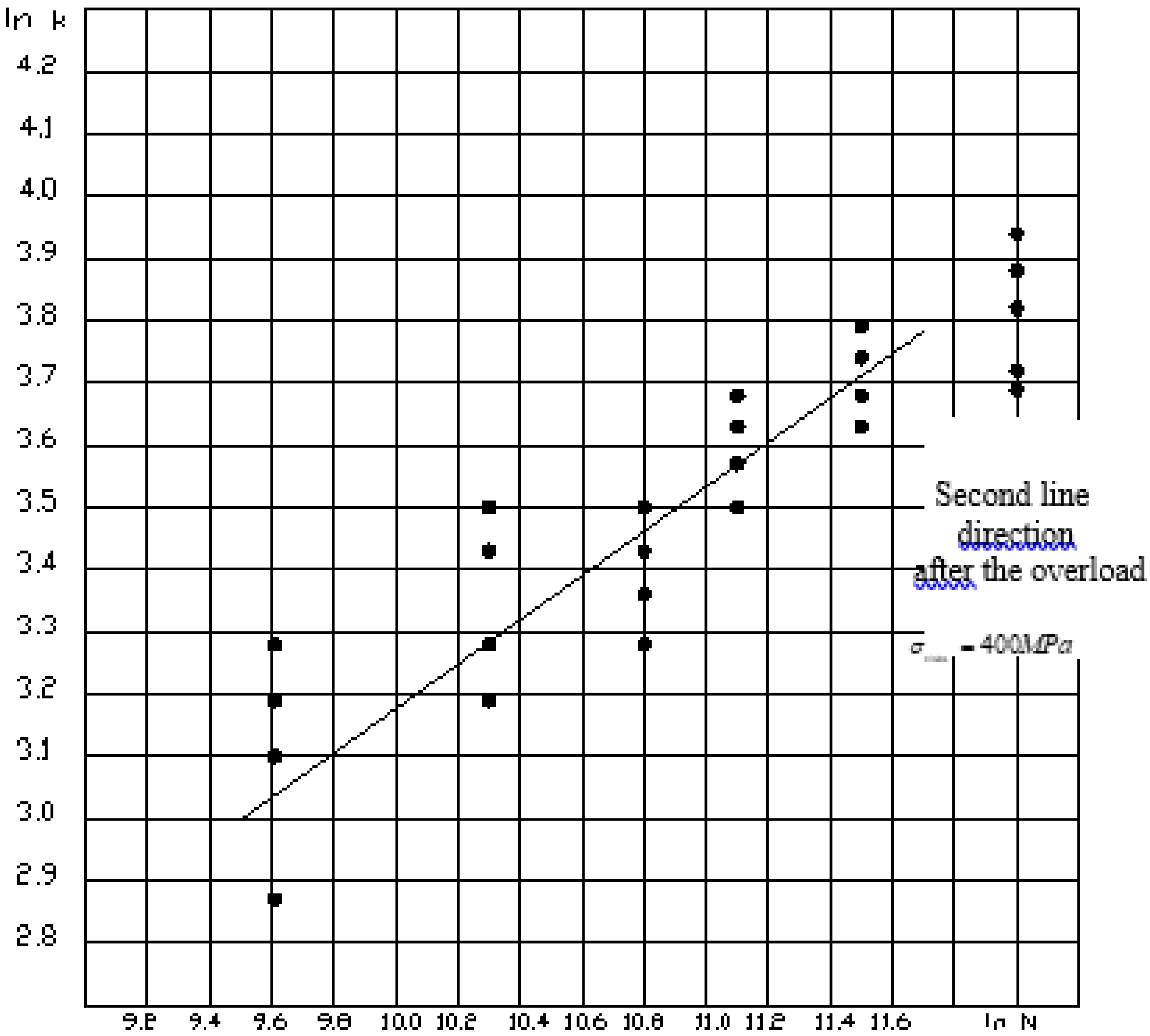

Fig 2.12 - Slip lines density at the regular modes of cyclic loadings with stress 130/70 MPa and overload

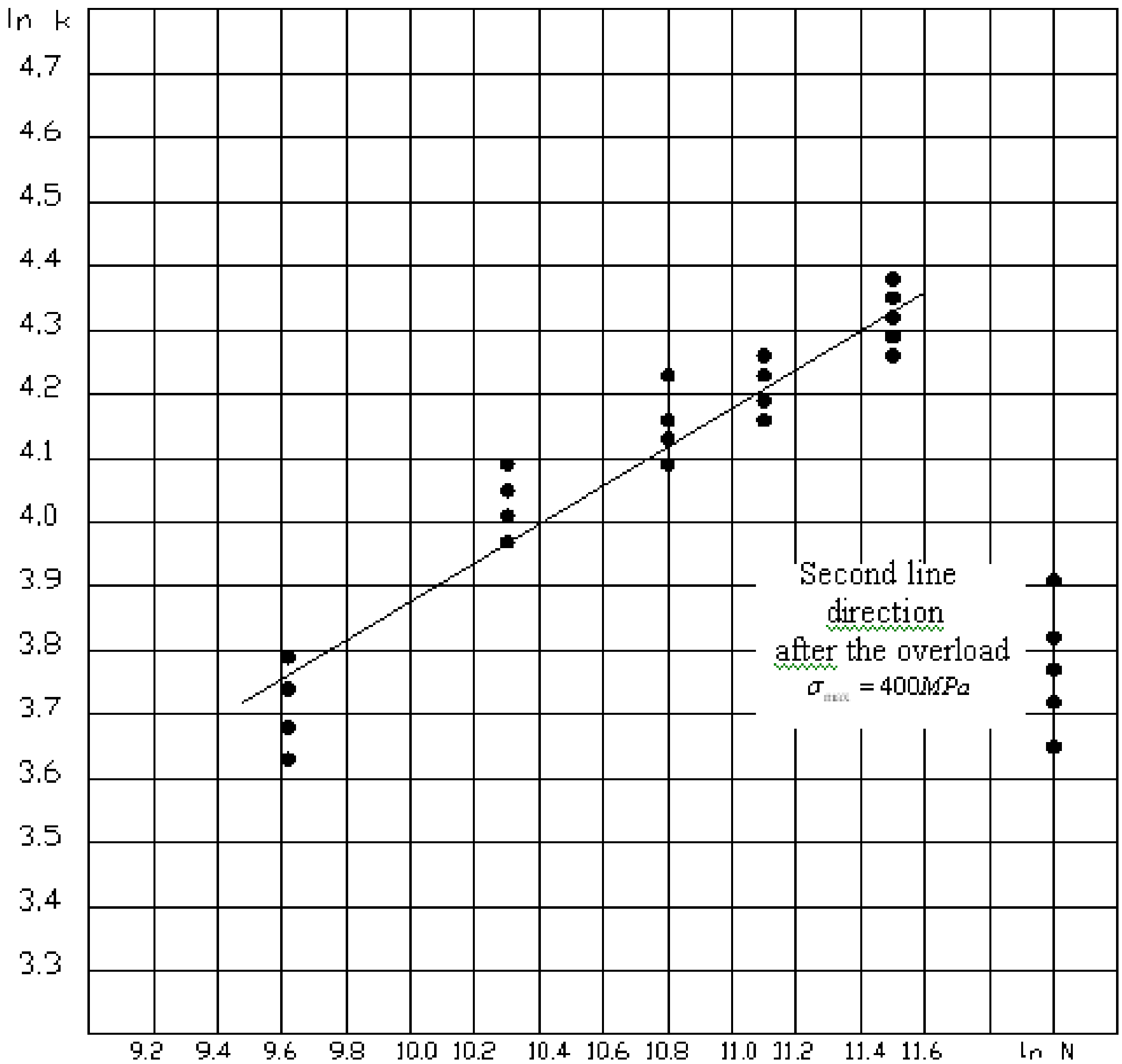

Fig 2.13 - Slip lines density at the regular modes of cyclic loadings with max stress 180 MPa and overload

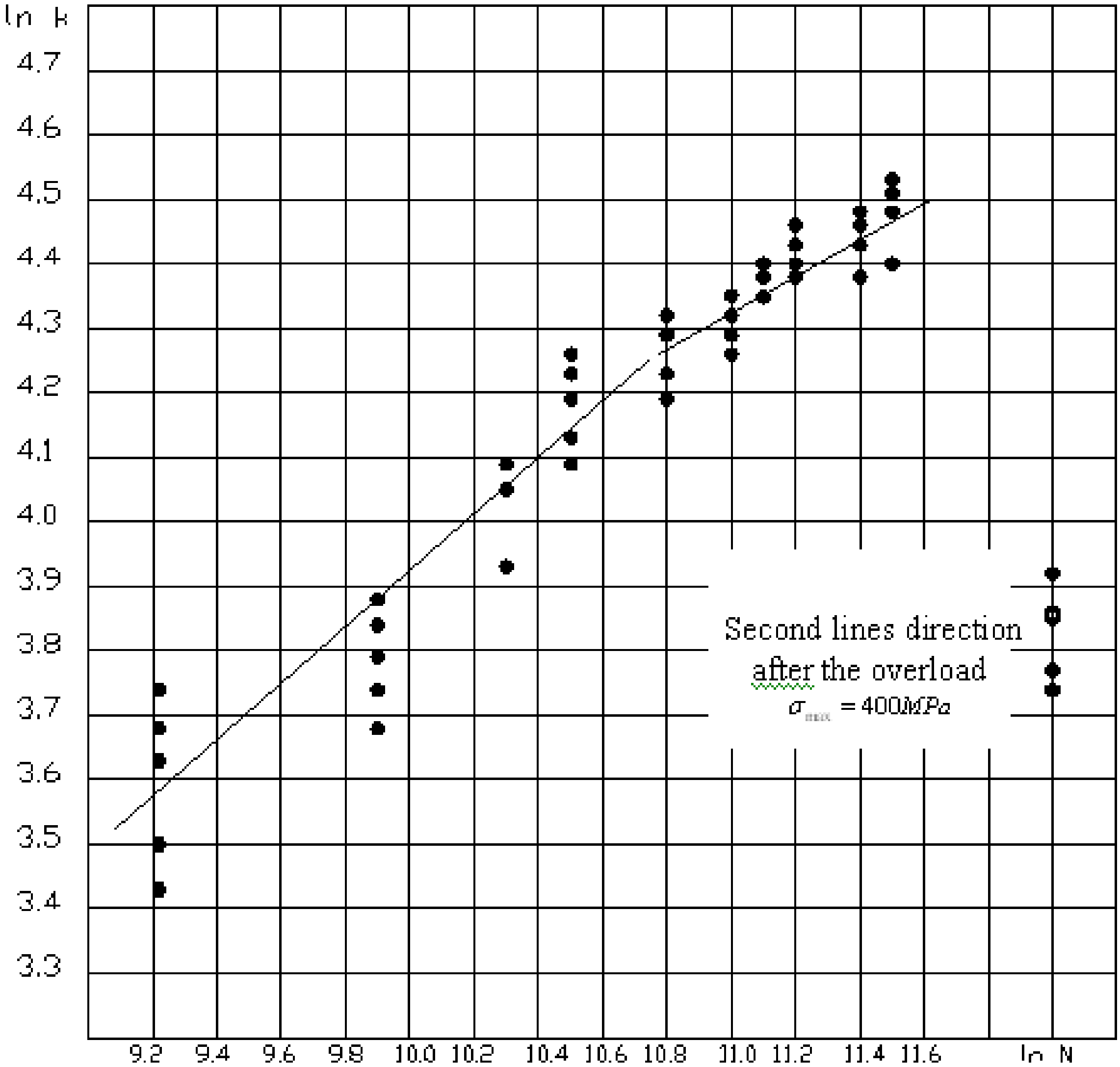

Fig 2.14 - Deformation relief slip line density at the irregular loading at transition from max stress 180 MPa to maximum stress 140 MPa and overload

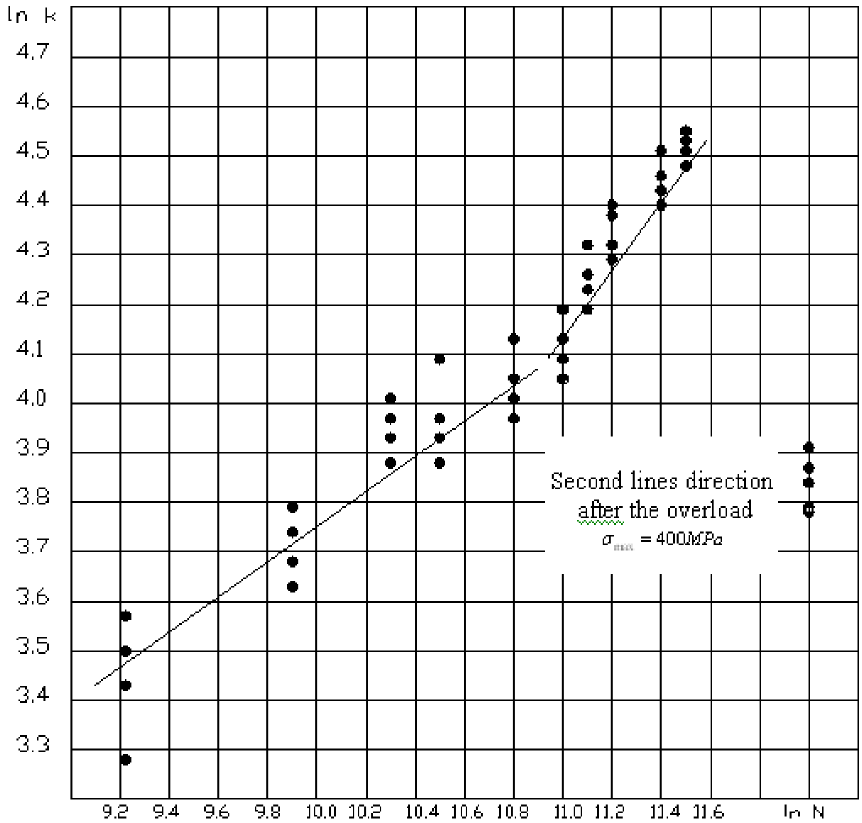

Fig 2.15 - Slip line density at the irregular loading at the transition from max stress 140 MPa to max stress 180 MPa and single overload 400MPa

Conclusion to part 2

The possibility to monitor accumulated fatigue damage by the single crystal element glued to the structural element is illustrated by the tests at the regular and irregular loads programs.

The influence of the crystallographic orientation on single crystal fatigue behavior opens opportunities to gain required indicator sensitivity by the application of certain orientation.

The crystallographic factors influencing single crystal sensitivity have been analyzed. The results of fatigue monitoring by application of single crystal indicator are presented.

PART 3

CHINA'S CONTEMPORARY AIRCRAFT AND RECOMMENDATIONS FOR IMPLEMENTATION OF THE SINGLE-CRYSTAL FATIGUE INDICATORS APPLICATION

3.1 Review of China's aviation industry

The design concept and research content of aviation structure fatigue have developed along with the improvement of aviation technology and aircraft performance. The flight speed of aircraft has developed from low speed to subsonic speed and then to supersonic speed, and the performance requirements of aircraft structures have also developed from safety to maneuverability, reliability, comfort and adaptability, etc. The design concept has also undergone the development process from static strength design, safe life design, breakage safety-damage tolerance design, durability/damage tolerance design to integrity reliability design[7]-[9]. Under the guidance of safe life design, the main research content of aviation fatigue is based on the nominal stress method of S-N curve to carry out the analysis of the crack sprouting life of the structure, considering the influence of geometry, stress concentration and other factors on the fatigue life of the structure. At the stage of breakage-safety-damage tolerance design, the main research content of aviation fatigue is based on the stress intensity factor of fracture mechanics and Paris formula and its modified model to calculate the crack extension life of the structure, taking into account the influence of the load sequence, stress ratio and other factors[10]. When the design concept of aeronautical structures developed to the stage of durability/damage tolerance design, the research content of aeronautical fatigue included both crack emergence life and crack extension life of structures, and the research objects were extended to fatigue, corrosion, surface integrity, nondestructive testing, health monitoring, etc., and the research methods were also more abundant, such as continuous damage mechanics, probabilistic fracture mechanics, fatigue reliability, etc[11]-[13].

After years of development, from imitation to independent development, China has established a structural fatigue technology system covering the whole life cycle, and basically realized the long-life fatigue-resistant design of new aircraft structures, and increased the design target life of fighter aircraft to 6000-8000 flight hours, trainer aircraft to 8000-10000 flight hours, and civil aircraft to 60,000-90,000 flight hours. The calendar life target of 25-30 years. However, due to the relatively late start of Chinese aviation industry, the accumulated data of testing and service is relatively small, and due to the limitation of industrial manufacturing level, there is still a certain gap with the aviation powers in terms of advanced design of anti-fatigue structure, accuracy of analysis and evaluation, systematization of testing and verification, stability of manufacturing process, and reliability of maintenance guarantee.

3.1.1 History of Aviation Fatigue Research in China

The early Chinese aviation fatigue research mainly adopted the strategy of imitating and following up, digesting and absorbing foreign related research, and the design thinking of aircraft structure went through the development process from safe life design, damage tolerance design, durability/damage tolerance design to reliability design. In the 1960s, China mainly adopted the "safe life" fatigue design method to develop aircraft. The researchers assumed that the delivered aircraft structure had no initial defects or damage, and obtained the fatigue crack emergence life of the structure based on fatigue analysis and full-scale structural fatigue tests, divided by a dispersion factor to give the service life, which took into account environmental effects, material and manufacturing deviations. In other words, the main emphasis is on adequate static strength (control of low design stress levels) and the selection of high dispersion factors to ensure flight safety during a given service life, without requiring effective measures to prevent damage to the aircraft structure due to defects or damage caused by the delivery of new aircraft or during service. Therefore, aircraft structures are not allowed to be delivered with defects or damage, and must be removed as soon as they are found. However, due to the constraints of non-destructive testing capabilities at that time, initial defects were always difficult to avoid, and even with high values of dispersion coefficients, it was not enough to completely guarantee the safety of the structure in service, so Chinese researchers gradually focused on the design method of damage tolerance considering initial damage or defects.

In the 1980s, Chinese aircraft structural fatigue research introduced the idea of damage tolerance design, combined with the idea of safe life design, and formed the design method of safe life design to determine the life and damage tolerance design to ensure flight safety. In the idea of damage tolerance design, fatigue design and damage tolerance design complement each other, and fatigue analysis and test results are used to determine the service life of the structure, and the slow expansion life of cracks is used to determine the maintenance cycle of the structure. For the structure with excellent damage tolerance characteristics confirmed by analysis and test, a lower dispersion factor can be selected; for the structure with poor damage tolerance characteristics, or where damage tolerance design is not possible, a high dispersion factor must be selected. The purpose of damage tolerance design is to analyze and verify the slow crack expansion life and residual strength of the structure to provide a basis for the maintenance cycle or the maximum initial damage allowed. The key to the damage tolerance design is to investigate the slow crack expansion characteristics of the developed structure (including single and multiple transmission paths) through the selection of materials, structural detailing, and the use of stress levels. In this way, delivered structures with undetected initial defects or damage can be effectively prevented from catastrophic damage within a given service life due to the controlled expansion of the defects or damage.

In the 1990s, based on economic considerations, researchers adopted the durability-based "economic life" design concept instead of the fatigue-based "safe life" design concept, and established the durability/damage tolerance design concept, In this way, a Chinese outline of aircraft structural integrity was established. Durability characterizes the ability of an aircraft structure to resist cracking, corrosion, thermal degradation, wear and external damage under specified operating conditions (load/environment) and maintenance conditions, and involves the entire process of aircraft design, production, testing, service and retirement. The "economic life" of durability represents a small crack expansion life, where the initial crack size is determined by the original fatigue quality of the structure, and the termination of the crack is based on the damage that affects the performance and safety of the aircraft under the design service load/environmental spectrum and is not economical to repair. An aircraft structure designed for durability requires not only that damage due to undetected defects or damage expansion be prevented for a given lifetime, but also that the number or size of cracks or other damage in each fatigue hazard zone of the primary structure of the aircraft not reach critical values, and that expensive maintenance, repair, or unplanned component replacement be avoided during the design life of the aircraft under the design service load/environmental spectrum. Planned component replacement. Structures designed for durability must be verified by damage tolerance characterization and testing to give a maintenance interval (maximum initial damage allowed for in-service non-inspectable structures) to ensure flight safety.

Since the end of the 20th century, with the rapid development of science and technology, aircraft structures have become more and more complex, and the performance indexes have become more and more demanding, so Chinese researchers have introduced the idea of reliability design, and adopted the principle of durability/damage tolerance design throughout the design process of military and civil aircraft. From the development of Chinese aircraft structural design thinking, safe life design and economic life design are both used to determine the service life of the structure, while damage tolerance design is mainly used to determine the maintenance cycle or critical damage size of the structure, which can be used in conjunction with both safe life design and durability design. The reliability-based design concept is to guarantee a low probability of failure for the durability/damage tolerance design results. In conclusion, no matter which design philosophy is adopted, avoiding catastrophic fatigue damage of aircraft structures is one of the most important goals. The Chinese aviation industry has implemented the National Military Standard GJB775A "Outline of Structural Integrity of Military Aircraft" and has managed the entire life cycle of new aircraft from demonstration to fleet operation management in accordance with the "five tasks" of the Outline, ensuring the quality and flight safety of new aircraft during the structural development and operational phases.

3.1.2 Main results of aviation fatigue research in China

In the process of implementing the above-mentioned ideas of aircraft structural design, Chinese researchers have done a lot of fruitful work and made important contributions to the development of China's aviation industry. Among them, the research team represented by "Aircraft Structure Fatigue and Fracture Resistance Technology and Reliability Research System Project" (AFFD System Project) has carried out rich and fruitful researches for many years[14].

In the area of durability/damage tolerance design and analysis, the following work has been carried out:

(1) Established structural durability and damage tolerance design principles and analysis methods, proposed aircraft structural durability design and ground test requirements, and compiled the "Outline of Structural Integrity of Military Aircraft";

(2) Through the research on the original fatigue quality of the fastening holes of the aircraft structure, the original fatigue quality model analysis and test methods were established, the test data and the original fatigue quality control technology of the domestic and American standard aviation materials were given, and the original fatigue quality control technology of the fastening holes was formed;

(3) Analysis method and a full set of calculation procedures were established for durability and economic life prediction of components or parts, damage tolerance assessment method for random multi-crack structure was proposed, and dynamic crack expansion crack stopping technology was developed;

(4) Established a three-dimensional finite element stress analysis program system for landing gear structure and a software package for durability and damage tolerance analysis, and compiled the "Aircraft Landing Gear Durability Design Guide";

(5) Established the elastic-plastic finite element analysis and test method for residual strength of reinforced fuselage wall plate under biaxial stress, and proposed technical measures to improve the crack expansion characteristics of reinforced wall plate structure and the engineering calculation method to determine the best structural parameters configuration method, as well as the engineering method to analyze the residual strength of reinforced wall plate structure with multiple cracks;

(6) The method of structural detail stress analysis in the area of hole and door frame is established, and the method of selecting the best configuration of parameters to stop cracking is given;

(7) Shear buckling fatigue analysis and test methods were established, as well as durability test techniques for full-size aircraft structures.

In the research of fatigue resistance and fracture strengthening technology, the following work has been carried out:

(1) A series of research on cold extrusion of hole wall, interference fit riveting, interference fit screwing, shot peening and other strengthening processes were carried out, and the best process parameters were determined, the corresponding S-N curve, a-N curve and da/dN-ΔK curve were given, and the corresponding strengthening process guiding documents were formulated;

(2) The residual stress determination and analysis methods for engineering use were established, and the test values and distribution curves of residual stress were given;

(3) Research on crack formation and extended life calculation methods for components with residual stresses, and the calculation methods and corresponding calculation procedures for crack formation and extended life for engineering use, including the calculation methods and corresponding procedures for stress intensity factors, were presented;

(4) Research on the effectiveness and reliability of detail fatigue rating (DFR) determination and life extension gain of typical structures based on strengthening technology was carried out, and the test results were presented in the form of curves, graphs and data.

In the field of structural reliability assessment and design research, the following work has been carried out:

(1) Initially, we have formed the idea system of aircraft structure reliability design, established the method of aircraft structure reliability assessment (including functional reliability assessment), as well as the reliability index system and reliability allocation method, and established the aircraft structure reliability database;

(2) The application research of reliability assessment of typical functional structure system was carried out, and the general reliability assessment analysis and test methods were provided, and the analysis and test methods of reliability assessment in the structural integrity design of new aircraft were provided;

(3) Conducted engineering application research on probabilistic fracture mechanics, and compiled the "Guide to Aircraft Structural Damage Risk Analysis" and "Crack Monitoring

Probability Curve Manual";

(4) Established failure tree and failure mode impact analysis procedures and requirements for typical mechanisms (including landing gear retracting system, flap handling system and cargo bridge gate retracting system of military transport aircraft, etc.), provided reliability assessment and test verification methods for typical mechanisms, completed reliability assessment and test verification studies for typical mechanisms of several aircraft types, and compiled "Aircraft Typical Mechanism Reliability Assessment and Test Guide".

The main work in the research of corrosion fatigue and corrosion protection technology includes:

(1) Established a database of aircraft structure use environment, provided a load-environment spectrum compilation method, and gave a quantified typical standard environmental spectrum;

(2) Established the corrosion fatigue crack sprouting and expansion life prediction method and analysis software;

(3) The corrosion fatigue life test verification method of typical structural parts under load-environment spectrum was established for engineering use, effective corrosion protection measures and engineering application examples for various types of structures were provided, and the "Aircraft Structure Corrosion Fatigue Design Guide" was compiled.

In addition, AFFD system engineering has also researched abrasion fatigue protection technology, laser irradiation life extension technology, structural adhesive method to stop cracking technology, crash damage resistance design and some typical structural life extension comprehensive management. In the 21st century, Chinese researchers engaged in aviation fatigue research have started to actively integrate into international research organizations.

In the basic research of aviation fatigue and structural integrity, the following work has been carried out:

(1) Wide-spread fatigue damage research;

(2) Research on fatigue and damage tolerance characteristics of new materials, new processes and new structures such as aluminum-lithium alloy, additive manufacturing, friction welding, etc;

(3) The building block test verification method for aircraft structures;

(4) Load spectrum measurement and compilation considering comprehensive environmental effects;

(5) Durability/damage tolerance analysis and reliability life assessment of aircraft structures;

(6) Health monitoring, damage detection and maintenance of aircraft structures based on fatigue/damage tolerance theory and testing.

In the area of applied research on aviation fatigue and structural integrity, the following work has been carried out:

(1) Full-scale component testing of MA600, ARJ21-700 and C919 models;

(2) Developed a variety of materials, components and typical detail strength test devices;

(3) Written a large number of standards and manuals on material and performance design; design and verification of damage tolerance of large size whole structure;

(4) Fatigue behavior prediction of wing-body docking structure;

(5) Airworthiness analysis of composite structures;

(6) The effect of fuselage wall panel structure crack stop on its damage tolerance performance.

The fatigue of aircraft structures is influenced by many factors and is extremely sensitive to material properties, manufacturing process, structural form, load history and environmental conditions, which makes the study of fatigue and fracture characteristics of aircraft structures still one of the most complex problems in aeronautical engineering. Especially, since the 21st century, the state has paid great attention to the aviation industry and provided strong support in terms of research funds, which has enabled many aviation fatigue research projects to be carried out continuously and deeply, and fruitful results have been achieved.

3.2 Principle structural elements and Fatigue Indicators placement.

Developed Single-Crystal fatigue indicator will be installed on the aircraft principal structural element, which is an element of structure that contributes significantly to the carrying of flight, ground, or pressurization loads and whose integrity is essential in maintaining the overall structural integrity of the airplane. Principal structural elements include all structure susceptible to fatigue cracking, which could contribute to a catastrophic failure.

The principle structural elements:

- **Wing and empennage, including** Control surfaces, slats, flaps, and their mechanical systems and attachments (hinges, tracks, and fittings); Integrally stiffened plates; Primary fittings; Principal splices; Skin or reinforcement around cutouts or discontinuities; Skin-stringer combinations; Spar caps; Spar webs.
- **Fuselage, including:** Frames and adjacent skin; Door frames; Pilot-window posts; Pressure bulkheads; Skin and any single frame or stiffener element around a cutout; Skin or skin splices, or both, under circumferential loads; Skin or skin splices, or both, under fore and aft loads; Skin around a cutout; Skin and stiffener combinations under fore and aft loads; Door skins, frames, and latches; and Window frames.
- **Landing gear and their attachments.**
- **Engine mounts.**

At the described stage of the research the application of the Single-Crystal indicator is ready for application for the fuselage and wing.

The next stage of the research should be devoted to the investigation of the relationships between the damage of the indicator and damage of the constructional material used for the detected principle structural element.

Conclusion to part 3

Based on the analysis of the process of research on fatigue problems in the Chinese aviation industry and the current research results, this chapter proposes the main application elements of fatigue indicators.

PART 4.
INVIRONMENT PROTECTION

Typically, an aircraft can fly for 25 to 30 years. Some retired aircraft do not reach the end of their service life, but rather the time to retire according to fleet planning. After a certain number of years of service, the relatively low utilization rate, high maintenance costs and fluctuating fuel prices can have an impact on the economics and safety margins of the aircraft. At this point, the aircraft faces the fate of retirement. Under this scenario, the number of retired aircraft worldwide is steadily increasing each year at a compound annual growth rate of more than 4 percent. According to Boeing's Market Outlook report, the world will need more than 44,040 new aircraft over the next 20 years, and nearly half of that number will be used to replace older aircraft. In other words, a large number of aircraft will be retired in the next 20 years. The American Aircraft Recycling Association (AFRA) expressed the same view in its latest industry watch report, which predicts that an average of more than 1,000 aircraft will be retired globally each year over the next 15 years[15].

After scrapping, used aircraft are often placed in airports, where degradation caused by ultraviolet light, rainfall and airframe oxidation can easily cause environmental pollution of soil and groundwater, and also take up a lot of land resources, causing huge environmental pressure. For example, the Cotswold Hills Regional Airport in the United Kingdom, as well as the great deserts of Southern Europe and the Midwest in the United States, are home to thousands of decommissioned aircraft that are no longer in use, and people call these places "aircraft cemeteries", which seriously affect the local ecological environment.

There are hundreds of usable materials in end-of-life aircraft, and the number is growing based on economic and technological developments in the recycling field. The problem of destroying all the disassembled parts without proper treatment and mixing them with various scrap metals, and not being able to effectively recover various valuable materials, makes the recycling rate of scrap metals less than 50%.

Fig 4.1- Schematic diagram of aircraft disassembly

Generally speaking, there are three ways to dispose of retired passenger aircraft: first, let them continue to fly, due to the existence of the second-hand aircraft market, the aircraft can be sold or subleased at a certain price, such as to relatively backward countries in Africa, South America and other regions, where airlines have less purchasing power and therefore tend to purchase lower-priced second-hand aircraft; second, the passenger aircraft is converted into a full cargo aircraft, the average service life of cargo aircraft than The average service life of cargo aircraft is 10 to 20 years longer than that of passenger aircraft, and many cargo aircraft currently in operation are converted from passenger aircraft such as Boeing 737 and Airbus A320; third, the aircraft is dismantled to achieve maximum recycling of aviation materials. The choice of different disposal methods does not depend on the newness of the aircraft, but is considered from the perspective of maximizing asset value. If disposed properly, retired aircraft can become new profit growth points, and aircraft dismantling is one of the effective ways. By recycling aircraft parts and materials, the residual value of retired aircraft can be maximized, allowing airlines to reach a sustainable stage in aircraft operations and material reserves.

4.1 Reuse of retired aircraft after modification

The current treatment methods for retired aircraft are mainly divided into two directions: one is to retain the structure of retired aircraft and the other is to change the structure of retired aircraft. Both methods aim to reuse the retired aircraft and adapt them to the new operating environment[16].

The main methods of preserving the structure of retired aircraft are: transferring retired aircraft to aircraft graveyards for closure or reselling them to other airlines. Transferring retired aircraft to the aircraft cemetery for storage means that the retired aircraft are scientifically packaged and stored in a reasonable manner to avoid rust, damage and abnormal loss of parts due to long-term open storage or poor packaging, and to ensure that the retired aircraft are always in a usable condition. Transferring aircraft to aircraft cemeteries for storage will extend the service life of aircraft to a certain extent, but at the same time occupy a large amount of land resources and make the entire aircraft cemetery a certain safety hazard due to the combustibility of some metals. The retired aircraft are sold to other airlines such as those in Africa. This method saves metal resources and gives the opportunity to reuse the retired aircraft. However, retired aircraft are sold at low prices, are less profitable, and have a higher accident rate than normal aircraft, making them a safety hazard.

The main methods of changing the structure of retired aircraft are: disassembling them for further use in other aircraft, converting them into cargo aircraft, and transforming retired aircraft into works of art. Dismantling a retired aircraft yields parts and large amounts of metal. According to statistics, dismantling an aircraft for parts is 50% more profitable than keeping it in the air. An aircraft dismantled for landing gear can be sold for $1 million, and an engine can be sold for $6 million. An industrially run aircraft dismantling center, with 20 Boeing 737s dismantled a year, could generate $200 million in output, with profits reaching $35 million. There are a large number of flammable and explosive items on the retired aircraft, which requires high requirements for dismantling environment and dismantling technology, and the dismantling process is risky.

The conversion of retired aircraft into cargo planes allows them to continue to fly in the blue sky. This not only achieves the reuse of retired aircraft, but also meets the requirements of sustainable development. Boeing, the world's largest manufacturer of civil and military aircraft, estimates that there will be about 840 new freighters in the next 20 years, but 7,000 retired aircraft. Even if all new freighters are converted from retired aircraft, that still leaves more than 6,000 aircraft that are unaccounted for. The market share of retired aircraft converted into cargo aircraft is relatively small, and there is also the potential problem of high accident rate of retired aircraft.

A professional scrap aircraft conversion company should be established to recycle retired aircraft from their bases, dismantle them and then provide artistic and life-like transformation. Invite civil aviation technicians for technical supervision, hire senior technicians, and introduce advanced foreign technology to continuously improve aircraft dismantling and subsequent artistic and living transformation techniques. We have established a special management organization and system. Product inspection standards are implemented according to industry standards, and quality supervision is carried out throughout the process.

There are many usable parts generated from retired aircraft, such as seats, fuselages, engines, cabins, etc. The economic value generated by converting them into crafts or lifestyle items is much higher than the economic value of converting passenger planes into cargo planes. The car seat system converted from airplane seat has low power, low power consumption, no increase in fuel consumption at all, zero emission and zero pollution. In the same rate consumption is also able to conduct a large area of air conduction cooling. Compared with the independent cooling system, the stability, safety, comfort and energy saving of the aircraft seating system is better; the desk converted from the engine is also installed with the color-changing LED lighting of the engine spin body, which can relieve eye fatigue caused by the long meeting time during the meeting and improve the efficiency of the meeting; the roof converted from the aircraft wing is large and less dense, and requires little support. With so many advantages of retired aircraft, these items can be promoted to achieve recycling of resources.

4.2 Dismantling of retired aircraft

Given the differences in the origin of retired aircraft, there are significant differences in the material structure, type, and composition of the aircraft. Therefore, the dismantling operation process will not remain unchanged, especially with the deepening of dismantling practice and the requirements of smart dismantling and green dismantling operation, the dismantling process will be optimized continuously, and some of the dismantled equipment will be sold directly, some equipment or parts will be sold through remanufacturing, and other metal materials and carbon fiber materials will be realized through new technology to achieve high-value utilization, as shown in Fig 4.2.

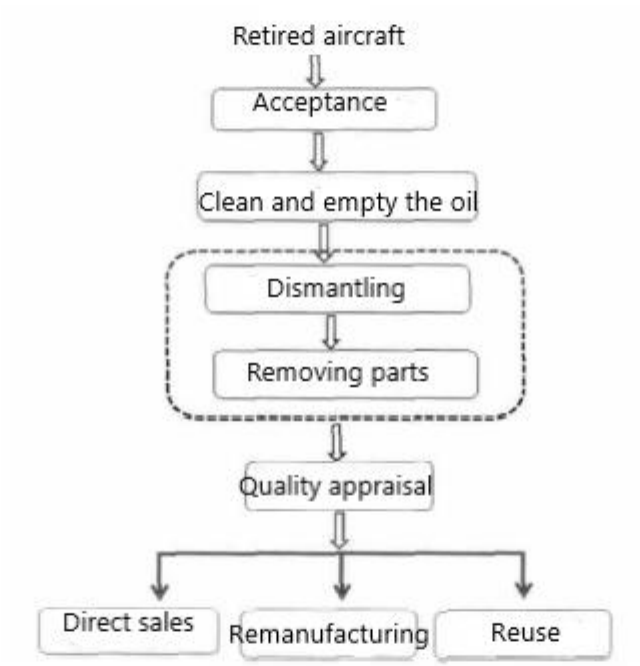

Fig 4.2 - Aircraft dismantling flow chart

(1) After the decommissioned aircraft enter the dismantling site for storage, firstly implement the safe storage procedures: clean the target and eliminate pollution, then empty the aviation oil and other flammable items, and at the same time implement acceptance and registration, and establish the corresponding archival data.

(2) Execute the dismantling of important equipment and parts, including: engines, auxiliary power units, landing gear, electronic equipment, etc. Through the corresponding testing and assessment, grade labeling. The output of this process can be directly sold products,

remanufacturable products and recyclable products.

(3) Intelligent dismantling and upgrading process. Through rapid material determination on site, harmful materials are removed first, then the body is completely dismantled and the dismantled materials are sorted and stored, and finally, they are processed and utilized separately in depth. The output of this process is various aluminum alloys, titanium, high-temperature alloys, stainless steel and other alloy materials and various non-metallic materials, etc. The value of the output of this process depends on the fine degree of disassembly and the perfect degree of classification and separation.

Titanium alloys, aluminum alloys and carbon fibers produced by aircraft disassembly have high reuse value.The main way to use the waste titanium alloy is to smelt and remanufacture titanium alloy, and the reuse of waste titanium alloy is of great significance to economic recycling, resource saving and environmental protection[17]. At present, there are three main recycling methods for global carbon fiber waste: physical recycling, chemical recycling and energy recovery. Chemical recycling is the use of chemical modification or decomposition to make the waste into other substances that can be recycled. Compared with physical recycling, this method is more difficult and costly to recycle thermoset composites, but the recycling effect is better. Although it is more difficult and expensive to recycle carbon fiber products, the recycling effect is better and it is applicable to the contaminated carbon fiber waste.

Conclusion to part 4

Therefore, it is in line with the trend of resource recycling and low-carbon development to carry out reasonable recycling and reuse for the old degree of aircraft. The dismantling of end-of-life aircraft is a systematic and complex project, and the recycling of aircraft is a comprehensive technology involving many disciplines. recovery and reuse is a comprehensive technology involving various disciplines. Combining airlines and recycling enterprises, to condense the technical direction and organize innovation as further optimize the technology and management of end-of-life aircraft dismantling and recycling. technology and management, provide technical support for domestic aircraft dismantling and recycling, and provide technical support for end-of-life aircraft disposal. The project will provide technical support for the dismantling and recycling of domestic aircraft, and find new ways for the disposal of end-of-life aircraft. Proper understanding of aircraft components and their impact on the environment in order to minimize the company will also be able to meet the expectations of society as a whole and create the greatest possible impact on the environment. The company's goal is to meet the expectations of society as a whole and create maximum value.

PART 5
LABOUR PROTECTION

5.1 Introduction

The work of this paper aims to deal with aircraft fatigue monitoring by applying single crystal fatigue damage indicator. And to suggest the application of single crystal fatigue indicator for Chinese aviation industry. Aircraft fatigue detection methods involve ultrasonic detection, radiographic detection, magnetic particle detection, penetration detection and the detection using single crystal fatigue indicator mentioned in this paper, etc. These methods require large equipment and instruments in practical application, and are accompanied by radiation and corrosion, which can cause serious hazards to human body, so it is important to analyze the test site and give labor protection measures[18].

5.2 Analysis of working conditions in the workplace

As an important base for scientific research and personnel training, laboratories are full of potential safety hazards. Because of the use of a variety of dangerous chemicals and various types of electrical equipment, and often involves high temperature, high pressure, vacuum, radiation, magnetic fields, bright light and other dangerous factors, coupled with the use of a narrow laboratory area per capita, laboratory personnel work long hours easily fatigue, many safety hazards so that laboratory safety issues can’t be ignored.

Inevitably in the experimental process to contact some flammable, explosive, toxic, harmful, corrosive substances, and often use water, gas, fire, electricity, etc., such as explosions, fire, poisoning, burns, cuts, electrocution and other dangerous accidents, these accidents often bring us serious personal injury and property damage[19].

The laboratory should be designed to accommodate 5-8 people, the total area should be not less than 100 square meters, different experimental equipment should be placed in different work areas, and there is a certain interval distance. The placement of experimental equipment should be in accordance with the requirements of the equipment operation manual.

The main unsafe factors that can arise in the experiments described in this paper are:

-Radiation Intense radiation is generated during the ray detection experiment

-Noise Various equipment running due to friction between parts, collision vibration generated noise

-Fire Risk of fire caused by short circuit and spontaneous combustion of electrical equipment

The working area of the laboratory should be in a dry, ventilated environment, and there should be a safe distance between the experimental equipment and the operator, while fire-fighting facilities should be available.

5.3 Labor protection measures

Because NDT involves electric current, magnetic field, radiation, ultraviolet light, lead vapor, solvents and dust, the operation may be at high altitude, in the field, or into the container loaded with flammable materials toxic, so NDT personnel must master the knowledge of safety and protection, both to work safely, to protect their own safety, and to avoid equipment and the personal safety of others. Therefore, the development of this protection protocol.

5.3.1 Radiation protection

Radiation staff must obtain a radiation staff card before they can go to work, no card shall not go to work. Operators must first understand the performance of the detection machine and operating procedures. The staff must be properly worn during the work of flaw detection There must be a security guard with a ray dose alarm around the "relative danger zone" to prevent others from accidentally entering the ray zone and generating overdose exposure. Before the high voltage must check whether all the personnel evacuated "relative danger zone" is strictly prohibited to open the machine, the patch personnel must carry the radiation dose alarm, open the machine, should slowly increase the pressure, current.

When an accident occurs, the person concerned should promptly report to the unit and the local radiation protection agencies and take appropriate measures to minimize and eliminate the harm and impact of the accident, promptly report and accept the supervision and investigation of radiation health protection agencies.

Operators must be regular health checks, check suffering from indications, should be immediately transferred from the radioactive flaw detection positions, and should comply with the following provisions:

1 radiation operators, internal and external exposure dose sum reaches or exceeds 3/10 of the dose limit, then an annual physical examination.

2 below 3/10 of the annual dose limit, every 2 to 3 years, a medical examination.

3 Radiation dose equivalent limit value (per person): one year: 5 roentgens; one month: 0.4 roentgens; one daily: 0.016 roentgens.

To reduce X rays and other radioactive rays, the dose of radiation exposure to the inspector. The following regulations should be observed.

1 Before operation, testing personnel must wear ray-protective clothing made of lead plates, wear anti-radiation containing lead goggles and personal radiation dose pen, and the dose of irradiation to the testing personnel are supervised one by one.

2 To reduce the dose of radioactive exposure, on the basis of ensuring the quality of detection work, try to shorten the exposure time.

3 Try to increase the distance between the operator and the radioactive source.

5.3.2 Surface flaw detection safety

a. Penetrating flaw detection agent used in penetrating flaw detection, in addition to dry powder developer, emulsifier and metal spray cans used in the Freon gas is non-combustible substances, most of the other are combustible organic solvents. Therefore, in the use of these combustible penetrating flaw detection agent, must be the same as the use of ordinary oil or organic solvents, should take the necessary fire prevention measures.

b. Storage of penetrating flaw detection agent containers should be covered and sealed storage location should be selected cold and dark, and avoid smoke and fire, hot air, direct sunlight, etc. Pressure spray cans are strictly prohibited in high temperature storage, because at high temperatures, the pressure in the tank will increase, there is a risk of spontaneous combustion explosion. Because the pressure spray cans filled with penetration probe at the same time, but also filled with propane gas or Freon and other high-pressure liquefied gas, penetration probe itself is a combustible material, filled with propane gas, the possibility of fire is greater, it becomes a highly combustible material so the operation of pressure spray can products, must pay full attention to fire prevention.

c. When using flammable penetrating agents, not only must pay full attention to fire prevention, but also in case of emergency, fire extinguishers should be installed at the operation site and penetrating agent storage.

d. Avoid operating in the vicinity of flames and in a hot environment, and special attention should be paid if the ambient temperature exceeds 50°C. The presence of open flame is prohibited at the operation site.

e. Penetrant probes using organic solvents are often harmful to humans, therefore, active health and safety precautions should be taken. The work site should be equipped with additional necessary ventilation devices to reduce the concentration of toxic substances in the workplace air.

f. Configure personal protective equipment, such as masks, gas masks, rubber gloves, protective clothing, protective glasses, etc.

g. When using fluorescent detectors, the exposure of the operator to strong ultraviolet radiation should be limited to prevent the eye from being in black light resulting in ocular fluorescence effect. If the black light shield rupture failure, shall not be put into use.

h. Magnetic particle inspection equipment grounding insulation resistance to meet the standard requirements, to ensure that the equipment in the absence of short circuit and wiring without loose use, especially when using water magnetic suspension, poor insulation will produce electric shock injury.

i. The oil-based carrier fluid, fluorescent magnetic powder, wetting agent, rust inhibitor, defoamer and solvent in the magnetic suspension, as a combination, long-term use will remove the natural oil in the skin, causing skin dryness or irritation, magnetic suspension into the mouth and eyes will stimulate the eyes caused by the throat and stomach reaction, so you should avoid breathing too much of the solvent vapor.

5.3.3 Darkroom operation regulations

1 The layout of the instruments and electrical equipment and flushing equipment in the dark room should be implemented for positioning management. Electrical insulation must

be reliable and there should not be any exposed conductors.

2 The dark room should have air conditioning equipment, must maintain good ventilation.

3 dark room work must be more than two people collaborative operation, one person is strictly prohibited to work alone.

5.3.4 Exposure room operating regulations

1 exposure room shielding thickness, must comply with the "basic standards of radiation health protection. The door of the exposure room must be equipped with a chain safety device to ensure that the door does not open when exposed. If the door is opened, the radioactive source automatically returned to the storage position or cut off the power supply.

2 exposure room must be equipped with warning signs and red lights outside the door. Red light must flash when running, prompting non-flaw detection personnel must not be close to the exposure room.

3 exposure room should be exhaust devices, timely exclusion of ozone generated within the exposure chamber.

5.3.5 Magnetic particle testing operating regulations

1 magnetic particle flaw detection test before, must check the magnetic particle flaw detection machine power and probe connection line insulation is good, there must be no bare.

2 flaw detection machine shell must have a reliable grounding, shall not be loose.

3 operation test, must wear protective glasses and rubber gloves.

4 magnetic suspension shall not be sprayed on the probe coil, shall not be sprayed to the lighting and its electrically charged parts.

5.3.6 Operating safety guidelines

1 A variety of equipment and instruments shall not be overloaded and run with disease, and to do the correct use, regular maintenance, regular maintenance.

2 Electrical equipment and lines should comply with the relevant national safety regulations. Electrical equipment should be fusible insurance and leakage protection,

insulation must be good, and have a reliable grounding or zero protection measures.

3 Equip and issue personal protective equipment for laboratory personnel, and properly wear labor protective equipment as required.

4 The newcomers must first carry out safety production of the three levels of education that (production units, departments, teams) before they are allowed to enter the operating position.

5 Laboratory operators must be trained in professional safety techniques and be allowed to operate independently only after strict examination.

6 Accident handling, accident scene personnel should immediately rescue the injured, protect the scene, and report to the unit leader.

5.4 Fire safety at the production site

Electrical failure is one of the major causes of fires. The laboratory uses a large number of various types of electrical equipment. Electrical equipment overload, short circuit, broken wire, loose joints, poor contact, insulation decline and other faults will generate electrical heat and electric sparks, igniting the surrounding combustible materials. Fire safety measures to do the following.

5.4.1 Strict implementation of operating procedures

Strict implementation of operating procedures is the most basic and reliable means of good laboratory fire prevention. Laboratory first of all, according to the nature of various types of experiments, based on accumulated experience, the establishment of scientific experimental safety operating procedures. Experimenters should be familiar with the nature of the substances used, the factors affecting and the correct way to deal with accidents; understand the instrument structure, performance, safety operating conditions and protection requirements, strictly according to the protocol. Experiments to modify the protocol, must be a small amount of scientific proof of the experiment, otherwise no changes.

5.4.2 Flammable and explosive hazardous materials operation of fire prevention requirements

Operation, pouring flammable liquids, should be away from the source of fire. Hazardous, such as ether or carbon disulfide operation, should be carried out in a fume hood or protective cover, or set up a vapor recovery device.

Hazardous operations such as those that emit flames, corrosive substances, poisons and explosives, the mouth of the container should be directed to an unoccupied place. When opening the reagent bottle, the mouth of the bottle should not face the human body; if the room temperature is too high, the bottle should be cooled first.

Contact with incompatible substances, such as oxidizers and flammable substances, which can cause fire and explosion accidents, should not be ground together. Peroxide and potassium shall not be weighed with paper.

Set up a special receptacle to collect waste liquid, waste, can ‘t be placed indiscriminately, so as not to cause ignition and explosion accidents.

5.4.3 The use of heating equipment fire prevention requirements

When lighting the gas lamp, no flammable and explosive substances shall be placed nearby. To prevent gas explosions, should be lit in the prescribed order, extinguish the gas lamp. The order of ignition is: close the wind, ignition, open the gas valve, adjust the air volume. Turn off the light order is: close the wind, close the gas valve. When the gas is stopped, all switches should be closed. Gas system should be tight not to leak, gas pipes, lamps and lanterns should be checked diligently, leaks should be repaired in time, not to be used until repaired. Prohibit the use of flame on the gas pipe to find the leak, the application of soap to check. Combustible gas concentration meter can be used to determine the content of gas and other combustible gases in the air to determine the degree of danger.

When using alcohol lamps and alcohol blowtorches, the amount of alcohol added should not exceed 2/3 of the capacity of the lamp, do not pour full to prevent alcohol spillage. Should be lit with a match, do not use another burning alcohol lamp to point, in order to avoid misfire. The flame of the burning lamp should be covered by the lamp cap to prevent the alcohol in the lamp from burning. The amount of alcohol used in the lamp to about 1/4 capacity, that should be added to the alcohol, so as to avoid an explosion in the bottle.

Baking materials with electric oven, should be based on the physical and chemical properties of the material to be baked strict control of baking temperature and time. The oven should be with automatic temperature control device, and should pay attention to check whether its work is reliable, so as to avoid control failure and cause accidents. It is advisable to gradually increase the temperature when heating up, to avoid heating up too fast. Objects with flammable liquid shall not be put into the baking. Flammable and explosive substances are strictly prohibited to be put into the baking. At the end of the work or power failure, the power should be cut off to prevent long operation, the temperature rises and ignite the material.

Commonly used small electric furnace, its electric heating wire exposed, can not be used to form a flammable vapor material heating. When using electric furnace heating, should pad asbestos wire mesh, so that the heated material is heated evenly. When melting paraffin, rosin and other combustible materials, special attention should be paid to control the temperature to prevent a large amount of smoke or heat temperature exceeds the self-ignition point. Heating easily tender liquid, the application of liquid bath, oil bath temperature shall not exceed the self-ignition point.

High-temperature electric furnace should be equipped with a temperature controller, if necessary, should be equipped with alarm devices, control failure shall not be used. High-temperature electric furnace shall not be placed around combustible materials, corrosive materials and other dangerous items to prevent fire or accidents due to corrosion of the furnace body. Fusible, combustible, volatile, corrosive, explosive materials shall not be placed in the furnace heating. Specimens should be suitable for high-temperature vortex, wrapped with filter paper wet precipitation should be dried, ashing and then sent into the furnace burning. Melting samples should be based on the nature of the solvent reasonable choice of citrus vortex material. To prevent staining, the bottom of the chamber should be filled with asbestos sheet.

Soldering iron operation, should be set aside on a non-combustible base away from flammable materials.

5.4.4 The use of electrical equipment fire prevention requirements

All types of electrical equipment in the laboratory should be strictly managed, the laying of electrical wiring, installation, protection and maintenance of electrical equipment should be strictly enforced by the relevant national norms.

Some electrical equipment with high power, the use of attention should be paid to prevent overload. Wiring should be solid, insulation should be good, switches, wires should meet the requirements, and it is appropriate to use a separate power supply line.

The electrical facilities of laboratories that often use flammable and explosive gases and liquids should meet the overall explosion-proof requirements.

Electrical equipment and lines should be inspected and updated in a timely manner to avoid operation with hidden dangers.

5.4.5 Strengthen fire safety management

If any flammable material stains the body surface during operation, it should be washed off immediately and should not be near the fire. If there is an oxidizer stained clothing, should also do so, otherwise a little heat is easy to catch fire.

Burning the remaining match stems, do not throw or throw into the waste bucket, should make completely extinguished, before you can be disposed of in the bucket.

Burning equipment should not be placed on combustible materials such as rubber, plastic or paper, but should be placed on non-combustible objects such as asbestos sheets away from combustible materials.

Operation of explosive hazardous substances, should not use the grinding mouth glass bottle, so as not to cause explosive accidents due to friction sparks when opening and closing the grinding mouth plug. Cork, rubber stopper or plastic stopper can be used.

Operation of combustible materials or heat decomposition of goods in the laboratory, should be hung curtains to prevent sunlight. Do not put flammable substances and glassware in the daylight to prevent localized hyperthermia due to the focusing effect of the glass bending surface and cause an explosion.

5.4.6 Pay attention to the fire extinguishing

For the initial fire, you should first extinguish all nearby sources of fire, cut off the power supply, remove combustible materials. Small containers of material on fire can be covered with asbestos or wet rags to extinguish the fire.

Larger fires should be extinguished with fire extinguishers according to the nature of the material on fire. Thousands of dry sand, asbestos blanket because of the isolation of the air to extinguish the fire, for the fire can not be extinguished with water.

Carbon dioxide fire extinguishers, suitable for extinguishing oil and advanced instruments and instruments on fire; dry powder fire extinguishers for extinguishing oil combustible gases, electrical equipment and precision instruments on fire.

Carbide, phosphate fires, can not be extinguished with water-based fire extinguishers.

Conclusion to part 5

Based on the analysis of the experimental equipment and laboratory environment, this chapter identifies the possible risk factors during the experiment and proposes the rules for the safe use of experimental equipment. It also gives the response in case of danger and the response to fire.

GENERAL CONCLUSIONS

Recommendations on the single crystals fatigue indicators application for the Chinese aviation industry have been developed on the base of experiments carried out at National Aviation University.

To gain this purpose the following task have been solved:

- The problem of aircraft fatigue have been analyzed;
- The contemporary concepts of aircraft design were described;
- Two approaches of the fatigue analysis were compared, namely direct investigations of metal state and application of the attachable indicators;
- The ways for the sensitivity optimization of the fatigue indicator have been substantiated on the base crystallographic nature of plastic deformation;

The recommendation of the single crystal fatigue indicator implementation into the Chinese aviation industry has been formulated.

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