A Life Estimation Method of Helicopter Transmission System Key-parts

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Abstract. In order to determine the life of helicopter transmission system key-parts accurately, a method using strain as the fatigue characteristic parameter is proposed to obtain the life span in this paper. It mainly includes the determination of the strain test points on the key-parts and predicting life span of the helicopter transmission system. Strain data is obtained in the joint ground test and the flight test. The judgment criteria for decomposing inspection of the test components is determined, according to the data of the ground joint test and the flight test in multiple load cases and states. The acquired data is analyzed to monitor change of the strain value and the cumulative fatigue damage value in real time. The life span of the key-parts can be determined by revising the predicted data and measured data. The advantage of this method is that it can obtain a relatively accurate life span of the components in variable and complex load situation. The method has been successfully applied in a self-developed helicopter transmission system.

1. Introduction
To obtain the life of the key components of the helicopter transmission system is a vital technology in aeronautical field. It is directly related to the success of the development [1-2]. The main reason of mechanical failure in helicopter transmission system is that life span of the key components is hard to decide precisely. Therefore, accurate life determination is an important task to be solved urgently in the development of helicopter technology. And various methods are researched to improve the accuracy of helicopter transmission system components life at home and abroad, such as nominal stress method, structural fatigue rating method, local stress and strain method and high and low cycle fatigue components life-span calculation [3-7]. In recent years, fatigue life determination technology in entire life cycle has been used for helicopter transmission systems [8]. These methods and techniques use load as a parameter of fatigue characteristic to evaluate the life of helicopter transmission components, which has theoretical guidance and practical significance to the development, use, maintenance and life span determination of the helicopter transmission system. However, due to the complicated surface shape of the helicopter transmission system components and the complex and variable flight load and conditions, the current methods and technologies cannot ensure that there is no fault in flight. Particularly, the life span of the unfinished parts cannot be accurately determined during the test flight. This is undoubtedly a major hazard to flight safety. Although researchers can roughly predict the life of the transmission system components through the finite element calculation, static test and fatigue test. The accuracy of life span is not high. For reducing the risk of flight, components disassembly inspection has been carried out usually after a period of flight. However, researchers cannot timely grasp force and damage situation of the in-flight components between two disassembly inspection. Especially the specific weak links cannot be found in time, and the exact source of the fault...
is difficult to be found quickly when the fault occurs. Therefore, how to assess life accurately of the helicopter drive system key components under a variety of loads conditions has become an urgent technical problem.

2. The method of determining life of the key components for helicopter transmission system based on strain measurement

The method is used to solve the technical problem of determining the key components’ life of a helicopter transmission system under complicated conditions. The flow chart, main steps, instructions and precautions of the new method are described below.

2.1 Process flow chart and procedure.

The method of determining life of key components for the helicopter transmission system based on strain measurements is as follows.

- Determine the strain test point
- Obtain strain data from each strain test point
- Determine the breakdown inspection standard for key components of the helicopter drive system
- Monitor each strain test point for each test helicopter in time.
- Correct the estimated life value to obtain the correct life value

Fig.1 transmission system fixed life flow chart.

2.2 Determination the strain test point.

According to the ground joint test and flight test of the helicopter to be tested, researchers will determine multiple strain test points and give estimated data of the life for the helicopter transmission system components to be tested and the monitoring limit value of the strain gauge. The determination of strain test points is based on finite element calculation and results of static test and the fatigue test. The selected points are the points that can best reflect the typical flight state or crack positions in the static test or fatigue test. Estimated parts life expectancy and strain monitoring limits are obtained by dividing the fatigue test results for the same parts of the helicopter drive system components by the safety factor greater than 1 respectively. The parts monitoring limits are divided into five levels. The five levels are the part fatigue life monitoring limit, the 50-hour monitoring limit, the 10-hour monitoring limit, the 5-hour monitoring limit, and the 1-hour monitoring limit.

2.3 Acquisition of strain data

During the ground joint test and flight test, strain data is taken from each strain test point. Strain data acquisition includes: install strain gage at a determined strain test point; determine strain gage storing methods (telemetry and / or direct storage) based on the strain gage installation environment and the number of strain channels ; judge the reliability of stored signal of strain data, remove the signal glitch,
and according to time period analyze the maximum static value and the maximum dynamic value of strain.

2.4 Determination of the inspection criteria
According to the joint test and the flight test of the helicopters under various states and load conditions, determine the disassembly criteria of the components in the helicopter. It refers to the monitoring limit value reaches 1 hour limit value many times or component cumulative fatigue damage value reaches the predetermined value.

2.5 Strain data monitoring
Measured data of helicopter transmission system components is analyzed, and strain gauge value over monitoring limit value at each strain test point as well as cumulative fatigue damage value are timely monitored and analyzed. The cumulative fatigue damage value of the components is obtained by using all the over-limit parameters of the helicopter transmission system components rain flow method. At the same time the rainfall-flow method is used to obtain the component cumulative limit value, the stress-strain correspondence graph, the four parameter SN Curve equation and Miner cumulative loss method are used too. When the component monitoring limit exceeds 1 hour limit, it determines that the current test helicopter exists a security risk and should display a warning signal to tell people to focus on the current corresponding strain test point. Testers use dedicated analysis software to calculate the static strain and dynamic strain at each strain test point of each helicopter to be tested. Based on the monitoring limits, we can determine whether each strain test point is overrun which includes exceeding the component monitoring limits and the duration and overrun limits. The cumulative fatigue damage value of the component is calculated by computing the strain test point of the over-limit through the fatigue damage calculation formula. When the strain test point component monitoring limit value is more than 1 hour monitoring limit value, at this moment, the method stipulates that the helicopter to be tested shall suspend the flight, then break it down and check for any problems. Besides, focus on inspection of weak areas reflected in helicopters to be tested during fatigue tests or flight tests. Or when the damage accumulated value of the helicopter to be tested has just reached 1, the cracked component is found through disassembly inspection, which shows that the safety margin of the current component is not enough, and the structural design of the current component needs to be improved.

2.6 Corrected life value
Combined with the test results in step 1.4 and the measured data in step 1.5, compare and correct the estimated data in step 1.2 to obtain the correct value of life. Corrected estimated life expectancy includes: the measured strain results according to the ground joint test and flight test carried out under various conditions and a variety of load conditions, disassembly test results and comprehensive correction of similar components life. The corrected result is the life of helicopter drive system components.

2.7 Main explanation
A description of the key factors and key methods of the key components of a helicopter drive system is given below.

2.7.1Selection of safety factor
To ensure flight safety, the safety factor for the key components of the helicopter drive system is based on Table 1 and Table 2. Table 1 is apply to low-cycle fatigue test, and Table 2 is apply to high-cycle fatigue test.

| Number of specimens | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------------|---|---|---|---|---|---|---|
| Table 1 Life reduction factor (applicable to low cycle fatigue) |   |   |   |   |   |   |   |
Table 2 Safety factor of fatigue strength

| Number of specimens | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------------|---|---|---|---|---|---|---|
| Aluminum alloy      | 3 | 1.74 | 1.67 | 1.64 | 1.62 | 1.61 | 1.60 |
| Steel and titanium  | 3 | 1.49 | 1.45 | 1.43 | 1.41 | 1.41 | 1.40 |

2.7.2. *four-parameter s-n curve equation.*
The equation of the four-parameter s-n curve is as follows [8]:

\[
\frac{S}{S_1} = H + A(N + C)^n
\]

In the formula: \( S \) – strain, \( N \)– number of load cycles; \( S_1 \)– fatigue limit.
\( H \), \( A \), \( C \), \( B \) -- material constants, namely "four parameters" in the four-parameter method. Please read the literature [8] in detail.

2.7.3. *Dedicated analysis software*
In the independent development of helicopter transmission system, our research institute independently has developed a powerful dedicated large-scale data analysis software, it can analyze various flight conditions, perform statistical analysis on acquired loads, vibrations, temperature, scrap metal and other signals, make early warning based on the gathered information, and evaluate the use condition and remaining life of each part.

2.8. *Precautions*
Considerations for the methods are as follows.

The method is suitable for determining the life of key components of a new type of helicopter transmission system. It takes a long period and takes various actual situations into consideration. Although more funds are invested in the earlier stage, the method has the advantages of high flight safety and lower follow-up cost.

Determining the number and location of test points not only needs to consider the actual situation of the flight state changes, but also requires the use of theoretical calculations, material sample test, and full-size component fatigue test results. Theoretical calculation and experimental verification comply with load and load spectrum determination method, strength and longevity calculation method and fatigue strength design criteria, as well as fatigue life validation criteria. Monitoring limits can be adjusted according to the actual situation of disassembly inspection. When using this assessment method to determine the critical stress points, the test points selected in each case are not less than 1, and the test points in the typical state are not less than 5.

When the measured life value is lower than the technical requirements, the components can reduce the required use, while the life value must be further reduced according to the actual flight situation, it is recommended to follow the measured life value of 50% for use. If the measured data is greater than the expected life expectancy, the actual use is still used in accordance with the development of life, but it can extend the decomposition inspection time.

3. *Applications*
Take the life of the helicopter tail gearbox casing as an example to illustrate the specific application of this method.

3.1 *Determination of the tail reducer casing strain test points and test methods*
Take the tail gearbox, which is an important part of the transmission system, for example, some of the
key stress measurement points determined by the ground joint test are shown in Figure 1, where S5 is the maximum stress measurement point under unfavorable conditions, and S12, S13 and S15 are the measuring points that can reflect typical flight conditions, and S16 are test points to consider for other reasons. Because of the large number of test points, direct measurement is used to obtain strain data.

![Image of test points](image.png)

Fig. 2 Test points of tail gear box.

3.2. Acquisition of the tail gearbox life.
Using the dedicated analysis software, according to the monitoring limit values in Table 3, the rainstorm method is used to calculate the cumulative damage value for the strain test points exceeding the fatigue limit \(^9\). According to Table 4, the cumulative total damage at S13 reaches 1, check the casing. The test results showed that the tail gearbox casing had broken, indicating that the margin of casing safety is not enough, and the actual life expectancy is slightly lower than the expected life expectancy. After a comprehensive analysis of all the available facts, the revised life expectancy is 80% of the life expectancy, and the actual safety life used is given at 40% of life expectancy.

| Parameter | Fatigue limit | 50 h | 10 h | 5 h | 1 h |
|-----------|---------------|------|------|-----|-----|
| S13, S15, S16 (\(\mu e\)) | 279 | 314 | 342 | 360 | 420 |
| S5 (\(\mu e\)) | 192 | 219 | 243 | 258 | 309 |
| S12 (\(\mu e\)) | 252 | 301 | 323 | 349 | 406 |

| Parameter | Previous cumulative damage | Current damage | Cumulative total damage |
|-----------|----------------------------|----------------|------------------------|
| S5        | 2.1e-08                    | 0.68           | 0.68                   |
| S13       | 8.9e-07                    | 1              | 1                      |
| S15       | 0                          | 0.47           | 0.47                   |

3.3. Countermeasures
After obtaining the life of the tail gearbox casing, countermeasures are as follows.

The actual life expectancy obtained is submitted to the design department, if the measured life expectancy value is lower than expected after analysis. The design department shall manage the tail gearbox casing which has been processed and manufactured according to the revised life value. To ensure safety, its monitoring limits at all levels must be properly reduced and the disassembly inspection interval is reduced correspondingly.

For critical components with lower life expectancy, the design department redesigns components...
based on the data obtained from stress monitoring and the results of the disassembly inspection. The actual life expectancy of gearbox casing obtained of this paper is slightly lower than the expected life, indicating that the design is basically reasonable and only partial improvements are needed. Improve the design of the tail gearbox casing, and the specific improvements are seen in the "The design improvement of a helicopter tail reducer casing [10]. After field test flight verification, its life value is greater than the technical requirements. When the key components fail in advance, the revised life expectancy value is lower than expected, indicating that the design is not reasonable, requiring major changes. When measured life of the tail gearbox casing after design improvement is greater than the development technical requirements, and the actual use is more than the development technical requirements which needs to extend the service life, more rigorous test validation should be carried out.

In service for 6 years, the key components of the transmission system has not had early failure cases, receiving the user's good evaluation. This ideal result shows that the method of determining the life of helicopter transmission system based on strain measurement has good usability and high engineering value.

4. Comparison of the life determination method based on strain measurement and traditional method

Table 5 shows differences between strain-based and load-based life assessment methods.

| Contrastive content       | Load-based life assessment methods                                      | Strain-based life assessment methods                                      |
|---------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Load characteristics      | The load is determined, or the load contains leading component of fatigue failure. | The load is complex and changeable, and the leading component of the fatigue failure can not be found. |
| Component features        | The component is taken as a whole or several large areas without considering the difference of fatigue strength between components, and a dominant load corresponds to a monitoring limit and life evaluation value. | Considering the sensitivity of the local structure to the load, it is easy to find the main stress source. Considering the difference of the local fatigue strength and the strain direction difference of the monitoring, each key stress measurement point corresponds to the respective monitoring limit and life evaluation value. |
| Determination of crack initiation position | The exact location of crack initiation can not be accurately located | It is easy to judge the crack initiation position and improve the local fatigue design. |
| Monitoring parameters     | A single load or load leading component, the number of channels is less | Many points are measured and the number of channels is large |

5. Conclusion

In order to solve the problem in using load as the parameter of fatigue life, a method to obtain the life of helicopter transmission system based on strain measurement is proposed. It regulates the determination method of helicopter drive system strain test point, the strain test mode, the measured strain data analysis, the judgment criteria and the flow of key components life determination. The on-site flight verification and user's formal use prove that the method is feasible. The conclusion is as follows:

1) The method is suitable for accurate acquisition of the life of helicopter transmission system components under a variety of loads, multiple conditions and different conditions of use. Estimated life value is based on the nominal stress method and a comprehensive analysis of tests, it has been tested to some extent with certain accuracy; the obtained values are further tested on this basis. The
experimental data obtained from the flight test are used to improve the accuracy of the data. The large amount of data and the long-term measured data provide a solid support for obtaining the accurate values.

(2) The method is an important technical means to determine whether the function of main components of helicopter drive system fails and find the weak links of the components. It can be used as a basis for further flight decisions, considering the sensitivity of the local structure to the load, taking into account differences in local fatigue strength. In determining the strain test points, the complex conditions of the flight and the main criteria for the subsequent improvement of the design work of the guiding components are taken into consideration.

(3) In the process of research and development, it can help ensure flight safety, reduce the uncertainty of the damage to the flight of the security risks, effectively prevent the occurrence of major accidents.

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