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Fatigue crack identification method based on strain amplitude changing

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Abstract. Aiming at the difficulties in identifying the location and time of crack initiation in the castings of helicopter transmission system during fatigue tests, by introducing the classification diagnostic criteria of similar failure mode to find out the similarity of fatigue crack initiation among castings, an engineering method and quantitative criterion for detecting fatigue cracks based on strain amplitude changing is proposed. This method is applied on the fatigue test of a gearbox housing, whose results indicates: during the fatigue test, the system alarms when SC strain meter reaches the quantitative criterion. The afterwards check shows that a fatigue crack less than 5mm is found at the corresponding location of SC strain meter. The test result proves that the method can provide accurate test data for strength life analysis.

1. Introduction

It is a difficult task to identify and predict the crack timely and accurately to avoid accident for the international society especially in the engineering. Engineers engaged in helicopter transmission system fatigue test hope to have a simple engineering method which can accurately identify the crack initiation location and time. It is very difficult to know exactly the location and time of crack initiation, because there are great differences of the crack initiation location and initiation time even among the castings of helicopter transmission system in the same batch which is due to the various structures, and the time between crack initiation and crack propagation is quite short... The common situation is that no crack initiation is found during multiple disassembly inspection until the crack is expanded (See figure1), which results in the failure of meeting the test purpose. The difficulty on identifying crack initiation location leads to the incapability of providing accurate information on specifying the location for necessary improvement.

Fig.1 Coarse and long crack at tail gearbox housing slim crack at main gearbox housing

Fig.1. is the Long Fatigue crack of the casting test sample. Many methods and techniques are used to identify and analyze the fatigue crack. Through finite element analysis integrated with OHIJ fatigue life law, the period of the crack initiation was given precisely by Song Shouxu[1] . A Bayesian analysis with time-energy density was committed to give the damage state of the selected zone[2], which was proven by experimental investigation on key position of typical structure. A method for crack identification was put forward based on the differential of relative strain variation Corresponding simulation model of block was established to simulate block fatigue test according to the block structure, and based on the zero and extreme points, the crack position was identified accurately by Zhang Pengwei[3]. The fretting fatigue crack identify system was developed, which solved the problems during fatigue experiment , such as hard to observe the crack, difficult to get the right time that the crack happens, etc.[4]. The methods mentioned above are applicable to simple, regular structures or specific research object, but not universal to identify the crack in castings of helicopter transmission system with different structures. Moreover, crack identification method for fatigue test of castings of helicopter transmission system at present mainly integrates computer simulation, visual inspection and non-destructive examination. There is no simple and accurate engineering method to identify the fatigue crack of casting so far. To fill this gap, a new method for fatigue crack identification based on strain amplitude variation is proposed.

2. Classification diagnostic criteria

Many diagnostic criteria of multiple similar faults proposed by Professor Tang Deyao[5-6] are used in the new method. Whatever differences of the faults caused by load and signal transmission pathways at different working positions, only one basic line appears in the analyze spectrum which is described as a common “fault fundamental frequency”, so that the diagnosis can be simplified. In this paper, the fatigue test results of several casting models of helicopter transmission system from multiple batches are analyzed. It is found that there are great differences in the locations of cracks, the numbers of the cycles and strain peak-valley values, which are shown in figure 2~4. Figure 2 shows the time domain and the frequency domain of the main gear box by differential pressure casting in high-cycle fatigue test which has completed 270 thousand cycles, when the crack was found on the left rear face near the upper mounting face. Figure 3 shows the time domain and the frequency domain of the main gear box by differential pressure casting in high-cycle fatigue test which has completed 770 thousand cycles, when the crack was found on the front leg position of the main housing. Figure 4 is the time domain and frequency domain of the gravity casting tail gearbox housing in high-cycle fatigue test which has completed 680 thousand cycles, when the crack was found on the mounting support.

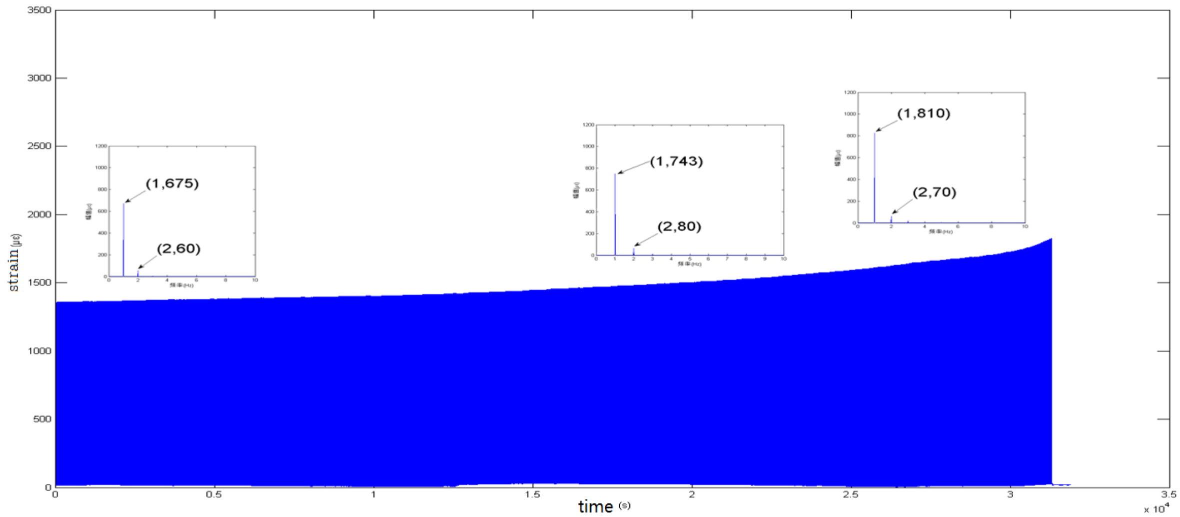

Fig.2. Crack of main gear box left rear face near upper mounting face, 27 million cycle-indexes

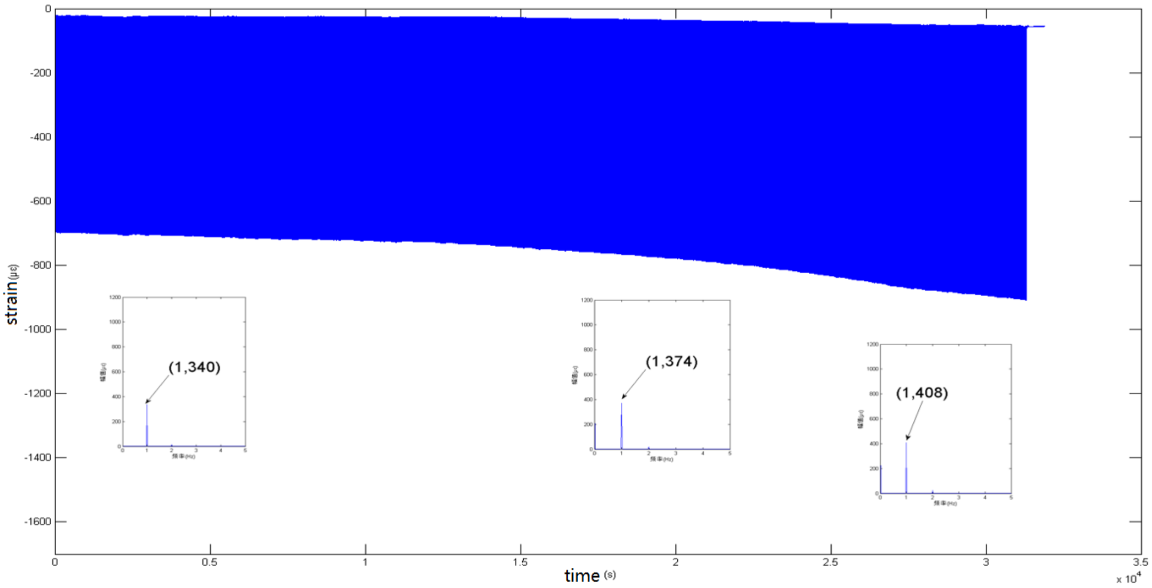

Fig.3. Crack of main gear box front leg, 77 million cycle-indexes

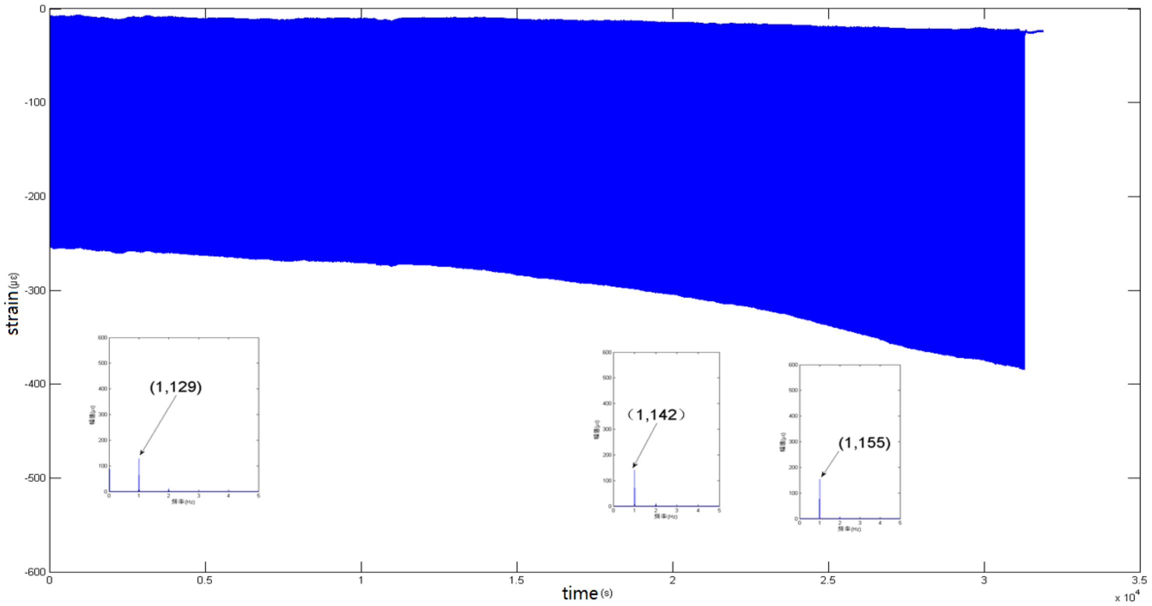

Fig.4. Crack of Engine box mounting support, 68 million cycle-indexes

Although the above faults are different with each other, there is a common rule in the FFT spectrum: the strain amplitude changes rapidly before the crack appears and the amplitude has the same varying trend, with basic frequency of 1Hz.The rule is consistent with the diagnostic criteria proposed by Professor Tang Deyao.

3. Crack identification procedures

When the fatigue damage of the specimen reaches a certain value, the crack will occur[7]. As the crack initiate, the spectrum energy changes rapidly. As the relative amplitude change of strain amplitude reaches a predetermined value, crack occurs. If the complex crack identification is simplified to monitor the relative variation of strain amplitude, which is particularly easy to realize in engineering, then the passive situation of incapable of applying many methods can’t be inverted. The procedure for identifying the crack in helicopter transmission system [8]. is as follow.

3.1. Obtain data from monitoring points

In most case, as the loads applied during fatigue test are determined, with strain gauges adhered to the specimen to obtain the strain data, the location of the crack can be identified. However, there are some differences in the dimension of the same batch of castings of the helicopter transmission system, especially the castings with complex structure. During the fatigue test, the crack initiation location and time are often different, which bring uncertainty to the test. This method makes use of strain data obtained by fatigue test instruments as the data of monitoring points, and acquires all the strain data through synchronizing the virtual channel of test instruments. The loading frequency is 1Hz, and the sampling rate is 1 kHz.

3.2. Data processing

After obtaining the data from all channels, in order to facilitate the diagnostic comparison of peak-valley value of time domain waveform, the filtering function of test instrument is used to process all the data, with primary filtration of 50Hz noise, successively of spurious tones. All the filtration is done automatically by preset instrument.

In the initial duration of fatigue test, the amplitude of peak-valley values and 1st order main spectrum of all signals are recorded as the initial value. Then peak-valley values are monitored and compared with the initial value by virtual channels. If the value varies more than 10% of the initial value for 30 to 50 times within one minute, the amplitude of the channel on FFT should be analyzed. If the 1st order spectrum relative variation exceeded 10%, the instrument sends an early warning signal in red fonts at the centre of the screen and outputs a control signal to stop the test.

3.3. Treatment of crack early warning

After the early warning signal is sent, the virtual channel outputs an alarming signal. The test and analysis personnel need to make a comprehensive analysis on the signal, upon which confirmation, put the data of all the channels with more than 10% variation between initial values and real-time values on the screen, and change the alarming threshold to 20% for 1st order spectrum amplitude. Then, restart the fatigue test, with the test operator closely observing the changes of the waveform. Generally speaking, while one peak-valley value increase, another will decrease. Since time from crack initiation to crack propagation is very short, test operators must accurately determine the authenticity of the signal. As long as the waveform is reliable, that is, the test device and test system are not malfunctioned, once the alarm comes, the test must be immediately stopped. Check the location where there are rapid changes strain value for crack by visual inspection, or other applicable crack detection inspection with specimen removed. If no crack is identified by crack detection, then continue the fatigue test. Usually, the cracking will happen anytime soon. For above mentioned 3 fatigue tests, the strain amplitude variation increased from 10% to 20% within 3 hours. Close attention has to be paid to the peak-valley values with large and increasing variation. When the relative variation of 1st order spectral amplitude exceeds 20%, cracks will be occur. The fatigue test must be stopped immediately. The specimens corresponding to figure2, figure3 and figure4 show already propagated cracks with the maximum relative variation of 1st order spectral amplitude all exceeded 20%.

4. Application Examples

The method of the fatigue crack identification method for the casting box of helicopter transmission system uses the strain gauge and strain testing system, without new equipment added. The simple program meeting identification method is inserted in the existing software meets the identification method or it you can be directly set up based on the virtual channels. The crack identification example of the casting part of helicopter transmission system shows as follows. In the actual work, a certain type of reducer casing can withstands a variety of complex loads. In order to evaluate the fatigue life, the working condition must be simulated and by multiple loading fatigue test is carried out. Fatigue test of a certain type of reducer casing adopts a multi way loading test system, which is controlled by a servo system. The system is composed of servo oil source, multi-way coordinated loading servo

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controller, upper computer, and displacement sensor [9]. In the first order of a gearbox the high cycle fatigue commissioning test, the strain amplitude of the first order frequency spectrum strain amplitude of the crack identification of the gearbox shows as follows.

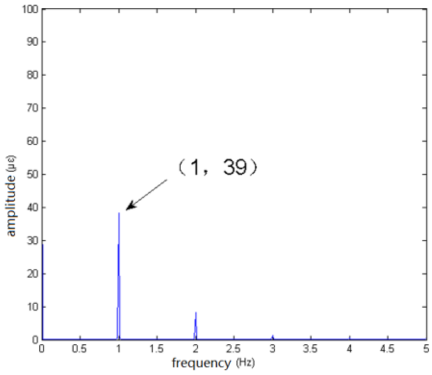

Fig.5. Initial strain amplitude of S_c

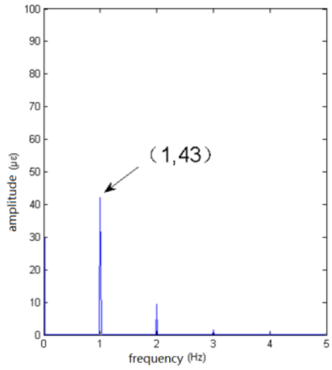

Fig.6. Early strain amplitude warning of S_c

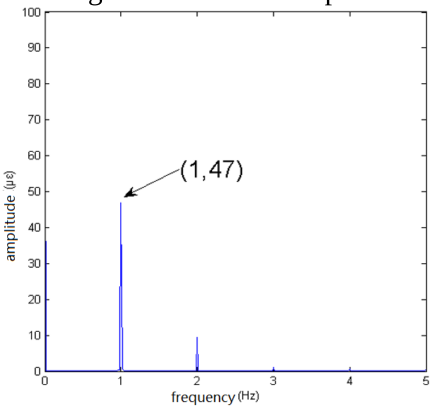

Fig.7. Alarm strain amplitude of S_c

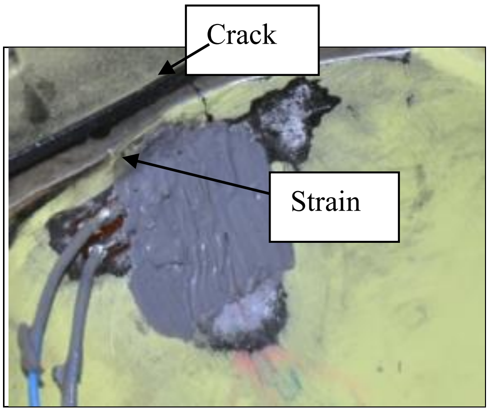

Fig.8. The crack picture

When the high cycle fatigue commissioning test of the reducer casing starts, the strain amplitude of the strain gauge S_c shows as Figure 5.When the warning signals send out, the test is paused. The strain amplitude of strain gauge S_c is shown in Figure 6, After the S_c area is checked, no cracks were is found. When the test system sends out alarm signals, the strain amplitude of S_c is shown in Figure 7, the fatigue life test stops. It was found that 4mm long crack is found around the area of the strain gauge S_c about, the specific location of the crack is shown in Figure 8.It can be seen from the monitoring process that the method is simple and effective, which is suitable for engineering application.

It should be noted that the location of the crack is not necessarily found around the largest amplitude of the strain, nor the largest strain value. The relative variation of the amplitude of the strain gauge in the vicinity of the crack is larger more, which is in line with the actual project. There are differences in the local structure of the transmission system castings. In the actual development process of several models, the results show that there is a difference of over 50% between the fatigue test results and the simulation results. This is an important reason why any theoretical analysis method must be tested and verified. What should be specially emphasized is that the method is a crack identification method is based on the common law of transmission system casting it the common law of fatigue crack, having the utility model has the advantages of high identification accuracy and strong applicability. Because of the complexity of the casting crack identification, the following issues have yet to be further studied, such as the quantitative criterion of the method which is the empirical data obtained on the basis of numerous dates. The empirical data summary method can still be modified in the practical application in the future. We strive to let the system accurately alarm before the crack is found less than 2mm accurately, meanwhile we can analyze it combined with the finite element calculation, make the criterion more reasonable and alarm timely, Whether the method is suitable for the crack identification of other test pieces needs further study.

5. Conclusion

(1) In this paper, the change of the strain amplitude rather than the maximum value is used as the sensitive monitoring factor. Crack identification is performed by monitoring the variation of the multiple strain data of the fatigue test, the crack position and crack initiation time can be obtained accurately which has more practical value in engineering.

(2) Taking the relative change of the main frequency amplitude as the judging standard, the method is suitable for the environment with serious signal interference, such as the power frequency interference, particularly suitable for dealing with the signal that the burr can't be ideally filtered and that the measurement of peak and valley of the time domain can't be implemented accurately

(3) The test equipment of this method are all conventional equipment, which is easy to operate and can stop automatically, no overhaul is needed before the warning; the labour costs can be significantly reduced.

(4) The Study of the fatigue crack identification method of helicopter transmission system is based on large number of experiment data, the method is very effective to analyze the general law of crack initiation, which is suitable for scientific research personnel people who long –term focusing on a field of scientific research personnel.

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