Research of Monitoring the Landing Gear Damage Based on the Optical Fiber Acoustic Emission Technology

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Abstract. The weld area of Aircraft landing gear often exist the fatigue cracks due to its structure characteristics and the impact force of take-off and landing. This paper based on acoustic emission and optical fiber transmission technology, and combines the idea of health monitoring, propose the monitoring technology of landing gear weld damage, and give the sensors’ layout scheme and experiment conclusion.

1. Introduction

As an important component of the aircraft, the main role of landing gear system is to support the plane body, especially bear the impact force in take-off, landing, taxiing, it is the multiple site of fatigue cracks, especially the weld area is stress concentrated area, which is easy to produce fatigue source, then develop into fatigue cracks. There are ultrasonic testing, magnetic particle testing and other commonly used detection methods, which belong to the static detection methods. The static detection methods mean that testing work could only work when the aircraft parked on the ground, it belongs to periodic detection, cannot achieve real-time damage monitoring.

Fig. 1  Weld area of airplane landing gear

Acoustic emission (abbreviated AE) is a physical phenomenon when objects rapid release elastic energy due to deformation or subjected to external effects which can produce transient stress wave. Internal stress changes in solid materials generate acoustic emission signals. Many factors cause stress changes in landing gear in the course of usage, such as dislocations, crack initiation and propagation,
fracture, no diffusion phase transition, magnetic domain wall motion, deformation of external load, thermal expansion and contraction, etc. [1]. Elastic waves emitted from these event sources reach the material surface, caused surface vibration that can be received by acoustic emission sensors, optical sensors converts the received surface vibrations into electrical signal, then the signal is amplified, recorded and processed. The acoustic emission mechanism that the material generate is observed and analyzed by received acoustic emission signal, then determine whether the material is complete and reliable.

This paper will preliminary explore that use health monitoring technology in the in-service monitoring of the landing gear weld, combined with acoustic emission technology, fiber optic transmission technology to achieve the long-term real-time monitoring of health status of the landing gear welding under work status. This will help the aircraft structure to achieve intelligent and automated monitoring, and can make structure itself discover timely the produce and propagation of damage, then reported timely the security status of landing gear to the pilot, which can effectively reduce the incidence of accidents.

2. Theoretical basis of adopting acoustic emission technique to monitor
Fatigue crack formation and propagation is also a major source of acoustic emission, especially more important for non-destructive testing. Crack formation and propagation is concerned with plastic deformation of the weld, once crack formation, stress concentrated of local area of weld is unloaded and produce acoustic emission. Fracture process of materials can be divided into three stages: 1) crack nucleation; 2) crack propagation 3) the final break, all the three phases can be strong sources of acoustic emission [2].

Concerning the formation of cracks many models have been proposed, such as the more famous dislocation pile theory applicable to brittle fracture. When applied to aircraft landing gear outer cylinder, it is believed that due to dislocation motion forward encountered obstacles at one end of slip bands, such as grain boundaries, impurities and hard particles, make the dislocation pileup and then caused stress concentration. The orthogonal stress $\sigma_c$ at the head of pileup is:

$$\sigma_c = \sigma_{cs} \sqrt{\frac{L}{c}} f(\theta) \quad (c \ll L)$$

In the formula,
$L$ --- Length of crack
$c$ --- The distance from force field accumulation to the head of pileup

According to Griffith theory, considering from the view of energy, when:

$$\sigma_c = \sqrt{\frac{4\gamma E}{\pi(1-\nu)^2}}$$

Crack generated
In the formula,
$E$ --- Young’s elastic modula
$\nu$ --- Possion’s ratio
$\gamma$ --- Surface energy

Thus, for isotropic solids, take $\theta=70^\circ$, and considering $E = 2G(1+\nu)$, the shear stress required to form the crack slip surface $\sigma_s$ is:

$$\sigma_s = \sqrt{\frac{3\gamma G}{8(1-\nu)L}}$$
Crack occurs when the shear stress $\sigma_s$ reaches the value of the above equation, $G$ is shear modus. After analyzed, the relationship between the number of dislocations $n$ on the slip surface and the shear stress $\sigma_s$, is:

$$L = \frac{Gbn}{\pi(1 - \nu)\sigma_s}$$

In the formula: $b$ —— Burgess vector

From the energy point of view to calculate the relationship of average length of crack $l$ and the number of dislocations $n$:

$$l = 0.5bn^2$$

Visible, crack length of 100 dislocations generate is approximately 0.1μm, which means that acoustic emission caused by a crack with 0.1μm length is approximately 100 times than a single dislocation glide caused. Before microscopic crack becomes macroscopic crack, the crack goes through the slow growth stage. Theoretical calculations show that the energy which crack propagation required is about 100 times to 1,000 times of the formation of cracks. Crack propagation is carried out intermittently, crack propagation step forward, the accumulated energy is released, the crack tip region of unloaded. Thus, the acoustic emission generated by crack growth is likely to be more larger than the crack formation. When the crack extends to the critical state, it comes into instability propagation stage and become fast break.

3. Fiber acoustic emission motionring testing of undercarriage weld

A. Arrangement of grating sensor Based on the above analysis, the grating sensor may be disposed in the outer tube weld of landing gear, capture the weld crack signal. Sensor arrangement mainly involves three aspects: one is how to reduce the number of sensors without losing dynamic information of structure. The other hand is the precision problem of signal acquisition, improper configuration position of the sensor can affect the accuracy of parameter identification. In terms of optimizing the sensor location, there are optimized methods based on the average mutual information (average mutual information, AMI), neural networks and genetic algorithms, etc. A third aspect is the installation position of the sensor, primarily in the landing gear and other load-bearing parts like the weld, and to fixed firmly, without affecting other parts of the aircraft [3].

The outer cylinder welds of an aircraft front landing gear were tested, the test used a total of nine fiber-optic sensor, among them 7#, 8#, 9# are SDPR triangular faces positioning to monitor the artificial defect, 1#, 2#, 3#, 4#, 5#, 6# are SDPL line positioning, to line location monitor the defect and the entire weld area. The sensor arrangement is showed in Fig.2. To facilitate observation, the weld in fig.2 is state along the axial direction of landing gear outer cylinder. Sensors is installed in landing gear outer cylinder surface by gluing way, which have no effect on the structure strength and stiffness of the outer cylinder, although the damage information inside the structure can not be accurately perceived [4].
B. Analog measurement of crack propagation signal

A certain type of 24-channel acoustic emission instrument made in Germany is used, the host gain of acoustic emission instrument is set to 20dB, threshold 40dB, the time of acoustic emission signal peaks is defined as 1000 microseconds, the impact time is defined as 2,000 microseconds, the impact lockout time is 20,000 microseconds. Loading device is the hydraulic pulsation fatigue testing machine, which simulate the load that the landing gear of the aircraft hit the ground, loading speed is 4t / s, keep 5min stable loading after reach 10t.

Use HB pencil lead breaking simulates acoustic emission sources, No. 1 position sensor is pencil broken point. Each parts measured four times and the averaged value is getted. Longitudinal attenuation measurement parts have 3cm, 5cm, 10cm, 15cm, 20cm, 30cm, 40cm distance respectively from sensors, as shown in Fig.3. The parameters of AE signal attenuation measurement results are shown in Table 1. It can be derived from Table 1, in a region close to the sound emission sensor within 10 cm, the energy of acoustic emission signal attenuates rapidly. The sound source is apart from the distance sensors 15 to 40 cm, the energy remained almost unchanged, these results demonstrate the propagation mechanism of acoustic emission wave in the weld is more complex, which is related to the special way of the weld formation. As can be seen from Table 1, as the distance between the sound source and the sensor increases, the acoustic emission energy was basically showing attenuation trend.

| Distance (cm) | 3   | 5   | 10  | 15  | 20  | 30  | 40  |
|--------------|-----|-----|-----|-----|-----|-----|-----|
| Amplitude (dB)| 88  | 86  | 80  | 79  | 75  | 68  | 59  |
| Energy       | 375 | 360 | 265 | 150 | 120 | 125 | 112 |
| Count        | 455 | 412 | 380 | 356 | 295 | 264 | 180 |
| Peak count   | 4   | 8   | 18  | 22  | 12  | 6   | 3   |
| Rise count (μs)| 10  | 18  | 22  | 30  | 40  | 52  | 69  |
| Duration (μs)| 300 | 280 | 220 | 160 | 100 | 220 | 240 |

C. Test Result and Analysis of Time Difference Characteristic Parameter

Using the time difference parameters of surface fatigue crack propagation for acoustic emission source location, there is no significant difference in the uncertainly distribution, basically meet the
normal distribution. Given the uncertainty of AE source which is located by time difference is small, it is considered the source of acoustic emission source is small, which means the location source that produce acoustic emission signal is unique, it is in the tip fracture of fatigue crack. According to material deformation and fracture law, combined with the results of testing, acoustic emission signals characteristics of each stage can be analyzed.

Elastic phase: In this phase, the weld is completely elastic deformation, after removing the load deformation will disappear completely, which is the effective range of welding work, irreversible deformation does not occur, there is no or little internal energy release, so at this stage there is basically no acoustic emission signals. Yield phase: When the stress exceeds the elastic limit, weld internal will produce crystal slip, the external representation is the plastic deformation, due to internal changes in the crystal structure, it will release a lot of energy, generate a lot of acoustic emission signals within this period and the signal energy is high.

In the upper yield point, the activity and intensity of acoustic emission signals are extremely high, amplitude, energy, etc. will reach the maximum value, in the course of upper yield point to the lower yield point, acoustic emission activity as well as amplitude and energy decreases rapidly; over the lower yield point, the signal strength and mobility as well as amplitude and energy will increase again.

Strengthening stage: After entering the strengthening phase, the ability to resist deformation of the weld has been enhanced, internal crystal structure of the material has been re-adjusted due to its plastic deformation, with the increase of force, plastic deformation also increased, this time the plastic deformation will be permanently preserved after unloading load. As a result of irreversible deformation, this stage there is still a large amount of the acoustic emission signal, and the activity, amplitude and energy of signal will be reduced gradually, but there is still a high signal intensity.

Cracking: Material cracked and then have an unrecoverable deformation, massive dislocation bit slips produce, release large amounts of strain energy, it will generate a lot of acoustic emission signals. Acoustic emission characteristics of this stage is mainly that the cracking process have a greater concentration of acoustic emission signals, the value of parameters like amplitude is big. The process of cracking ended with fracture.

The landing gear is generally in elastic stage at normal work state, in this stage there is generally no acoustic emission signal. Once entered the yield stage, weld damage begined, a large number of acoustic emission signal is produced, then strong acoustic signal is received and pilots is warned to take urgent measures to hedge, reduce losses to the minimum.

4. Conclusion and Outlook
As can be seen from the fiber optic acoustic emission test in the the weld of landing gear, if the weld cracks, in the course of their work a large amount of acoustic emission signals is produced in the acoustic source, that is crack tip, indicating that use the acoustic emission technology to monitor the weld aircraft of landing gear is feasible. Since the optical fiber acoustic emission technique involves extensive knowledge and disciplines, there are some important issues still to be studied:

(1) Comprehensive analyze stress of the welds of landing gear, and analyze various damage mechanisms, analyze characteristics of typical acoustic emission signal through experiments and field collection, establish acoustic emission signal library of landing gear weld damage, which can determine more accurately the damage of the weld.

(2) Since the landing gear noise is particularly large during operation, one of the key issues plagued the effective application of acoustic emission technology is how to effectively identify real acoustic emission signals from the background noise, the classic spectrum analysis, modern spectral analysis, wavelet analysis and artificial neural network pattern recognition are worthy of further study.

(3) The problem of sensor arrangement is worth of further research, the changes of internal signals of weld is needed to be more accurately and more fully measured, while the other structures of airplane are not affected.
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