Infrared temperature spectrum analysis of air conductor considering vibration factor

Xiangyang Yu¹, Yuliang Zhao¹, Linghong Yao¹, Shi Zhao¹, Lingu²

¹Naval Aviation University QINGDAO Brance, Shandong, 266041, China
²Engineering University of CAPF, Shanxi, 710000, China

Abstract. Through the analysis of the thermal state model of the wire, it is considered that the temperature rise is the characteristic parameter to measure the working state of the wire, which is related to the actual heat dissipation coefficient and heat dissipation surface area, and is determined by practical factors such as laying mode, operating current and thermal load, and external working condition. A method to determine its thermal state by obtaining infrared temperature spectrum is proposed, and the relatively stable temperature rise is taken as the evaluation index. The vibration condition promotes the establishment of heat exchange and its equilibrium. Different laying methods have different sensitivity to vibration and thermal stress.

1. Introduction

Air wire as the basic unit of the plane line, is the carrier of electricity distribution and transmission control signal. In the practical work, often in different ways of laying the cabin, the body through the frame. With the mechanical shock caused by the action of vibration source such as aircraft engines and manipulation of the rudder surface, the air wire will be subjected to varying degrees of wear and the insulation will reduce which cause potential risk. It is necessary to carry out the analysis of conductor performance and condition. At present, there are mainly time domain reflection, frequency domain reflection, time frequency domain reflection and infrared thermal imaging. XD series power cable fault diagnosis system of xi’an dianzi university can provide a small pulse to measure reactance, and even find the location of cable damage to realize location diagnosis [1]. In to evaluate wire, British scholar put forward the application of the discrete wavelet transform technology, to launch a small signal wire, at the end of the wire to install a sensor to the reception of the output signal, through the analysis to determine the received signal wire performance state [2], but need to be compared with the normal signal analysis, can realize judgment and positioning. With the improvement of the accuracy of infrared thermal imaging, it has become possible to accurately read the temperature distribution of the detected part through thermal imaging. In addition to its advantages such as small size, high efficiency and large area online monitoring, it plays an increasingly important role in line detection and fault diagnosis [3-6]. Some domestic experts and scholars have begun to fault diagnosis for mechanical and electrical equipment of ability and its influencing factors were studied, such as setting the infrared technology to the fault diagnosis ability evaluation index, has put emphasis on access to the device under test temperature distribution and the temperature of the point of failure, as for identifying the cause of the problem, influence factors and the failure degree of important basis [7-9].

Plane cable actual installation method, the author of this paper, the selection of laying on the typical and common model, set up the experimental platform, the conductor electricity experiment under different current status, and on the experiment platform with vibration meter as active incentive, the selection of parts is measured by infrared thermal imager, respectively, in the presence of vibration...
conditions, by setting, the status of the boundary conditions and access to state information of each measurement point is characterized by temperature parameters, analyze the differences, and extract the evaluation index.

2. Wire thermal state model

In the actual trend path, the air conductor will generate thermal effect under a certain current flow, and its thermal state will be regional. Wire conductor through the insulation materials, inner core wire wrapped, laying path to transfer heat, its temperature is usually higher than the environment temperature, after a period of time to reach thermal equilibrium, the actual thermal state model, influenced by various factors, it is difficult to accurately calculate, the related influence factors to determine the general approximate values by experimental method. Most of the heat generated by the wire (80% ~ 90%) is usually dissipated by convection. The remaining heat is almost all dissipated by radiation, and the insulation layer surface of the conductor and the laying environment conduct heat transfer by natural convection. When heat and heat dissipation reach a thermal balance, the temperature distribution tends to be stable.

Ignoring the effect of temperature on the conductor’s direct current resistance, when there is a current I through the wire, there is electrical energy converted to heat energy. Part of the heat generated by current I in time dt is used to heat the wire, and the other part is used to heat the surrounding medium in the form of heat. The heat balance equation is:

\[ I^2R \, dt = K S (\theta - \theta_0) \, dt + G C d \theta \]

Where G is weight of wire, C is specific heat capacity, \( \theta_0 \) is temperature of the surrounding medium of the conductor, \( \theta - \theta_0 \) is temperature rise of wire, S is cooling surface area of wire, and K is heat dissipation coefficient.

When the initial conditions are substituted, \( t=0 \), \( \theta = \theta_0 \) then:

\[ \theta = \theta_0 + \frac{I^2R}{K S} \left( 1 - e^{-\frac{t}{T}} \right) \]

Temperature rise \( (\theta - \theta_0) \) is a characteristic parameter to measure the working state of the wire, which is related to the actual heat dissipation coefficient and heat dissipation surface area of the wire, and is determined by practical factors such as laying mode, operating current and thermal load, and external working condition. The thermal state of the wire can be determined by obtaining its infrared temperature spectrum in real time.

3. Experimental scheme

Considering aircraft cable actual installation way, the selection on line, line and allowance, laying model of 16 kinds of typical and common, construction of experimental platform for the main body, with different heat load current, and the vibration meter as active incentive, the selection of parts is measured by infrared thermal imager, respectively, in the presence of vibration conditions, through the boundary conditions and set, the status of the state information for each measuring point.

Considering that the vibration source on the aircraft mainly comes from the engine, conducted through the fixed structure such as the compartment in the engine room, the vibration amplitude of the nose part is slightly smaller, while the vibration amplitude near the engine part is larger. In order to make the vibration effect conform to the actual situation, the vibration meter is installed in the center of the platform. The vibration value of the vibration area is shown in table 1.
Table 1. table of vibration values in the vibration area of the experimental platform.

| Group | Current (A) | Upper left vibrational value (m/s²) | Central vibration value (m/s²) | Lower right vibration value (m/s²) |
|-------|-------------|-------------------------------------|-------------------------------|----------------------------------|
| 1     | 0.5         | 2.6                                 | 2.4                           | 2.7                              |
| 2     | 1.5         | 2.6                                 | 2.4                           | 3.1                              |
| 3     | 2.7         | 2.8                                 | 2.4                           | 3.1                              |
| 4     | 3.5         | 2.8                                 | 2.4                           | 3.0                              |
| 5     | 4.4         | 2.8                                 | 2.4                           | 2.9                              |
| 6     | 5.5         | 2.9                                 | 2.4                           | 2.9                              |
| 7     | 8.8         | 2.9                                 | 2.4                           | 3.0                              |

The measuring instrument used in this experiment is FLUKETi400 infrared thermography, with measuring accuracy of ±2℃ or 2%, The emissivity is epsilon=0.9, the ambient temperature is t0=15 ~19 C, and the air humidity is 50%. The indoor environment factors such as solar radiation and wind power are not considered. Test sample selection of 0.75 mm copper core PVC heat conductor, the nominal pressure values 450/750 V, resistance around 0.01 Ω/m, external rated working voltage of 27.5 V. Given that the working current of the electrical equipment on board is relatively large in the range of 5 ~ 7A, usually no more than 10A, the working current (applied stress) in the experiment is regulated by the power sliding rheostat, the specific given value is shown in table 2.

Table 2. operating currents in different states.

| State | State2 | State3 | State4 | State5 | State6 | State7 |
|-------|--------|--------|--------|--------|--------|--------|
| Working current (apply stress)(A) | 1.5    | 2.7    | 3.5    | 4.5    | 5.5    | 8.8    |

Part of the aircraft skin as the background to complete the wiring, wiring wiring terminal between the lines in series processing; The external power supply is loaded on the wiring terminal through the distribution end, and the output current is adjusted through the sliding rheostat to change the thermal load at the load (wiring) end. The vibration excitation is physically isolated from the electrical control part of the wiring platform. During the experiment, data were collected once at an interval of 20min, and the continuous power supply time was generally 2h.

4. Data processing and analysis

4.1. Regional temperature spectrum

As shown in figure 2, the three-dimensional numerical diagram of the junction line near the terminal shows obvious thermal characteristics. In the regional temperature spectrum distribution and gradient spectrum, the branch shape distribution is obvious near the terminal end, and the temperature trend along the terminal end is obviously upward. The temperature at the junction line is higher, and the highest temperature is near the junction line end, and the temperature level is obvious. The results show these thermodynamic characteristics very well.

(a) regional temperature spectral distribution map (b) regional temperature spectral gradient map

Figure 2. Temperature spectrum of the area near the measurement point P
4.2 Vibration condition temperature peak $T_{max}$ map

The state information is obtained by means of evaluation, and the temperature variation of different laying methods accumulated over time under different current and thermal loads, and the vibration factor is taken into account, that is $T = F(I, P(n), t)$, where $I$ is the current value, $P(n)$ is the measuring point, and $t$ is the acquisition time.

Figure 3 to Figure 5 show the comparison of temperature peak $T_{max}$ under different conditions. As shown in FIG. 3, when $I=1.5a$, each measurement point gradually increases with time. When $I=0.5a$, the fluctuation amplitude decreases. The measurement point 4 has large fluctuation. As shown in figure 4, when $I=4.4a$, each measurement point shows a gentle upward trend with the accumulation of time, but there is a certain volatility. When $I=3.5a$, the upward trend is basically the same and the inflection point is relatively clear. 4 values of measuring points are still high; As shown in FIG. 5, when $I=8.8a$, each measurement point accumulates with time and increases in step at $t_2$. When $I=5.5a$, the upward trend is basically the same and the inflection point is relatively clear. The 4 values of measurement points are still high. Under the same vibration excitation, the sensitivity of different measuring points to thermal current load is quite different.

(a) temperature trend spectrum under vibration condition
(b) gradient spectrum under vibration condition

Figure 3 I=1.5A, Comparison of temperature peak $T_{max}$ at some measuring points

(a) temperature trend spectrum under vibration condition
(b) gradient spectrum under vibration condition

Figure 4. I=4.4A, Comparison of temperature peak $T_{max}$ at some measuring points
4.3 relatively stable temperature rise TS

Under a certain current of heat load, with the accumulation of time, the conductor insulation layer of heat exchange with the environment situation tends to be stable, the highest temperature of each measurement point tends to be stable, relatively stable temperature rise as evaluation indexes, namely take stabilizing the highest temperature and initial maximum temperature difference, for a relatively stable temperature rise, $T_s$, namely,

$$T_s = T_{\text{max}} - T_0$$  \hspace{1cm} (3)

$T_{\text{max}}$, the maximum temperature value of a certain state tends to be stable, $T_0$, the maximum temperature value at the initial time of a certain state.

As shown in figure 6, for vibration conditions, the comparison of each measurement point relatively stable temperature rise of TS, state 2 and 5 is the inflection point curve, state 2, before each measurement point is relatively stable temperature rise with the increase of the thermal stress, small wave motion state of each measurement point after 2 relatively stable temperature rise with the increase of the thermal stress, but there are some fluctuations, basic stability; Between state 3 and state 5 (when the given current value is $2.7 \leq I \leq 4.4$), the relatively stable temperature rise of some measuring points fluctuates slightly, which should be the training period when the measuring point is relatively stable temperature rise. After state 5 (when the given current value is $I > 4.4$), the measuring point is more sensitive to the increase of thermal stress, showing an increasing trend, and the relatively stable temperature value of measuring point 5 is the highest.
As shown in figure 7, the comparison of the relatively stable temperature rise TS at each measurement point under the non-vibration condition. Compared with the vibration condition, the connection line at the inflection point in state 5 is more clear and backward. The inflection point before state 5 has disappeared, and the relatively stable temperature rise of each measurement point tends to be basically stable with the increase of thermal stress. With different working current, the sensitivity difference of different laying methods to thermal stress decreases.

Under the condition of vibration, the time to reach the stable temperature rise is short, and the vibration promotes the establishment of the balance of the heat exchanger. Under different working current thermal load, the sensitivity to thermal stress shows great differences.

Under the action of different working currents, the infrared temperature spectrum is obtained by conducting electrification experiments on the wire, taking vibration and other practical conditions into consideration. The maximum temperature peak and relatively stable temperature rise were taken as the characteristic values to form trend spectrum and gradient spectrum, and the differences of different laying modes were analyzed to distinguish their sensitivity to vibration and thermal stress to some extent. The feasibility of applying thermal imaging technology to the performance evaluation of aviation wires is verified, which has certain reference significance for the active prevention and on-line diagnosis of line faults.

References
[1] Du hongchao. Research on power cable fault diagnosis and positioning system [D]. Xi ‘an: xi ‘an university of electronic science and technology,2013.
[2] Li huan, wang yongxing, zou jiyan, huang zhihui, zhou yue. Experimental study on accelerated aging of insulation of aviation cables [J]. Electrical and energy efficiency management technology. 2017no.7
[3] A.S. Nazmul Huda, Soib Taib. Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment[J]. Applied Thermal Engineering , 2013.61(2):220-227.
[4] Liu xiaolin. Research on aircraft conductor fault diagnosis and location [D]. Qinhuangdao: yanshan university, 2013.
[5] Li x g, fu d m. infrared imaging detection and diagnosis technology [M]. Beijing: China electric power press, 2006. (in Chinese with English abstract)
[6] Liu fei. Study on insulation aging assessment of 35kV and below XLPE power cables [D]. Shanghai: Shanghai jiaotong university, 2014.
[7] Lu shigui, Yang li, fan chunli, sun fengrui. Numerical simulation and analysis of infrared thermal characteristics of cable aging [J]. Journal of engineering thermal physics.2013.2:332-335.
[8] Wang huawei. Research on key technology of temperature field measurement based on infrared thermal imaging [D]. Beijing: university of Chinese academy of sciences, 2013.

[9] Kou xiaoming. Research on performance evaluation method of infrared imaging observation system [D]. Xi'an: xi'an university of electronic science and technology, 2011.