Protection Design and Effectiveness Verification of High-temperature Fire for Civil Aviation Emergency Locator Transmitter

Liangtang Liu [1, a], Xu Zhou [1], Yuan Hong[1], Hao Wang[1], Liming Yang[1] and Wencai Wu [2]

[1]Space Technology Co., Ltd., Beijing 100194, China;

[2]China Academy of Civil Aviation Science and Technology, Beijing 102206, China;

[a]liangtangliu@163.com

Abstract. Considering the coupling between the heat of emergency locator transmitter and the external high-temperature fire environment, a thermal protection system for external insulation and internal heat absorption is proposed. The external insulation layer consists of flexible nanofiber heat insulation film and quartz ceramics to withstand the thermal impact of the external environment. The internal heat absorption layer is composed of microcapsulated paraffin, which is used to absorb the heat transmitted through the insulation layer and the heat generated by emergency locator transmitter. Using the enthalpy method to establish a transient heat transfer mathematical model of thermal protection system, and the protection performance of the system in high-temperature fire is analyzed. The calculation results show that the system can withstand a high-temperature fire for at least 15 minutes, during which the temperature of emergency locator transmitter is controlled below 60℃. After the fire is over, under the coupling of the waste heat of the incoming system and the heat of emergency locator transmitter, the temperature of emergency locator transmitter continues to rise to a maximum of 107℃. Then, as the influence of the waste heat of the incoming system weakens, the temperature of emergency locator transmitter gradually decreases. Finally, the accuracy of the simulation model and the effectiveness of the thermal protection system are verified through destructive experiments.

Keywords: emergency locator transmitter; high-temperature fire; Protection design.

1. Introduction

The emergency locator transmitter is a terminal equipment that can work independently in the aviation life-saving system. It is mainly divided into two categories: fixed and portable. It is carried on aircraft and other aircraft. It is used to send radio alarm signals after the crash of aircraft and other aircraft to help search and rescue organizations identify aircraft in distress. Location information in order to quickly carry out the rescue work.

In the event of crashes in aviation flights such as aircraft, extreme environments are usually caused, mainly including strong impact environments and high-temperature fire environments. According to the design standard RCA/DO-204A description of emergency locator transmitter, 1) Strong impact environment: 500g, duration 4±1ms. 2) High-temperature firing environment: heat flux 20W/cm2, flame temperature not less than 1100℃, duration not less than 2 minutes [1]. As the main basis for the design of the current emergency locator transmitter, the standard requires that the emergency locator transmitter must have the ability to withstand the above-mentioned strong impact environment, but it does not require that it must have the ability to withstand the above-mentioned high-temperature fire environment. Therefore, emergency transmitter products based on this standard generally do not have the endurance or weak endurance of high-temperature fire, and cannot survive in a high-temperature fire environment. In reality, according to the 257 crashes in the past 30 years, there have been 173 cases of carrying an emergency locator transmitter, only 39 of which have been activated, and the activation probability is only 22.5% [3]. Most of the rest have been damaged in the accident. The lack of adaptability of the emergency locator transmitter to the high-temperature firing environment is the main factor contributing to this phenomenon.

In view of the current problem of insufficient adaptability to the high-temperature fire environment of the emergency locator transmitter, this paper proposes a thermal protection system for external heat insulation and internal heat absorption, which can withstand 15 minutes of continuous high-temperature fire. The effectiveness of the system is verified through theoretical analysis and destructive experiments, which provides engineering technical reference for the thermal protection optimization design of emergency locator transmitter products.

2. Thermal protection design

The emergency locator transmitter thermal protection system, as shown in Fig. 1, consists of a two-stage heat insulation layer and an internal heat absorption layer.

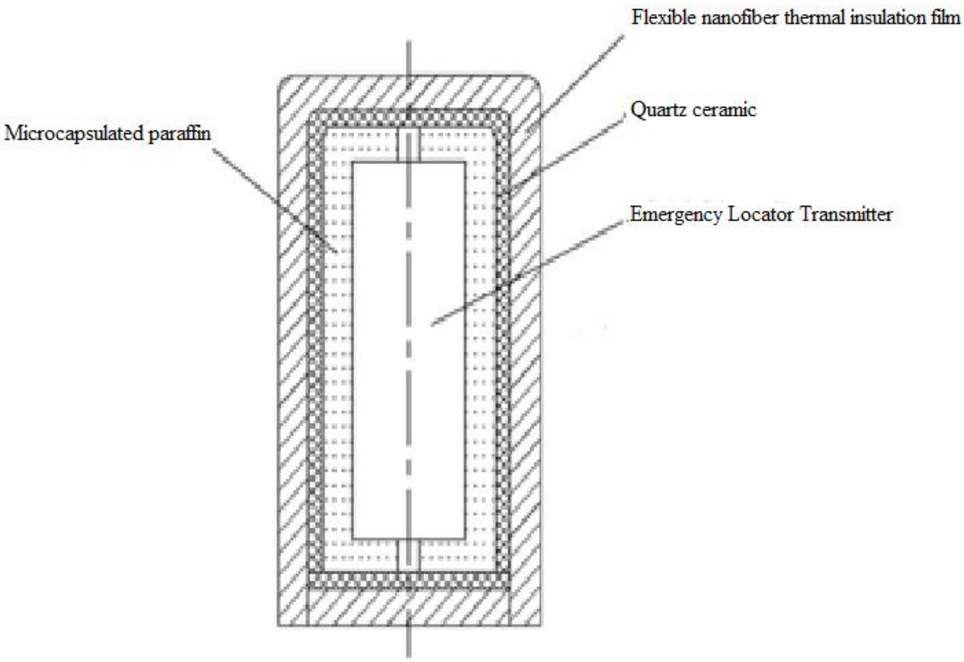

Fig. 1 Schematic diagram of emergency locator transmitter thermal protection system

From outside to inside, the two-stage insulation layer is 15mm thick flexible nanofiber thermal insulation film and 7mm thick quartz ceramic. As the first-level insulation, flexible nanofiber thermal insulation film directly withstands the thermal impact of the external fire environment. As the second-stage heat insulation, quartz ceramics also take into account the carrying function of the structure. The two work together to prevent the transfer of external heat to the inside. The physical parameters of the material are shown in Table 1.

Table 1 Physical parameters of thermal insulation materials

Name	Unit	Flexible nanofiber thermal insulation film	Quartz ceramic
Density	kg/m^3	200±20	1850±50
Specific Heat capacity	J/(kg · K)	≥900	≥900
Thermal conductivity coefficient	W/(m · K)	0.026	1.2
Temperature-resistant	℃	1200	1200
Dielectric constant	/	3.5±0.2	3.5±0.15

The internal heat absorption layer is 772.5g microcapsulated paraffin material, which is used to absorb the heat introduced through the insulation layer and the heat generated by the transmitter. The physical parameters of microencapsule paraffin are shown in Table 2.

Table 2 Physical parameters of microcapsulated paraffin

Name	Unit	Microcapsulated paraffin
Density	kg/m^3	940
Specific Heat capacity	J/(kg · K)	1700
Latent heat	kJ/kg	180
Thermal conductivity coefficient	W/(m · K)	0.3
Phase transition temperature	℃	60~63
Dielectric constant	/	2.5~2.95

3. Theoretical description

3.1 Physical model

Assuming that the outer surface of the thermal protection system of the emergency locator transmitter evenly withstands fire heating, the heat is only transmitted along the direction of the wall thickness, the thermal response of the heat protection system can be simplified to a one-dimensional unsteady heat transfer problem, as shown in Fig. 2, where the symmetrical axis is the inner wall of the system.

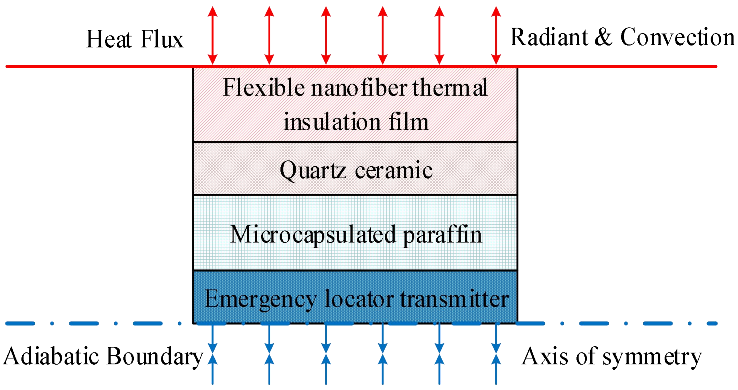

Fig. 2 Schematic diagram of Physical model

3.2 Mathematical model

The transient heat transfer model of the emergency locator transmitter thermal protection system is established by enthalpy method.

$$\rho\frac{\partial H(x,t)}{\partial t} = \lambda\frac{\partial^2 T(x,t)}{\partial x^2} \tag{1}$$

In the formula, t is the time,s; x is the depth, m; $H(x,t)$ is the enthalpy of material, kJ/kg; $T(x,t)$ is the temperature, ℃; ρ is the density of material, kg/m^3; and λ is the thermal conductivity of material, W/(m · K).

Among them, for traditional materials, the relationship between enthalpy and temperature is as follows:

$$H = C_p \cdot T \tag{2}$$

In the formula, C_p is the specific heat capacity of the material, J/(kg · K).

For phase transition materials, the relationship between enthalpy and temperature is as follows:

$$H=\begin{cases} C_{ps}(T-T_s), & T\le T_s \\ H_s+\frac{\Delta H_m(T-T_l)}{T_l-T_s}, & T_s<T<T_l \\ H_l+C_{pl}(T-T_l), & T\ge T_s \end{cases} \tag{3}$$

In the formula, C_{ps} is the solid heat capacity of phase change materials, $\mathrm{J/(kg\cdot K)}$; C_{pl} is the liquid heat capacity of phase change materials, $\mathrm{J/(kg\cdot K)}$; H_s is the solid phase enthalpy of the phase transition material, kJ/kg; H_l is the liquid phase enthalpy of the phase transition material, kJ/kg; ΔH_m is the latent heat of phase transition materials, kJ/kg; T_s is the temperature at the beginning of the phase transition,℃; T_l is the temperature at the end of the phase transition,℃.

The boundary conditions of the thermal protection system include the outer wall boundary conditions and the inner wall boundary conditions, as follows:

1）Boundary conditions of the outer wall

The outer wall is subject to high-temperature fire. Considering the influence of radiation and convective heat transfer, the outer wall boundary is shown below.

$$q_{fire}-\varepsilon_{out}\sigma T^4-h(T-T_a)=-\lambda\frac{\partial T}{\partial x},\ x=0 \tag{4}$$

In the formula, q_{fire} is the heat flow, W/cm^2; ε_{out} is the radiation coefficient of the outer wall, and h is the convective heat transfer coefficient of the outer wall, $\mathrm{W/(}m^2\cdot\mathrm{K)}$.

In this article, the heat flow on the outer wall is q_{fire}=20 W/cm^2, with a duration of 15 minutes.

2）Boundary conditions of the inner wall

The inner wall is an adiabatic boundary. Considering the heat of the emergency locator transmitter itself, the inner wall boundary is shown below.

$$Q_{ELT}=-\lambda\frac{\partial T}{\partial x},\ x=\delta \tag{5}$$

In the formula, Q_{ELT} is the heat consumption of the emergency locator transmitter, W.

In this paper, the average heat consumption of the emergency locator transmitter is Q_{ELT}=5W.

4. Simulation analysis

According to the above mathematical model, the system was simulated for 19 hours at 25℃. The results are shown in Fig. 3.

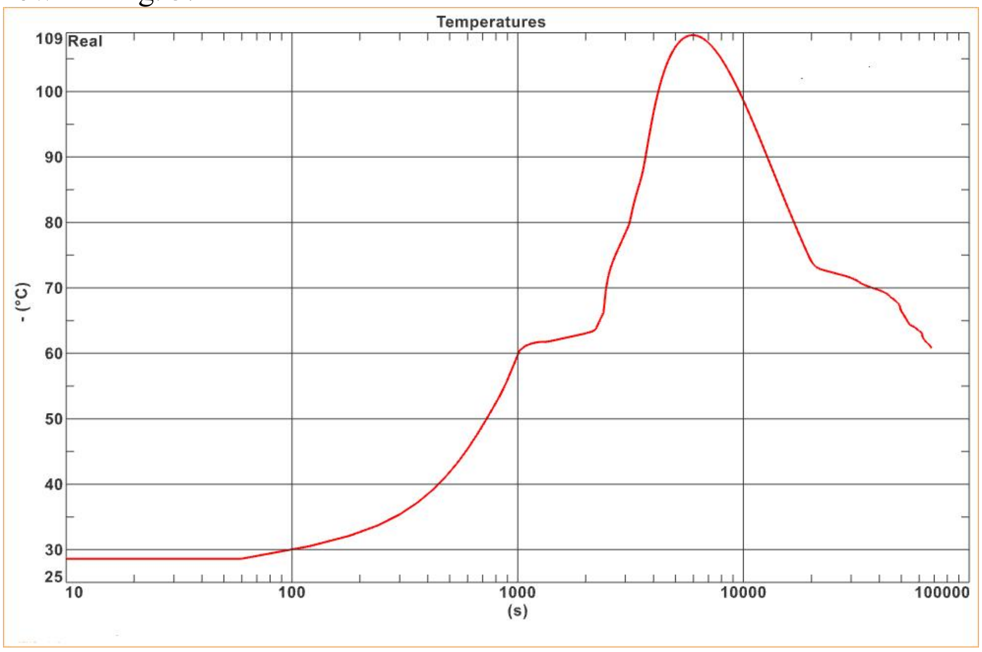

Fig. 3 Temperature monitoring curve of emergency locator transmitter

As can be seen from Fig. 3, in the 0-900s range, under the action of high-temperature fire, the temperature of the emergency locator transmitter gradually rises to 58℃, not reaching the phase transition point of the heat absorption layer (60℃). At this time, the heat absorption layer mainly absorbs external heat. After 900s, the high-temperature fire ends. At this time, under the coupling of the heat of the transmitter and the waste heat of the system, the temperature of the transmitter continues to rise. At 1000s, reach the phase transition temperature of the heat absorption layer (60℃). Under the influence of the latent heat of the heat absorption layer, the temperature rises slowly. When it reaches 2265s, the temperature rises to 65℃, and the heat absorption layer material is completely phased. After 2265s, the transmitter temperature rises rapidly. With the weakening of the waste heat of the external load, the transmitter temperature reaches the maximum temperature of 109℃at 6000s, which meets the permitted requirements, and then begins to decrease. By the end of 19 hours, the transmitter temperature dropped to 62℃.

5. Destructive experiments

In order to verify the effectiveness of the thermal protection system, aviation fuel is used to simulate the firing environment after the plane crash, as shown in Fig. 4. After 900s continuous fire, the emergency locator transmitter protection system is shown in Fig. 5. After 5100s natural cooling, the protection system is opened, and the temperature of the transmitter is 107℃ through the temperature tester, which is basically consistent with the simulation results, which proves the accuracy of the simulation results. Take out the transmitter for performance testing. The performance index of the emergency locator transmitter meets the design requirements, as shown in Table 3, which proves the effectiveness of the thermal protection system.

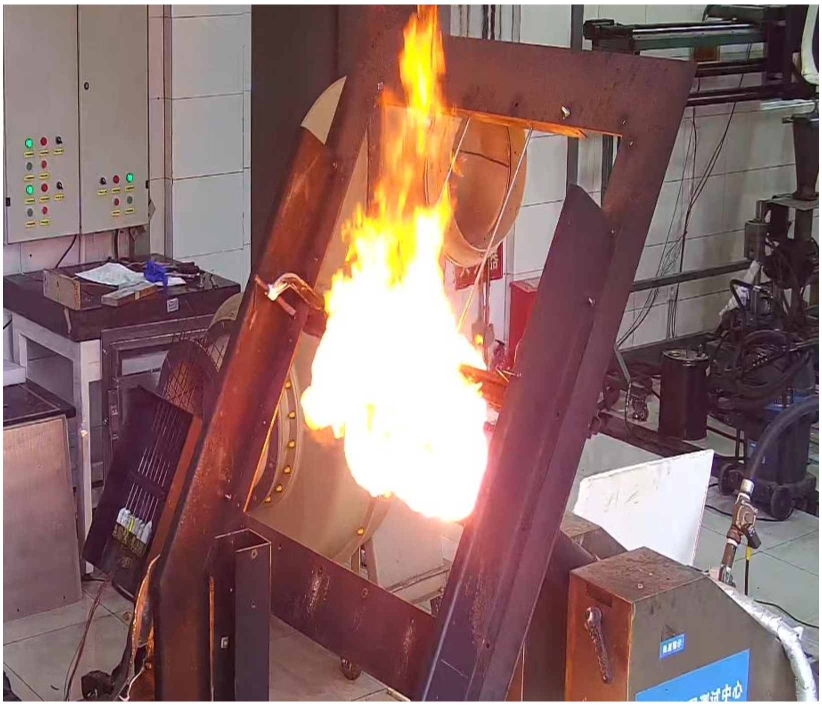

Fig. 4 Emergency locator transmitter burning experiment

Fig. 5 Results of the emergency locator transmitter fire experiment

Table 3 Performance Test Results of Emergency locator Transmitter

Name	Unit	Target value	Test value
Frequency	MHz	121.5±0.006	121.5
		406.025±0.002	406.025
Transmission power	dBm	21±4.5	21.81
		37±2	35.35

6. Summary

In this paper, the high-temperature fire protection system of the emergency locator transmitter has been simulated and experimentally verified, and can withstand 15 minutes of continuous fire, which effectively improves the adaptability of the transmitter in extreme environments. It also provides engineering and technical support for the thermal protection optimization design of emergency locator transmitter products.

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