Advances in Mechanical Engineering and its Applications (AMEA)
Vol. 3, No. 2, 2013, ISSN 2167-6380

www.worldsciencepublisher.org

Study on Flame Temperature Measurement of Electric Igniter Using Multi-Spectral Radiation Thermometer

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Abstract – On the basis of the principle of multi-spectral radiation thermometry, the multi-spectral radiation thermometer was developed for measuring the transient temperature. By analyzing the spectral radiation characteristics of the output flame of the electric igniter, the appropriate spectral working channels were selected to measure the radiation energy. The radiation energy curves and the brightness temperature curves were got. With the reference temperature mathematical model, the true temperature T and the spectral emissivity of the output flame of the electric igniter were obtained by the least squares method and the multiple regression method. Experiments indicated that the multi-spectral thermometer would be expert in measuring the output flame temperature of the electric igniter, when the appropriate spectral working channels were selected based on analyzing the spectral radiation characteristics. This thermometry lays a foundation for the research of transient temperature field.

Keywords – Flame temperature; Electric igniter; Multi-spectral radiation thermometry; Reference temperature mathematical model

Introduction

The crew emergency evacuation security system was used to break an escape hatch in airliner in case of emergency in the air, which had been installed in a new regional airliner. In the system, when electric igniter was started by impulse current, a high temperature flame would be formed. Through a series of transmitting-explosive, the high temperature flame would ignite gun powder. Then, the high temperature and high pressure gas was generated to push the service door in the airliner to move. When the service door was moved for a distance, an escape hatch was formed finally. The high-speed photography results showed that the duration time of the output flame of the electric igniter was less than 700us. As the starting element, the igniter is the most important element in the exploder. The temperature of the output flame is a particularly important parameter, which affects ignition capability observably. So it's very necessary to make a research on thermometry to measure the temperature of the output flame of the electric igniter.

At present, the main temperature measurement technologies on the transient flame are the thermocouple temperature measurement technology and the infrared thermograph temperature measurement technology, and so on. When the thermocouple temperature measurement technology was applied, thermocouple was installed on the electric igniter port to measure the temperature of the output flame. Because of the install location, the temperature field distribution of the output flame was destroyed. The measurement range is narrow, and the thermocouple response is lag. And it could not get micro-second flame temperature. The spectral emissivity of flame is need in infrared thermograph temperature technology, but it is difficult to get it. So the true temperature of the flame could not be measured.

Recent years, with the development of the spectroscopy and the combustion, the multi-spectral thermometer had been improved tremendously. It is non-contact, high speed response, and wide temperature range. Particularly, this method is suitable for measuring the temperature of the transient flame of the electric igniter.

1. The measurement principle of multi-spectral radiation thermometer

The different radiance of the measured object could be obtained by the multi-spectral radiation channels in an instrument. And the temperature of the object and the material spectral emissivity would be got through analyzing the radiance of the measured object.

The multi-spectral radiation thermometer follows the Plank radiation law. (When there are n-spectral channels in the instrument) the output signal of the i-th wavelength could be expressed as:

$$V_i = A_{\lambda_i} \times \varepsilon(\lambda_i, T) \times \lambda_i^{-5} e^{-\frac{C_2}{\lambda_i T}}, \quad i = 1, 2, \cdots, n \qquad (1)$$

In which, the radiation parameter A_{λ_i} is only related to wavelength but temperature. When the wavelength was confirmed, the radiation parameter A_{λ_i} would be related to the spectral responsivity of the detector in the wavelength, the transmittance of the optical element, the geometric dimension, and the first radiation constant. And $\varepsilon(\lambda_i, T)$ is the spectral emissivity of the measured object. T is the temperature of the measured object; λ_i is the i-th effective working wavelength; and $c_2 = 1.4398 \times 10^{-2} \mathrm{m} \cdot K$.

When there are n-channels in the multi-spectral radiation thermometer, n-equations including (n+1)-unknown amounts would be formed. In which, the temperature T and the n-spectral emissivity $\varepsilon(\lambda_i, T)$ would not be known. Since the spectral emissivity varies with the different the wavelength, the spectral emissivity $\varepsilon(\lambda_i, T)$ could be shown with (n-1) wavelength functions of adjustable parameters.

When the radiation parameter A_{λ_i} had been measured at different wavelengths, the temperature T and (n-1) adjustable functions could be obtained with the least squares method and the multiple regression method.

From the principle of multi-spectral radiation thermometry, we know that continuous spectrum radiation energy of the flame is the main measured object. So when the thermometer would be used, the continuous spectrum of the flame should be selected to analyze. And the characteristic spectrum should be avoided.

2. The multi-spectral radiation thermometer

The multi-spectral radiation thermometer is made up of the optical system, the circuit system, the data acquisition section, and the data processing section, which are shown in Figure 1. There are twelve spectral channels in the system. And the single-channel sampling frequency is 100kHzs-1. According to the spectral distribution of the output flame of the electric igniter, appropriate spectral channels would be select.

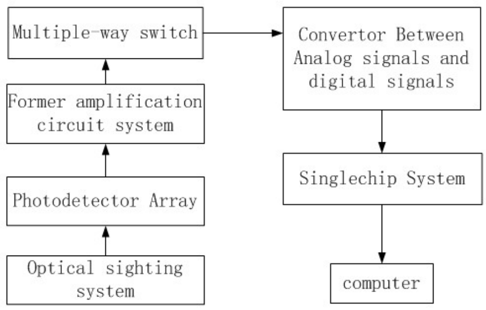

Figure 1. The multi-spectral radiation thermometer

The optical system is made up of the sampling system and the spectrophotometer system, which are shown in Figure 2. The sampling system is composed of the main objective lens L1, the field stop (FS), and the aperture diaphragm located on the collimating lens L2. The main objective lens L1 could be focused by moving the handle, so that the pixel of the object could be focused on the field stop. The spectrophotometer system consists of the collimating lens L2, the chromatic dispersion prism P, the black-box objective lens L3, the mirror M, and the focal plane array (FPA A). The radiant energy, which is obtained by the field stop FS from the object surface, is collimated into parallel beam. The parallel beam would be dispersed into multiplexer different wavelength parallel beam, which have different angles. After the black-box objective lens L3 and the mirror M, the parallel beam image on the FPAA. Then it is received by multi-detector array in accordance with the order of the wavelength.

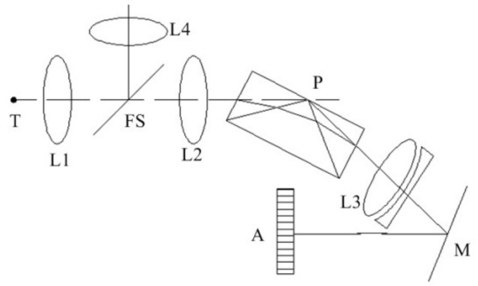

Figure 2. The optical system of the multi-spectral radiation thermometer

3. The analysis of the experimental results

The multi-spectral radiation thermometer was used to measure the flame temperature of the electric igniter. And the test curves and results were obtained successfully.

(1) The multi-spectral radiation analysis on the output flame of the electric igniter

The gunpowder within electric igniter is composed of different kinds of gunpowder. The composition and the combustion intensity of varieties of gunpowder are very different. The constituent components, the wavelength and the spectral information of the output flame are different. Therefore, when the temperature of the output flame would be measured, the spectral range containing little radiation emitting material should be selected. And it would reduce the impact on the true temperature by the radiation emitting material.

Therefore, study on the multi-spectral radiation characteristics and essence of the output flame would be necessary.

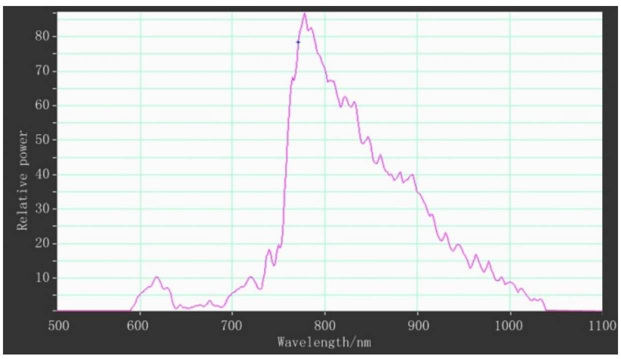

Figure 3. The radiation spectrum of the output flame

The test result was shown in Figure 3, in which the horizontal axis is the wavelength and the vertical axis represents is relative energy. From the Figure 3, we can know that the main part of the spectral range of the output flame is the continuous spectrum, with little characteristic spectrum. And the characteristic spectrum is between 770nm and 790nm.

The effective wavelengths of the 12 spectral channels of the multi-spectral radiation thermometer are not between 770nm and 790nm. So, all channels could be used to measure the output flame temperature of the electric igniter.

(2) The measurement results of the multi-spectral radiation thermometer

The electric igniter was installed on a fixed foundation. When the electric igniter was ignited by an electrical conductor, the radiation energy curves and the brightness temperature curves were got. The radiation energy curve of the fifth channel is shown in Figure 4. And the brightness temperature curve of the eighth channel is shown in Figure 5.

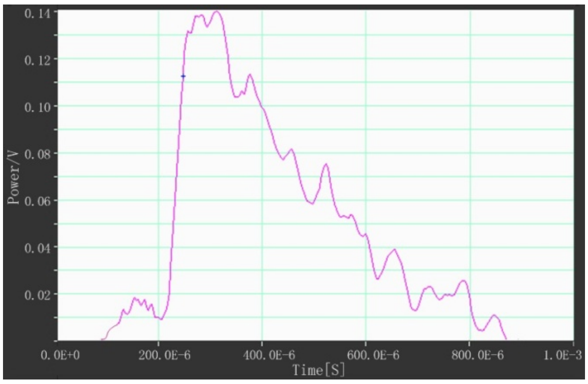

Figure 4. The radiation energy curve of the fifth channel

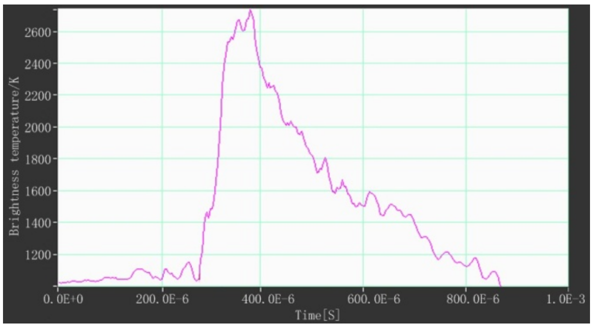

Figure 5. The brightness temperature curve of the eighth channel

(3) The calculate with the reference temperature mathematical model

Assuming that

$$\ln \varepsilon(\lambda,T)=\sum_{i=1}^{m} a_i \lambda^i \quad (m \le n-2) \tag{2}$$

The output signal V_i of the i-th channel of the multi-spectral radiation thermometer was shown in the formula (1). And at the blackbody reference temperature $T^{'}$ of the fixed point, the output signal of the i-th channel would be $V_i^{'}$:

$$V_i^{'} = A_\lambda \lambda_i^{-5} e^{-\frac{C_2}{\lambda_i T}} \tag{3}$$

From the formula (1) and the formula (3), we can know that,

$$\frac{V_i}{V_i^{'}} = \varepsilon(\lambda_i, T) \cdot e^{\frac{C_2}{\lambda_i T^{'}}} \cdot e^{-\frac{C_2}{\lambda_i T}} \tag{4}$$

Then,

$$\ln(\frac{V_i}{V_i^{'}}) - \frac{C_2}{\lambda_i T^{'}} = -\frac{C_2}{\lambda_i T} + \ln \varepsilon(\lambda_i, T) \tag{5}$$

Assuming that,

$$Y_i = \ln(\frac{V_i}{V_i^{'}}) - \frac{C_2}{\lambda_i T^{'}}, a_{m+1} = -\frac{C_2}{T}, X_{m+1,i} = \frac{1}{\lambda_i},$$
$$X_{1,i} = \lambda_i, \cdots, X_{m,i} = \lambda_i^m$$

From the formula (2) and the formula (5), we can know that:

$$\begin{gathered} Y_i = \ln(\frac{V_i}{V_i^{'}}) - \frac{C_2}{\lambda_i T^{'}}, a_{m+1} = -\frac{C_2}{T}, \\ X_{m+1,i} = a_0 + a_1 X_{1,i} + \cdots + a_m X_{m,i} + a_{m+1} X_{m+1,i} \end{gathered} \tag{6}$$

In which, $i = 1, 2, \cdots, n; m \le n-2$.

According with the least squares method and the multiple regression method, the coefficients a_0, $a_1, \cdots$, a_m, a_{m+1} could be obtained. Ultimately, the true temperature T and the spectral emissivity $\varepsilon(\lambda_i, T)$ of the output flame of the electric igniter were got. The temperature T curve of the output flame of the electric igniter is shown in Figure 6.

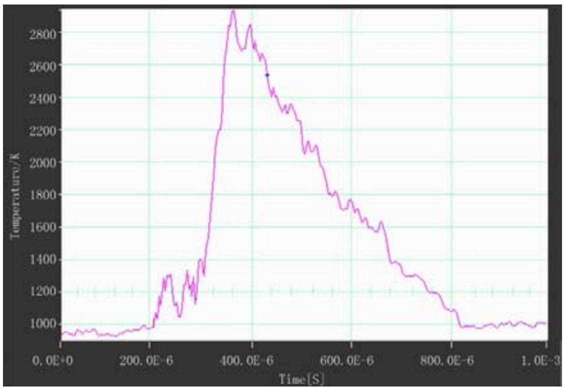

Figure 6. The true temperature curve of the output flame of the electric igniter

4. The Conclusion

The multi-spectral radiation thermometer with high sampling frequency spectral channels has been used to receive the radiation energy to measure the flame temperature of the electric igniter successfully. Without breaking the temperature field of the flame, the thermometer measured the flame radiation energy continuously. All experiments show that the thermometer is a high sensitivity, high stability and high accuracy method. Specially, the multi-spectral radiation thermometer is expert in measuring the temperature of the transient flame. The multi-spectral radiation thermometer lays a foundation for the research of transient temperature field.

References

[1] DAI Jing-min. Survey of radiation thermometry [J]. Techniques of Automation & Applications, 2004, 23(3): 1-7.

[2] DAI Jing-min, SUN Xiao-gang. Theory and Application of Multi-Spectral Radiation Thermometry. Beijing: Higher Education Press, 2002.

[3] Yang Zhao, Liyi Zhang, "System Dynamics Modeling and Simulation of Information Resources Allocation of R&D Cooperation in China, " International Journal of Digital Content Technology and its Applications, Vol. 5, No. 2, pp. 21-33, 2011.

[4] SUN Xiao-gang, YUAN Gui-bin, LIN Ke-feng etal. J. Tsinghua University (Science and Technology), 2005, 45(7): 999.

[5] Coppa P, Dai J M, Ruffino G. The transient regine of a multi-wavelength pyrometer[J]. Int J Thermophysic

-s, 1993, 14(3): 599-608.

[6] Svet D Y. Sayapina V J. Levchuk V V, et a1. Optical photoelectronic pyrometer for measuring the true temperature of metals by radiation[J]. HighTemp High Press, 1979, 11: 117-118.

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