Proceedings of the 9th World Congress on Momentum, Heat and Mass Transfer (MHMT 2024)
London, United Kingdom – April 11 – 13, 2024
Paper No. ICMFHT 170
DOI: 10.11159/icmfht24.170

Optimization Method of Working Wavelength Couple for High-Precision Fluorescence Temperature Measurement

Yongkai Quan[1,2,3], Qiuyang Yin[1,2,3], Jichen Liu[1,2,3], Jieming Chai[1,2,3], Jianyu Liu[1,2,3], Lina Zhang[1,2,3,*]
[1]National Key Laboratory of Science and Technology on Aero-Engine Aero-thermodynamics, Research Institute of Aero-engine, Beihang University, Beijing 100191, China
[2] International Innovation Institute, Beihang University, Hangzhou 311115, China
[3]Tianmushan Laboratory, Hangzhou 310023, China
zhangln@buaa.edu.cn

Extended Abstract

High-precision temperature measurement is crucial to the performance and safety of the aircraft engine. The harsh environment of aerospace engines poses great challenges to temperature measurement technology. Traditional temperature measurement technologies include thermocouples, infrared temperature measurement, etc. Thermocouples are intrusive and difficult to install in rotating components. Infrared temperature measurement technology is significantly affected by the complex gas atmosphere of aircraft engines and changes in emissivity of hot-end components. The above problems can be resolved using phosphor thermometry technology, which is a technology with great potential to be applied to aerospace engine temperature measurement.

There are two methods of phosphor thermometry, lifetime decay method and fluorescence intensity ratio (FIR) method. Lifetime decay method utilizes the relationship between lifetime and temperature to measure temperature by monitoring the lifetime of phosphorescence. The FIR approach compares the emission intensities of two wavelengths that correspond to thermally coupled energy levels to determine temperature. The FIR method is independent of spectrum losses and fluctuations in the excitation intensity. However, the narrow energy gap of the thermally coupled energy levels leads to low temperature measurement sensitivity. In order to improve the temperature measurement sensitivity, previous research has been done. Some new thermally coupled levels and non-thermally coupled levels were constructed [1-3]. The energy gap and the relative sensitivity were greatly improved by modifying the host's composition [4]. The relative temperature sensitivities and temperature resolutions were compared for different intensity ratios of the non-thermally coupled levels [5]. However, how to obtain the optimal working wavelength couple for high-precision temperature measurement is still unclear.

In this paper, we started from the temperature measuring requirements of aero-engine hot-end components, considered the strong thermal radiation in the aero-engine environment, and established an evaluation system for working wavelength couples based on error theory. A working wavelength couple optimization method suitable for high-precision phosphorescent temperature measurement in high-temperature environments was proposed, and verified using the temperature-changing spectral data of YAG: Dy.

First, an error analysis was conducted, and the total error was divided into systematic error and random error. Based on the total error requirements, both systematic error and random error were limited to less than 0.5%. The average value and difference of 20 experiments were taken to evaluate the systematic error and random error respectively. Then, the effect of background radiation at high temperatures is reduced by selecting short wavelengths and offset correction. Furthermore, the evaluation system for working wavelength couples was established. Random errors are mainly caused by thermal radiation at high temperatures. To improve the temperature measurement performance at high temperatures, among the working wavelength couples that meet the system error requirements, choose the one with the smallest random error. Finally, the optimized working wavelength couples and typical wavelength couples of thermally coupled energy levels are compared to evaluate the effectiveness of the optimization method.

The results show that the maximum system error of the phosphorescent sample was reduced from 2.68% to 0.37% after optimization. The relative sensitivity and absolute sensitivity of the optimized working wavelength couples were

significantly better than those of typical wavelength couples of thermally coupled energy level. The optimization method of working wavelength couple proposed in this study can significantly improve the error and sensitivity of temperature measurement.

References

[1] Z. Sun, M. Jia, Y. Wei, J. Cheng, T. Sheng, and Z. Fu, "Constructing new thermally coupled levels based on different emitting centers for high sensitive optical thermometer," *Chemical Engineering Journal,* Article vol. 381, 2020 FEB 1 2020.

[2] V. Kesarwani and V. K. Rai, "Non-contact optical thermometry via non-thermally coupled levels in upconverting glass," (in English), *Journal of Applied Physics,* Article vol. 132, no. 11, p. 9, Sep 2022, Art. no. 113102.

[3] X. Cui, Y. Cheng, H. Lin, F. Huang, Q. Wu, J. Xu, Y. Wang, "Towards ultra-high sensitive colorimetric nanothermometry: Constructing thermal coupling channel for electronically independent levels," *Sensors and Actuators B-Chemical,* Article vol. 256, pp. 498-503, 2018 MAR 2018.

[4] M. Shi, L. Yao, S. Yu, Y. Dong, and Q. Shao, "Enhancing the temperature sensitivity of Cr3+ emissions by modification of the host's composition for fluorescence thermometry applications," *Dalton Transactions,* Article vol. 51, no. 2, pp. 587-593, 2022 JAN 4 2022.

[5] N. Stopikowska, M. Runowski, P. Wozny, S. Goderski, and S. Lis, "Improving temperature resolution of luminescent nanothermometers working in the near-infrared range using non-thermally coupled levels of Yb3+ & Tm3+," *Journal of Luminescence,* Article vol. 228, 2020 DEC 2020.