Optik 127 (2016) 246–249

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Excimer and Nd:YAG laser-based systems incorporating air-cooled fiber-optic probes for turbine engine high-temperature fluorescence intensity imaging and fluorescence decay lifetime thermometry measurements

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ARTICLE INFO

Article history:
Received 7 December 2014
Accepted 30 September 2015

Keywords:
Thermographic phosphor
Fiber-optic endoscope
Photomultiplier
CCD camera
Pixelation effect

ABSTRACT

In this work, a description for a pulsed Nd:YAG laser-based system operating at 266 nm (generated by passing the 1.064 μm fundamental wavelength through two non-linear KD*P crystals) for non-contact high-temperature 1-D thermographic phosphors fluorescence intensity and decay lifetime measurements is provided. Also, the article provides a description for a pulsed XeCl excimer laser-based system operating at 308 nm (XeCl) for non-contact high-temperature 2-D thermographic phosphor fluorescence intensity measurements. Both laser systems incorporate air-cooled fiber-optic probes for delivering the excitation laser energy to an engine part coated with thermographic phosphor (Y_2O_3:Eu or YAG:Tb). Furthermore, the air-cooled probe used with the Nd:YAG laser measurement system incorporates nine 1000 μm core diameter fibers for guiding the emitted fluorescence radiation to the photomultiplier detection system. Whereas, the air-cooled probe used with the excimer laser-based system incorporates a coherent fiber-optic bundle endoscope for imaging the engine parts. The honeycomb pattern (pixelation effect) imposed on images captured by the CCD camera (12 × 13.7 μm pixel size) coupled to the endoscope eyepiece is removed by applying digital high-frequency spatial filter to the image 2-D Fourier transform. Moreover, fluorescence decay lifetime and intensity measurements collected from Y_2O_3:Eu and YAG:Tb phosphors as a function of temperature are discussed.

1. Introduction

Turbine engine designer are striving towards improving the efficiency of fuel consumption and reducing the emission of gaseous pollutants (i.e., NO_x compounds) produced by modern turbine engines. As such, novel engine components cooling schemes, thermal barrier protective coatings and superalloys are introduced into new turbine engine component designs in order to allow engines to operate at higher temperatures and to reduce gaseous pollutants [1].

Collecting surface temperature measurement from rotating turbine engines parts only possible using optical pyrometry [2,3], thermal paints and thermographic phosphors [4–12]. In comparison with thermocouples, the conventional wire technique for temperature measurements, these non-contact surface temperature techniques are immune to electromagnetic radiation interference, would not perturb gas glow patterns and can be used for acquiring surface temperature measurements from rotating engine parts (i.e., blades).

The use of thermographic phosphors [9,10] in turbine engine surface temperature measurements, exploiting the fluorescence intensity radiation and decay lifetime has been demonstrated by several researches [1,4–8,10–12]. In these turbine engine demonstrations thermographic phosphors are applied to the engine parts using chemical binders or plasma flame spray techniques.

The purpose of this work is to describe a Nd:YAG laser-based system operating at 266 nm for fluorescence intensity and decay lifetime measurements and an XeCl excimer laser-based system operating at 308 nm for imaging engine parts coated with thermographic phosphor (Y_2O_3:Eu or YAG:Tb). Both systems incorporate air-cooled fiber-optic probes for delivering the excitation UV laser beam into the engine part coated with thermographic phosphor. The fiber-optic probe used in the Nd:YAG laser-based system incorporates nine step-index optical fibers for guiding the fluorescence radiation emitted from the engine part to the detection system. Whereas, the excimer laser-based system air-cooled probe

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http://dx.doi.org/10.1016/j.ijleo.2015.09.254

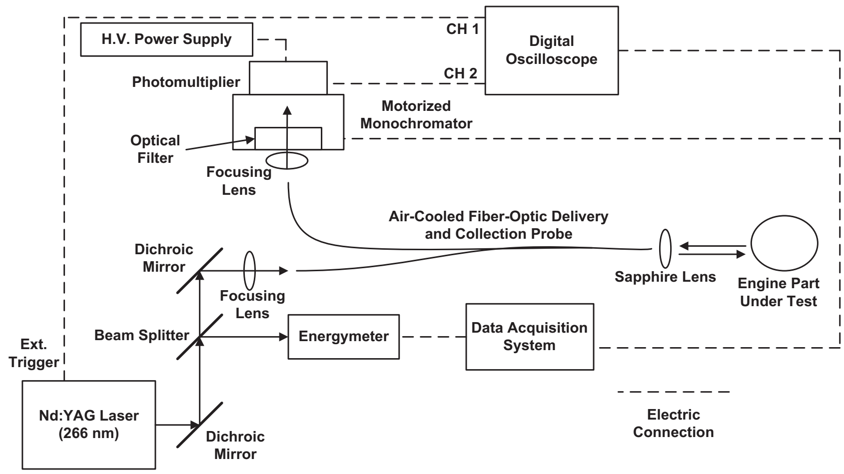

Fig. 1. Schematic showing the Nd:YAG (operating at 266 nm) laser-based system incorporating air-cooled fiber-optic probe for high-temperature 1-D intensity and decay lifetime thermographic phosphor fluorescence measurements.

incorporates a coherent fiber-optic bundle endsoscope for imaging the engine part and a large core diameter optical fiber for delivering the pulsed laser energy to the engine part. Additionally, the article discusses fluorescence intensity and decay life measurements collected from Y_2O_3:Eu and YAG:Tb thermographic phosphors as a function of temperature at the 611 nm and the 544 nm fluorescence emission lines, respectively.

2. Measurement systems description

The Nd:YAG laser-based system which is used for 1-D fluorescence intensity and decay lifetime measurements is schematically depicted in Fig. 1.

The emitted 266 nm laser beam is reflected off two dichroic mirrors and focused into the excitation 2.0 mm core diameter fused-silica step index multimode fiber by the means of a fused silica lens (FL = 60 mm). The pulsed 266 nm laser beam (4–6 ns FWHM) is generated by passing the 1.06 μm fundamental wavelength emitted from a Nd:YAG laser (Spectra Physics-Quanta Ray GCR-14, 30 Hz) through two KD*P (potassium dideuterium phosphate) crystals. The KD*P crystals are placed inside a heated enclosure to stabilize the laser output caused by ambient temperature variations and to minimize unwanted optical effects caused by water absorption. Then, the 266 nm excitation laser beam is focused into the core of a 2000 μm core diameter step-index fiber (Fiberguide Industries, Superguide G, NA = 0.4). As depicted in Fig. 2, the excitation 2000 μm core diameter fiber is surrounded by nine 1000 μm core diameter fused-silica fibers (Fiberguide Industries, Superguide G) for collecting the fluorescence signals from engine part coated with Y_2O_3:Eu (Sylvania Chemical, p/n 1137/P56-OS-RAN, Eu 4.52%) or YAG:Tb (Sylvania Chemical, p/n 1271/P53; Tb 5%) thermographic phosphors. Sapphire lens (FL = 12.7 mm, diameter = 6.35 mm) is mounted approximately 5 mm from the distal ends of the fibers to reduce the beam spot size formed at the engine part and to couple the fluorescence radiation into the nine 1000 μm core diameter fibers. The excitation and collection fibers are housed inside an air-cooled probe designed to isolate the fibers from the engine harsh environment.

The laser energy launched into the excitation fiber is monitored by reflecting 5% of the laser beam into a calorimeter (Scientech, Model 360201) using a beam splitter inserted between the two dichroic mirrors. The output of the calorimeter is read using a data acquisition system (Hewlett Packard-HP 75000B) which is programmed to average and save the laser beam readings. The

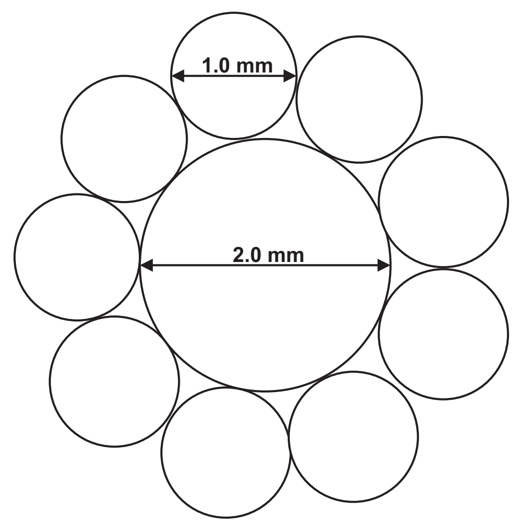

Fig. 2. Schematic showing the arrangement of the air-cooled fiber-optic probe excitation and collection fibers. The center 2000 μm diameter fiber is used for delivering the 266 nm pulsed laser beam to the phosphor coated target and the surrounding nine 1000 μm diameter fibers are used for collecting the emitted fluorescence radiation from the engine part.

collected fluorescence readings are normalized by the energy meter readings collected over the same measurement cycle.

Fluorescence radiation emitted from the phosphor is coupled into the nine 1000 μm core diameter fibers and focused into the entrance slit of a motorized Czerny-Turner monochromator (f/3.9, 0.275 m, Model: Spectra Pro 0.275, Acton Research Corp.) by the means of a fused silica lens (FL = 50 mm). A band-pass optical filter is placed behind the monochromator entrance slit to prevent the 266 nm radiation from reaching the 12-satge photomultiplier tube (Philips-XP2233B) which is interfaced with the monochromator exit slit via a quartz rod. The monochromator motor movements are controlled using the data acquisition system shown in Fig. 1. The output of the photomultiplier tube is fed into a wideband 20 dB amplifier (Comlinear Corp., Model CLC140) and then to a 350 MHz digital oscilloscope (LeCroy-Model 9450). The oscilloscope is programmed to average each measurement 300 times and is triggered externally from the laser trigger out. The averaged fluorescence reading is dumped via a GPIB (IEEE-488) interface into the data acquisition system.