Brake disc surface temperature measurement using a fiber optic two-color pyrometer

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Abstract

A fiber optic two-color pyrometer was developed for brake disc surface temperature measurement. The two-color pyrometer is composed of a fluoride glass fiber and two HgCdTe detectors equipped with bandwidth filters. The two-color pyrometer allows the measurement of brake disc temperature in the 200-800 °C range with a time resolution above 8 µs. Calibration formula for the signals obtained using a blackbody of known temperature are used to compute the true temperature of a known temperature target.

1. Introduction

The determination of the surface temperature of a brake disc requires radiometric techniques with a low response time under 1 ms. One of the most important parameters that influences the radiometric measurement during braking is the brake disc emissivity, which varies during braking. In this paper, a low response time two-color pyrometer is presented, which make possible to reduce errors in brake disc temperature measurement caused by emissivity variations during braking.

2. Principle of the method

The theory of two-color pyrometry is given in several references [1,2,3,4]. This method uses an approximation of the Planck's law [1, 5, 6, 7]:

$$L_\lambda = \varepsilon . C_1 . \lambda^{-5} . \exp\left(-C_2 / \lambda T\right) \qquad (1)$$

$C_1=3.74\times10^{-16}$ W.m^2 : $C_2=1.44\times10^{-2}$ K.m

λ: wavelength (µm) ; T: temperature (K) ; ε: emissivity.

The two-color pyrometry method measures the infrared luminance at two different wavelengths λ_1 and λ_2. Assuming that the emissivity remains constant between λ_1 and λ_2, (grey body behaviour) the voltage ratio $R=S_1/S_2$ from the wavelength outputs S_1 and S_2 is used to determine the target temperature T:

$$T = \left[C_2\left(1/\lambda_1 - 1/\lambda_2\right)\right] \Big/ \ln\left(S_{\lambda_1} / S_{\lambda_2} . A_{\lambda_2} / A_{\lambda_1} . \left(\lambda_1/\lambda_2\right)^5\right) \qquad (2)$$

A_{λ_i}: Apparatus constant of each detector

The assumption of the grey body behaviour becomes more valid as $\Delta\lambda=\lambda_1-\lambda_2\rightarrow0$ but as $\Delta\lambda\rightarrow0$ the measurement errors become more significant [1, 7]. Increasing the separation of the wavelengths reduces the effects of the luminance measurements errors. Therefore, we can determine two optimal wavelengths by studying the relative temperature uncertainty:

$$\Delta T/T = K.\Delta S/S \qquad (3)$$

where $\Delta S/S$ is the relative uncertainty on the wavelengths outputs and K a constant which depends on λ_1, λ_2,T and constant characteristic of detector. For one temperature, we can draw the curves of constant value of K in the space λ_1, λ_2 (fig. 1). The wavelengths chosen in these study are 2.55 µm and 3.9 µm, leaving to K= 1.308.

The two-color pyrometer presented in this study is composed of a fluoride glass fiber and two HgCdTe detectors equipped with bandwidth filters (see table 1).

3. Results

The two-color pyrometer was calibrated using a blackbody cavity AGEMA (emissivity =0.99±0.1). The target temperature is obtained as a function of the voltage ratio $R=S_1/S_2$ from the wavelength outputs S_1 and S_2. Figure 3 shows the data points acquired from the blackbody calibration and the exponential calibration curve.

To validate the two-color pyrometer, tests were carried out on a disc covered with a black paint. (ε=0.93±0.2).The surface temperature is measured using a K-type thermocouple. A good correlation between thermocouple and pyrometer results was obtained (fig. 4).

4. Conclusion

A two-color pyrometer with a low response time was developed that allows the brake disc surface temperature measurement of unknown emissivity. The two-color pyrometer was calibrated using a blackbody cavity. Test were carried out on a known temperature target and good correlation between thermocouple and pyrometer results was obtained. Surface temperature measurements of rotating disc are under investigation.

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Table 1. Characteristic of the two-color device

Optical Fiber	Fluoride Glass Spectral range: 0.5-4 µm Attenuation for 4 µm: 0.3 dB/m Length: 1m Transmittivity: 0.85
Detectors	Detector HgCdTe 1mmx1mm Time response: <2µs
IR Filters	Bandwith Filter Filter 1 central wavelength: 2.55 µm±2% Filter 2 central wavelength: 3.9 µm±2% Transmittivity: 0.7

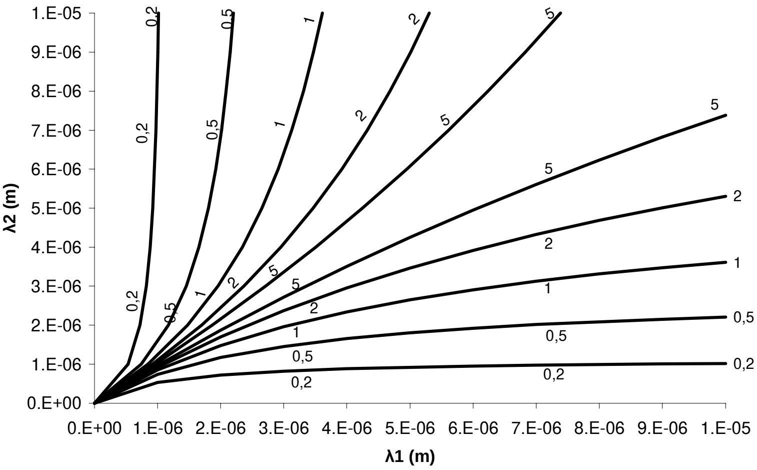

Fig. 1. "Iso-K" curves in the space (λ_1,λ_2)

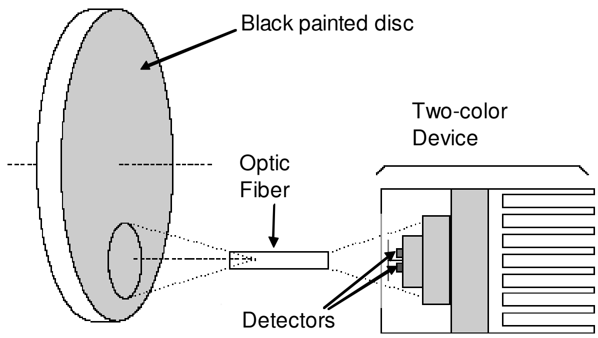

Fig. 2. Experimental device

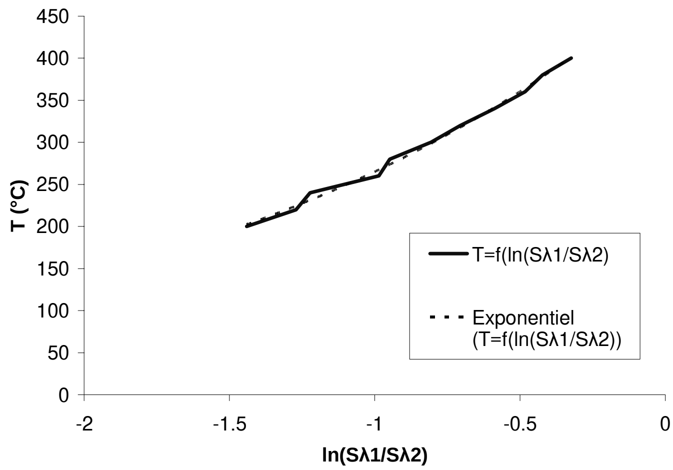

Fig. 3. Calibration Curve

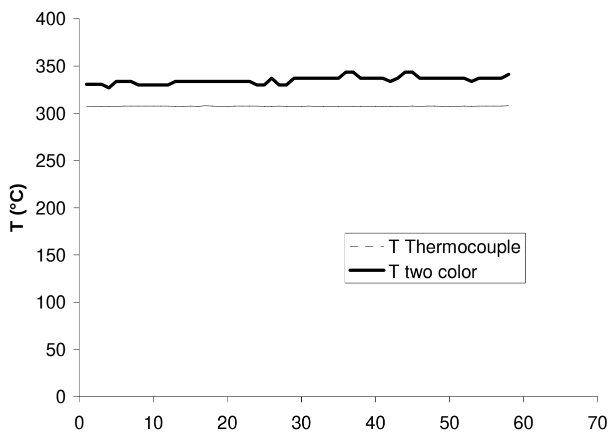

Fig. 4. Experimental Results