Optik 138 (2017) 390–397

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

# Multi-parameter calibration of streak/framing camera based on integrated optical system with delay and attenuation modules

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ARTICLE INFO

*Article history:*
Received 30 December 2016
Accepted 13 March 2017

*Keywords:*
Optical design
Calibration
Sweep speed
Temporal resolution
Dynamic range
Camera

ABSTRACT

We demonstrate a multi-parameter calibration method of the streak camera and the framing camera with the help of beam division delay and attenuation devices in an integrated optical system based on sub-picosecond short-pulse UV laser. In the designed optical scheme, the four operating modes employed the optical delay, beam division delay and attenuation, and etalon modules can be switched to synchronize the UV laser pulse with the trigger signal of diagnosis instruments, calibrate the temporal resolution and dynamic range of framing cameras, and correct the sweep speed of streak cameras, respectively. The results show that the delay time error of $\pm0.1$ ns in the optical delay module, the uniform distribution of sub-beams with the delay time precision of $\pm0.03$ ps and isocon descending energy in the beam division delay and attenuation modules, and pulse broadening of ~22% in the whole system are achieved. In the meantime, the experiment results display the sweep speed of 1.2 ps/pixel in a streak camera and the dynamic range of 131 in a framing camera. The proposed folding optical system with high-precision, low-loss and multi-function can be extensively applied in the temporal calibration of diagnosis instruments such as streak cameras and framing cameras.



## 1. Introduction

The high-resolution temporal calibration of the diagnosis instruments such as the streak camera and the framing camera is a key and difficult problem in Inertial Confinement Fusion (ICF) diagnosis research. The streak camera employed to investigate ultrafast phenomena on a picosecond and femtosecond scale is currently undergoing intense development [1–3]. The framing camera is a powerful diagnostic tool for laser-driven ICF experiments due to its high temporal resolution and two-dimensional spatial imaging capability [4,5]. With the progress of ICF experiment, some important characteristics of the diagnosis instruments such as temporal resolution, dynamic range, sweep speed, sweep linearity and exposure time, etc., have been greatly improved. For instance, the temporal resolution of the traditional streak camera is up to 10 ps [6], while that of an ultrafast x-ray streak camera reaches 233 fs defined by the Rayleigh criterion, and the spatial resolution is up to 10 μm, as mentioned in the report [7]. In the meanwhile, for the traditional framing camera equipped with a microchannel plate of 0.5 mm in thickness, currently, the temporal resolution is 100 ps [8,9], in contrast, that of the framing camera

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http://dx.doi.org/10.1016/j.ijleo.2017.03.049

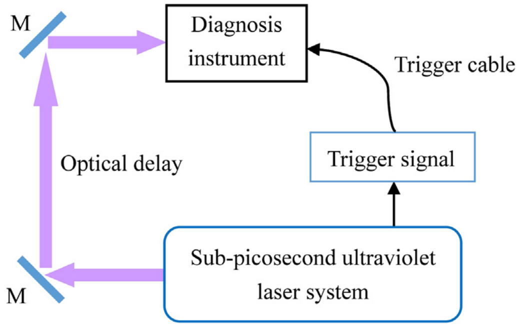


**Fig. 1.** Schematic diagram of the optical calibration system.

based on pulse-dilation technology has been up to less than 10 ps [10]. In order to make quantitative measurements meet the high accuracy requirements of ICF experiments, the streak camera and the framing camera as essential instruments are extensively characterized and calibrated. For most experiments, it is significant to calibrate their temporal resolution, dynamic range, sweep speed and sweep linearity, and the calibration results determine directly the reliability and accuracy of the whole experiments.

As mentioned above, the parametrical measurement and calibration of streak cameras and framing cameras have become increasingly important. At present, the measurement of the spatial resolution and dynamic range of the streak camera can be achieved by using a spatially and temporally calibrated etalon based on a 100 ns pulse length laser [6]. The data collection and analysis on characterizing the flat field, dynamic range, spatial resolution, temporal resolution and sweep linearity of the streak camera are standardized and automated [11]. For a framing camera, the temporal resolution and exposure time are measured using the fiber bunch [12,13]. The delay circuit can be used to synchronize the UV laser pulse with the gating electrical pulse of the diagnosis instrument [12].

In this paper, we present an optical system based on a sub-picosecond short-pulse UV laser for calibrating the characteristics of streak cameras and framing cameras, which is specially established for the ICF diagnosis system. The optical system incorporates the optical delay module (ODM), the beam division and delay module (BDDM), the beam division and attenuation module (BDAM) and the etalon module. ODM is the folding beam path used to synchronize the UV laser pulse with the gating electrical pulse for instruments and realize the switch of four operating modes with multi-function. BDDM and BDAM are the specially designed optical elements for calibrating the temporal resolution and dynamic range of framing cameras. The etalon module is applied on the calibration of the sweep speed of streak cameras.

## 2. Principles

Fig. 1 schematically depicts the principle of the optical calibration system. The sub-picosecond short-pulse UV laser beam operates at the wavelength of 248.5 nm with a pulse width of approximately 0.5 ps. The trigger signal needs to be correlated with the UV laser for synchronizing with the laser pulse. In order to minimize the time delay between the laser pulse and the trigger signal, the trigger signal is obtained from the divided beam of the laser by using a phototube with high voltage. Taking the inherent delay of diagnosis instruments and the time delay of the trigger cable into account, the gating electrical pulse is posterior to the laser pulse. Therefore, an optical delay method is designed to delay the laser pulse for synchronizing the laser pulse with the gating electrical pulse of diagnosis instruments, which is more appropriate for the optical system with large uniform spot output.

The design of ODM and BDDM is based on the principle of optical delay. The time delay $\Delta t$ originating from optical path delay $\Delta L$, their relationship can be expressed as follow

$$\Delta t = \Delta L/v = \Delta L n/\mathrm{c}, \tag{1}$$

where, $n$ is the refractive index of transmission medium, and $v$ and c are the velocity of light in the transmission medium and vacuum, respectively.

The pulse widening of the calibration light signal is an essential factor to be considered for sub-picosecond short-pulse UV laser. The Schrodinger equation is utilized to calculate the pulse widening, and the pulse propagation can be modeled by [14]

$$\frac{\partial u}{\partial z} = -\mathrm{i}\frac{\beta_2}{2}\frac{\partial^2 u}{\partial t^2} - \frac{\alpha}{2}u + \mathrm{i}\gamma|u|^2 u, \tag{2}$$

where, $t$ and $z$ represent time and propagation distance, respectively, the variable $u$ is the slowly varying amplitude of the pulse envelope, $\beta_2$ is the second-order dispersion coefficient, $\gamma$ is the cubic refractive nonlinearity, and $\alpha$ is the propagation loss in glass. The three terms on the right-hand side of Eq. (2) govern, respectively, the effects of dispersion, losses, and nonlinearity on pulse propagation.