Traceability of laser pulse energy measurements by linking reference standards for CW and pulsed measurements

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Abstract. A method linking pulse energy scale to continuous wave (CW) power scale is described. The connection between CW power and pulse energy is established by generating pulses from CW beam, and correlating the CW signal measured by reference optical power meter and pulsed-signal measured by calorimeter. In this connection CW laser source from which pulses are generated is Nd:YAG laser and the lengths of pulses adjusted are at the order of milliseconds. The realized energy scale is transferred from calorimeter to laser energy meters through using pulsed Nd:YAG laser having one fundamental (at 1064 nm) and two harmonics (at 532 nm and at 365 nm) with nano-second level pulse length.

1. Motivation
The most basic method of checking the performance of a laser is to measure accurately its power and energy. Accurate measurements of laser power and energy is key factor in making the proper decisions to be made for choosing the best equipment for the job in variety of medical, scientific, industrial and biomedical applications [1,2]. This makes it so important to properly select the suitable sensors, measurement procedures and achieve the required pulse energy measurement traceability for securing the reference measurements in the national metrology laboratories [3-6].

2. Principle and Instrument
This work constitutes two stages; first stage covers traceability of laser energy calorimeter, which is used as transfer standards for Q switch pulse laser energy measurements to the continuous wave (CW) laser power reference measurement standards, second stage covers the transfer of energy scale from laser energy calorimeter to laser energy measurement sensors.

At first stage, for the traceability of laser energy calorimeter CW Nd: YAG laser (1064 nm and 532 nm), optical power reference measurement standards (Electrically Calibrated Pyroelectric Radiometer (ECPR) and Thermal Power Meter (3A-P-SH), Scientech Astral Series S laser energy calorimeter (AC2501S), 500 MHz oscilloscope, fast Si photodiode (UPD-50-SP, Rise time <40ps) , high speed chopper (SR540, 4kHz) and some opto-mechanical accessories were used as shown in Figure 1

The work in this section was basically carried out according to the following principle: Using a high speed optical chopper CW laser beam converted to quasi pulse beams having pulse widths of order of milliseconds. Then, this beam was passed through a beam splitter such that one part of it sent to the CW reference optical power measurement standard and another part of it was sent onto the fast photodiode. Since these measurements were carried out up to 800 mW optical power levels, in order to avoid the surface damage of measurement sensors, beam was homogenized and its diameter was expanded from 6 mm to 12 mm using laser beam expander.

Similarly on the fast photodiode branch using neutral density filters (Optical Density from 0.1OD to 4.0OD) the beam power was attenuated to below the saturation level of high speed photodiode. Apart
from this beam branch, all the other laser beams emerged from the beam splitter were blocked using beam traps which are suitable for CW/Pulse laser beams up to 50 W.

Figure 1. Measurement set up for linking pulse energy to CW power

Following to these preparation processes, initially optical chopper was turned off and the laser beam along the power measurement line was dropped on the CW laser power reference measurement standard and the optical power was recorded. Then the CW laser power reference measurement standard was substituted by laser energy calorimeter and the laser chopper turned on. The optical power recorded by laser energy calorimeter is the average optical power of quasi pulse beams created by high speed optical chopper. The peak power corresponding to this average power is the power which was measured by the CW laser power reference measurement standard. To convert this average optical power to the peak power and also to calculate energy correspond to each pulse, quasi pulse widths and laser injection time parameters recorded by high speed photodiode and oscilloscope were used, see Figure 2. Pulse energy, peak and average power for the created quasi pulse were calculated using the relations given in Eqn1.

\[
P_p = \frac{E}{\Delta t} \quad \text{and} \quad P_{av} = \frac{E}{T}
\]

Where \(P_p\) is the peak power, \(P_{av}\) average power, \(E\) is the energy per pulse, \(\Delta t\) is the pulse width and \(T\) is the period of pulses.

The calibration factor for laser energy calorimeter was derived by adjusting its calibration factor such that to get the same power value as measured by the reference power meter. The measurements were done using two different reference optical power standards. From 10 mW to \(< 100\) mW optical power interval ECPR which is traceable to silicon photodiode based trap detector and from 100 mW to 800 mW optical power interval 3A-P-SH which is traceable to ECPR were used. The uncertainties corresponding to these intervals were evaluated as 4.8% and 5.2% respectively.
At second stage, for the transfer of energy scale from laser energy calorimeter to laser energy meter, Q switch Nd:YAG laser, laser energy calorimeter, laser energy meter to be calibrated which has a pyroelectric based energy sensor (J-50MB-YAG), and display, 500 MHz oscilloscope, fast photodiode and some opto-mechanical accessories were used, the schematic diagram of our setup is shown in Figure 3.

The J-50MB-YAG sensor which is designed for use with pulse lasers operating at 1064 nm, 532 nm and 355 nm wavelengths and with low repetition rates. The Q switch Nd:YAG laser has pulse energies of 400 mJ, 160 mJ and 110 mJ at 1064 nm, 532 nm and 355 nm wavelengths respectively. The pulse has approximately 6 ns pulse width, 20 Hz repetition rate and about 3 mm beam diameter. The above energies for Q switch Nd:YAG laser at 1064 nm, 532 nm and 355 nm wavelengths are the maximum energies and can be tuned to a few mJ level by adjusting related attenuators.

At this stage Q switch Nd:YAG laser at each wavelengths using attenuators were adjusted to their lowest energy levels and the beam emerged from the laser was directed to beam splitter. Where one
part of the beam was used for the energy measurements using laser energy calorimeter (reference) and laser energy meter and another part of the beam was used for determining the optical characteristics of pulse beam using high speed photodiode and oscilloscope.

On the energy measurement side in order to prevent surface damage on measurement sensors due to high current densities of laser beams, initially laser beam size were adjusted to about 12 mm using suitable beam expander for each wavelengths. Then damage threshold cards were put in front of sensors and from attenuators laser energy level gradually increased so as to determine maximum were respectively placed in front of pulse laser beam and their responses to energy values were recorded.

The laser energy calorimeter which is used as reference device has time constant of about 3 sec. So it was adjusted to record the average power within defined injection period. Then using injection period and repetition rate of pulse, corresponding energy values was calculated for the energy range from 10 mJ to 180 mJ as presented in Figure 4. Then the calibration factor of the laser energy meter was derived by adjusting its calibration factor to get the same energy values as measured by the laser energy calorimeter.

![Graph](image)

**Figure 4.** Final results of linking the scales for achieving the traceable pulse laser energy measurements

References

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