U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
PHYSICAL MEASUREMENT LABORATORY
Boulder, Colorado 80305

Report of Calibration (42240C)

LASER POWER PROBE
Macken Instruments Inc.

Detector model D3C, **S/N** 31650, **NIST ID** 686268

Meter model DM5, **S/N** 02402

Submitted by

Macken Instruments Inc.
3186 Coffey Lane, Suite 604
Santa Rosa, CA
95403

Table 1. Calibration results

Wavelength (µm)	Nominal average input power (W)	N	Calibration Factor (Rdg/ W)	Standard deviation (%)	Expanded uncertainty (*k*=2) (%)
10.6	952	10	1.0102	0.18	1.073

Calibration Summary

The laser power detector head was compared to NIST standard calorimeters [1] at a laser wavelength of 10.6 µm using a continuous wave (cw) CO_2 laser. The laser beam had a nominal annular diameter of 20 mm at 99 % of the total beam power, and was centered and normal to the detector's absorbing surface. The laser energy impinging upon the test instrument was compared to a NIST standard calorimeter and a monitor detector was used to detect the laser power changes during the measurements.

Before the measurements began, the test instrument was allowed to reach equilibrium with the laboratory environment. The ambient temperature during these measurements was approximately 21 °C ± 1 °C, with a relative humidity of 30%. The probe was cooled to 22.8 °C ± 0.9 °C (as indicated by the probe display) prior to each injection. The calibration factor was found by dividing the test instrument display reading by the calculated average incident laser power.

A summary of the measurements is given in Table 1. If the readings of the test instrument are **divided** by the appropriate calibration factor listed in the table, then, on the average, the resulting values will agree with those of the NIST measurement system. Table 1 shows the results obtained using our absolute measurement system at one power level (see Figure 1).

[1] E.D. West, L.B. Schmidt, A system for calibrating laser power meters for the range 5-1000 W, NBS Technical Note 685, May 1977

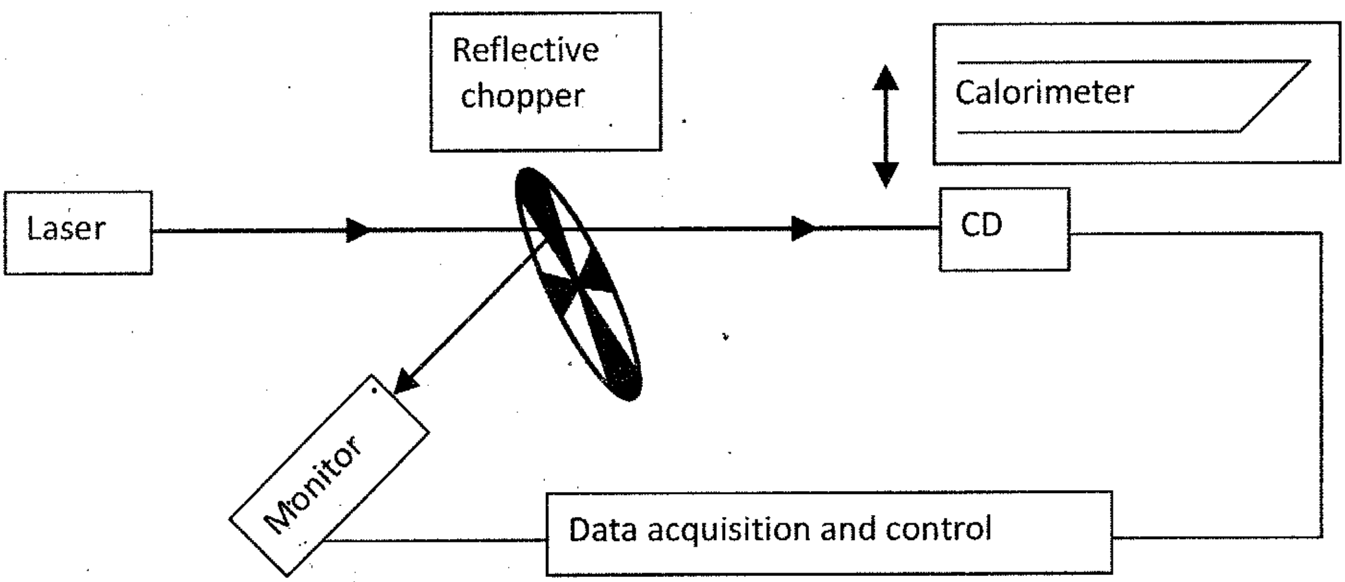

Figure 1. Measurement system diagram.

Uncertainty assessment

The uncertainty estimates for the NIST laser power and energy measurements are assessed following guidelines given in NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" by Taylor and Kuyatt, 1994. Uncertainty is separated into uncorrelated components ascribed to either Type A or Type B sources in current measurement process. Neither correlated nor unidentified uncertainty sources are significant in comparison to the identified Type A and Type B uncertainties.

Type A uncertainty components are assumed independent and normally distributed. Consequently, the relative standard uncertainty, $u_{rel,\ Type\ A}$, for each component is

$$u_{rel,\ Type\ A} = \frac{1}{\bar{x}\sqrt{N}}\sqrt{\frac{1}{N-1}\sum_{h=1}^{N}(x_h - \bar{x})^2}\ ,$$

where x_h represents the individual measurements of a value, $\bar{x}$ the average of measurements, and N is the number of measurements made.

Type B uncertainty components are assumed independent, typically with a uniform distribution. Consequently, the relative standard uncertainty, $u_{rel,\ Type\ B}$, for each component is typically

$$u_{rel,\ Type\ B} = \frac{\delta_{rel}}{\sqrt{3}}\ ,$$

where the value has an equal probability of being within the region, $\pm\delta_{rel}$, and zero probability of being outside that region.

Certain uncertainty sources arise from both Type A and Type B uncertainty components. Consequently, the relative standard uncertainty, $u_{rel,\ c}$, for each combined component is

$$u_{rel,\ c} = \sqrt{\sum u_{rel,\ Type\ A}^2 + \sum u_{rel,\ Type\ B}^2}\ .$$

The relative expanded uncertainty U_{rel} combines relative standard uncertainties u_{rel} in quadrature, multiplying this result by a coverage factor $k = 2$ where such an expansion supports a 95% confidence interval. The expanded relative uncertainty, U_{rel}, is then

$$U_{rel} = 2\sqrt{\sum u_{rel}^2}\ .$$

Relative uncertainties used to calculate the relative expanded uncertainty of the calibration factor are listed in Table 2. The number of decimal places used in reporting the mean value of the calibration factor listed in Table 1 was determined by expressing the total NIST uncertainty to at least two significant digits.

Table 2. Calibration uncertainties

Source	Standard uncertainty (type)
Inequivalence	0.14 % ($u_{rel,\ Type\ B}$)
Absorptivity	0.34 % ($u_{rel,\ Type\ B}$)
Heater leads	0.19 % ($u_{rel,\ Type\ B}$)
Electronics	0.058 % ($u_{rel,\ Type\ B}$)
Electrical calibration	0.017 % ($u_{rel,\ Type\ A}$) (N=53)
Laser/System instability	0.29 % ($u_{rel,\ Type\ B}$)
Optical shutter	0.027 % ($u_{rel,\ Type\ A}$) (N=3)
Reflective Chopper Attenuator - 1	0.085 % ($u_{rel,\ c}$)
Reflective Chopper Attenuator - 2	0.12 % ($u_{rel,\ c}$)
Test meter measurements	0.057 % ($u_{rel,\ Type\ A}$) (N=10)
Beam splitter measurements	0.041 % ($u_{rel,\ Type\ A}$) (N=3)

Report reviewed by:

MATTHEW SPIDELL Digitally signed by MATTHEW SPIDELL Date: 2022.06.17 10:46:15 -06'00'

Matthew Spidell, Leader
Laser Power and Energy Meter Calibrations Project
Sources and Detectors Group
Applied Physics Division

Report prepared and calibration performed by:

KYLE ROGERS Digitally signed by KYLE ROGERS Date: 2022.06.16 17:37:25 -06'00'

Kyle Rogers, Calibration Leader
Sources and Detectors Group
Applied Physics Division