

Noval calibration method for mass comparator based on optical force below milligram

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1 Introduction of Photon force for sensitivity calibration

Photons have momentum, in mass or force and optical metrology fields, the small mass used for the sensitivity calibration of mass comparator can be traceable to SI using the laser power in (1):

$$m = \frac{nP}{cg} (2R + A) \cos \theta, \quad (1)$$

where g is the acceleration of gravity, c is the speed of light, P is the incident laser power, and n is the number of reflections of the laser at the sensing mirror. R is reflection ratio, and A is the absorptivity of the mirror and θ is the angle of incidence of the laser on the sensing mirror.

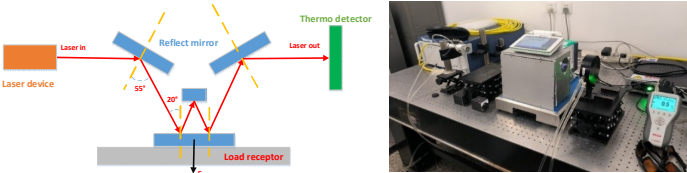


Figure 1. Experimental setup and the diagram of laser path for generation of photon force.

2 Experimental setup

As shown in Figure 1, the laser source used in the experiment is the RFL-C1000 fiber laser from Raycus, and the laser central wavelength is 1080 nm. The laser beam diameter of laser is about 10 mm. The XPR56 balance from Mettler Toledo with resolution of 1 μ g is used as the test balance. Two reflection at an angle of 20° occurs at the top surface of load receptor of the balance. The reflectivity of mirrors used is higher than 99.99 % under the laser wavelength of 1080 nm.

Figure 2 shows the test results of indication of mass comparator under photon force of laser power from 20 W to 120 W in 10 cycles.

Laser power from 20 W to 120 W as different sensitivity mass standards are used to test the linearity of the calibration system for balance. The reference value of laser power is from thermopile power meter.

3 Results and discussion

Table 1 shows the measurement uncertainty of laser power of 20 W (about 30 μ g) as sensitivity mass standards, which shows that the expanded uncertainty is 1.35 % ($k = 2$).

Figure 3 shows the linearity results for laser power from 20 W to 120 W applying on balance, which shows that the repeatability and linearity of laser power as mass standards is good.

For that the fixed applied photon force on mass comparator, and applied on the centre of the load receptor, the eccentricity can be neglect during the uncertainty evaluation. The scale interval of balance is 1 μ g so the contribution of scale interval during the calibration of balance at 30 μ g is also calculated in Table 2. The expanded uncertainty of 30 μ g is 1.1 μ g ($k = 2$).

The sensitivity (s) of balance can be calculated according to OIML R111(2004E), and the results are showed in Figure 4. The average value of sensitivity is 0.971, and the max deviation is 0.014.

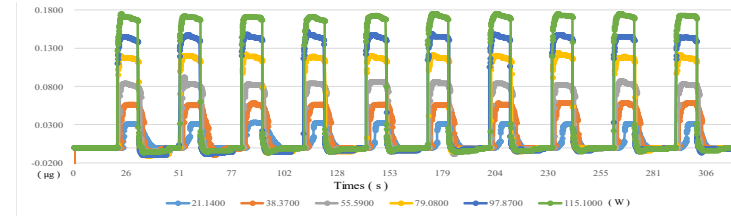


Figure 2. Test results of indication of mass comparator under photon force of laser power from 20 W to 120 W in 10 cycles.

Table 1. Uncertainty of laser power of 20 W (30 μ g) as sensitivity mass standards.

Uncertainty source	Value	Sensitivity coefficient	Uncertainty contribution
Laser power by thermopile, $u_{\text{thermopile}}$	0.60 %	1	0.60 %
Mirror reflectivity, u_{mirror}	0.05 %	1	0.05 %
Laser incidence angle, u_{angle}	0.30 %	1	0.30 %
Standard uncertainty, $u_{\text{laser}}, k = 1$	/	/	0.67 %
Expanded uncertainty, $U_{\text{laser}}, k = 2$	/	/	1.35 %

Table 2. Uncertainty of error of balance when sensitivity weights generated by photon force from laser power of 20 W.

Source	Uncertainty contribution
Reference weight from photon force, u_{laser}	30 μ g $\times$ 0.67 % = 0.20 μ g
Repeatability, $u_{\text{repeatability}}$	0.30 μ g
Scale interval of balance of no-load, u_{d0}	0.29 μ g
Scale interval of balance when loaded, u_{d1}	0.29 μ g
Standard uncertainty, $u(m_s - I_s), k = 1$	0.546 μ g
Expanded uncertainty, $U(m_s - I_s), k = 2$	1.1 μ g

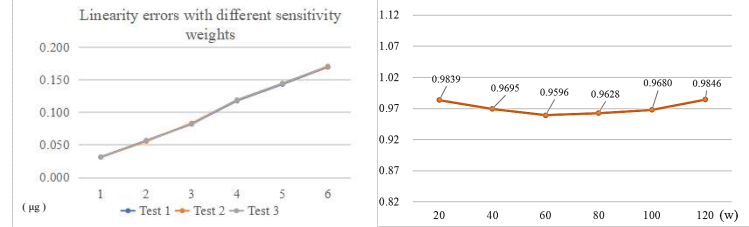


Figure 3. Linearity errors ($m_s - I_s$) for laser power from 20 W to 120 W applying on balance. Figure 4. Sensitivity results (m_s/I_s) for laser power from 20 W to 120 W applying on balance.

4. CONCLUSIONS

Laser power measured with laser power meter is used as reference sensitivity mass standards to calibrate the error of balance in micro gram level.

The sensitivity calibration for mass comparator based on laser optical force was carried out using an optical power range between 20 W and 120 W (approximately equal to gravity force of 30 μ g to 170 μ g weights) at a wavelength of 1080 nm. The air density meter is used to sense the stability of the laser power and optical force. Uncertainty of measurement is evaluated. With a coverage factor $k = 2$, relative expanded uncertainty of reference sensitivity mass standard using photon force of laser is better than 2 %. The expanded uncertainty of 30 μ g is 1.1 μ g ($k = 2$).

5. REFERENCES

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