Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 3, 316-320

Comparative Analysis of Methods for Measuring Laser Power

Tsanko Karadzhov
Technical University of Gabrovo
Gabrovo, Bulgaria
karadjov_st@abv.bg

Lyubomir Lazov
Rezekne Academy of Technologies
Rezekne, Latvia
llazov@abv.bg

***Abstract*. The application of lasers in many fields of technology and medicine is constantly increasing. This causes the development of new physical methods and principles for correct measurement of power, energy, and other parameters of laser sources. In most cases, the correct measurement of the laser power is important because the quality of the processes in which laser sources are used depends on it. In the paper, a comparative analysis of the existing methods for measuring the power and energy of laser radiation of diverse types of laser sources is made. This research aims to help users of laser equipment to choose the right measurement method depending on the laser source.**

Keywords: laser power, measurement methods, types of measuring devices, physical principles.

I. Introduction

The main parameter it requires control during laser processing is the power of laser radiation and its stability during the technological operation. Currently, many methods have been developed to measure the power of laser radiation because in recent years, the laser industry has developed extremely fast, with more new laser sources with new wavelengths, higher power and energy, frequencies, and modes of operation. For measurement, the power of laser radiation is necessary radiation receiver, which converts radiation into an electrical signal subject to measurements [12]. The existing radiation receivers work on various physical principles, but the most distribution received photoelectric and thermal receivers. The result and the quality for each specific laser technology such as laser welding, cutting, marking, engraving, drilling, etc. depend on many factors, including laser power therefore its measurement and control is important.

II. Classification of laser power measurement methods

In fig. 1 shows the classification of methods for measuring laser power. Nowadays, a wide range of high precision laser power meters are available, suitable for all professional users, some of which require high measurement accuracy. The large ranges of power and energy to be measured require a considerable number of devices because the range of any one device is relatively limited but there are already also measuring devices that are relatively insensitive to wavelength, because the greater the useful range, the less devices need to be designed, tested, calibrated, and maintained. An advantage of calorimeters, which convert radiant energy into heat and measure the amount of heat, is that they can be designed to work over a wide range of wavelengths. There are companies on the market that offer universal laser power meters capable of measuring powers from 100 µW to 200 W over a wide wavelength range from 250 nm to 11 µm. Such a meter is suitable for measuring the power of both CW and pulse lasers such as diode lasers, dye lasers, CO^2 lasers, HeCd lasers, Nd:YAG lasers and others. The operating conditions also affect the measurement. Single pulses usually require an energy measurement and CW lasers require power measurement. In some cases, it is necessary to use high-speed laser power measurement devices [6]. What has been said so far defines the wide variety of methods and principles for measuring laser power – fig. 1.

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7252

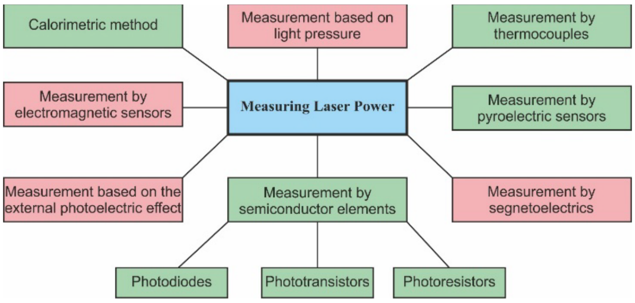

Fig. 1. Classification of methods for measuring laser power.

III. Methods for Measuring the Power of Laser Radiation

A. Thermocouple laser power meter

The thermopile consists of a central, light-absorbing disk, thermocouples that surround this disk, and an annular heat sink around the ring of thermocouples – fig. 2. Laser energy falls on the absorbent disc and is converted into heat [2]. The heat then passes through the disk from the thermopile to the radiator, which is supported at a constant ambient temperature by forced cooling. The temperature difference between the absorber and heat sink is converted into an electrical signal by the thermocouples, then an electronic system converts this signal into a laser power reading.

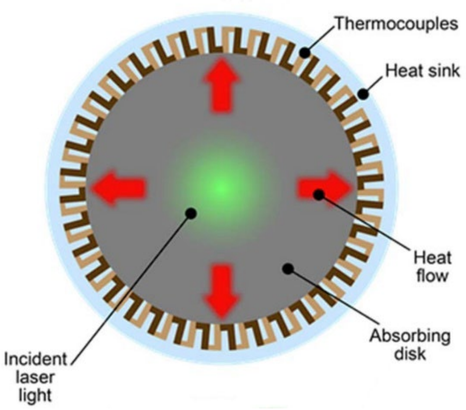

Fig. 2. Construction of thermopile.

Thermocouple sensors have the following advantages, wide spectral range, operation in a wide power range, high damage-resistance when measuring powerful laser radiations.

B. Measurement of laser power with pyroelectric sensors

The operation of pyroelectric receivers is fundamentally on the occurrence of charges on special faceted noncentrosymmetric crystals at temperature changes.

The output signal of pyroelectric receivers is proportional to the rate of change of the temperature of the sensitive element, which determines their high speed and rapid action – fig. 3. When a light pulse hits the absorbing surface of the detector, it heats up and polarizes the crystal, thereby creating an equal and opposite charge on both surfaces of the detector. The surface of the detector is metallized, so the charge is collected on the parallel capacitor, regardless of where the laser beam falls on the surface [5]. Therefore, the charge on the capacitor is proportional to the pulse energy. After the pulse ends, the capacitor voltage is measured by an analog-to-digital converter and then the capacitor is discharged to measure the energy of the next pulse. The advantages of pyroelectric receivers are high speed and sensitivity. The main disadvantage is the need for modulation when measuring continuous radiation. For this reason, pyroelectric detectors are particularly suitable for measuring pulse energy in pulsed lasers. They can measure up to several thousand pulses per second and at the same time are quite sensitive. Their disadvantage is that they are not particularly durable, and for this at higher energies and powers, an optical filter is placed in front of the sensor crystal to reduce the energy on the pyroelectric crystal. Pyroelectric sensors for pulse energy measurement are now available that use an innovative technology that allows pulse measurements over a wide range, from long pulses up to 20 ms to pulses with repetition rates up to 25 kHz.

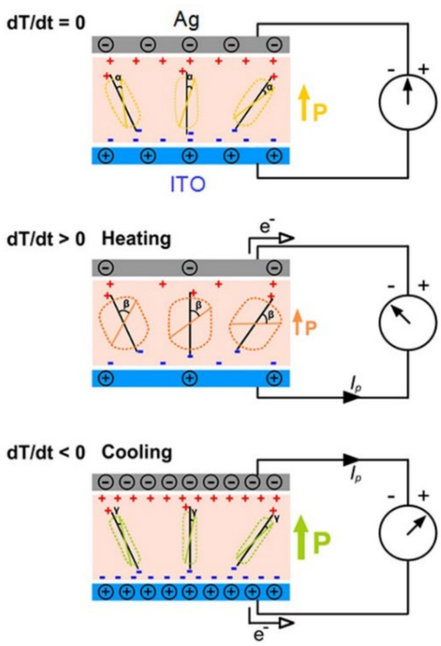

Fig. 3. Pyroelectric detectors [8].

C. Colorimetric sensors for laser power measuring

The calorimetric method is based on the thermal effect of optical radiation. Laser calorimetry is the measurement of laser power or energy by measuring the increase in temperature of an optical absorber irradiated by a laser beam. Radiation falls on the optical absorber, under the influence of which the temperature of the optical absorber changes [1]. By measuring the difference in the temperature of the absorber compared to the ambient temperature, one can find the energy or power of the incident radiation. Instruments that measure energy parameters of lasers in this way are called calorimeters [3]. The absorbers of the calorimeter, as a rule, are devices that are types of black bodies, for example, a cone blackened inside. At the top of the cone is a fast-acting temperature sensor, such as a semiconductor bolometer or a thermistor, whose resistance changes with temperature. The absorber can also be made in the form of a sphere, inside which there is an insulated wire, the resistance of which changes under the influence of the thermal effect of radiation. There are calorimeters hold two absorbers, one of which is under the action of ambient temperature, and the measured radiation falls on the other. The absorbers must be identical. In this case, they are measured not the absolute values of the temperatures of the absorbers are measured, but their difference, which significantly increases the accuracy of measurements. These are the so-called differential calorimeters. The operation of the calorimeter can be described using the simplified equation for heat conduction:

$$mc\frac{dT}{dt} + \alpha S\Delta T = \Phi \qquad (1)$$

where m is the mass of the absorber; c – specific heat capacity; α is the coefficient of heat exchange between the absorber and the environment; S is the surface area through which heat exchange occurs; ΔT is the temperature difference between the absorber and the environment [16].

D. Laser power measurement with photodiodes

The photodiode measurement principle is one of the most common methods for measuring the power of laser radiation. Photodiode sensors convert incident laser photons into charge carriers (electrons and holes), which are then measured as voltage or current. The action of the photodiode is based on increasing the reverse current of the p-n junction when it is illuminated, which is practically used to measure the intensity or power of laser radiation. Measuring the power of laser radiation with photodiodes has several advantages. They have low noise and high sensitivity, which allows them to be used in measuring of lasers with extremely low radiation power. The photodiode has the fastest response of all optoelectronic photodetectors, which is also its greatest advantage. It can be used to measure fast-changing laser radiation. The photodiode can work in two modes – photoconductive (fig. 4) and photovoltaic (fig. 5) mode, and both modes can be used to measure the intensity of laser radiation. To measure the power of pulsed lasers, so-called PIN photodiodes are used, which have a greater speed than traditional photodiodes with a PN transition [10].

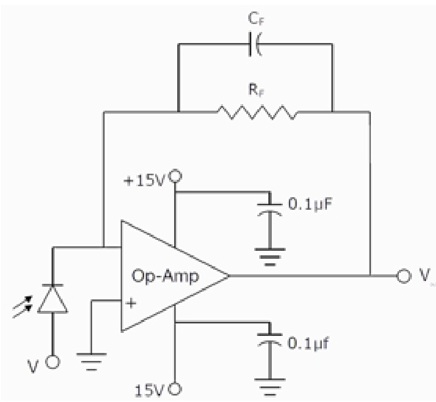

Fig. 4. Photoconductive mode [9].

Most laser power measurement circuits use light to voltage converter at which the output voltage is proportional to the luminance over the active area of the photodiode created by the laser beam fig. 4 and fig. 5. The other important advantage when measuring with photodiodes is that they have a linear light-to-current conversion characteristic, which allows more correct measurements to be made. There are also power meters that use light to frequency converter with a photodiode at the input in which the number of pulses per unit time is proportional to the power of the laser radiation.

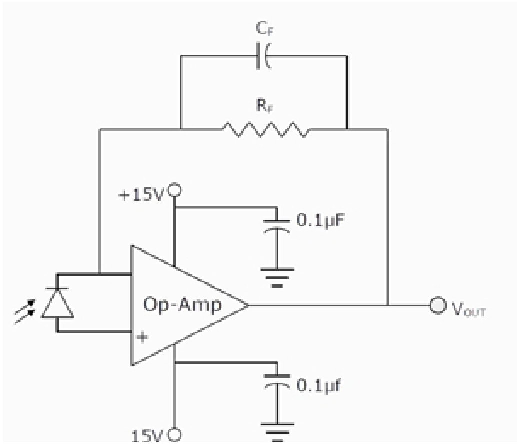

Fig. 5. Photovoltaic mode [9].

IV. Comparative Analysis of Laser Radiation Power Measurement Methods Depending on the Type and Power of the Laser

A. Criteria for choosing a method for measuring the power of laser radiation

Choosing a sensor and method to measure laser power or pulsed laser energy is an essential and important task. When choosing a type of device to measure, it is not always enough to know only the power range of the device and the laser, but also to consider other important characteristics of the laser that can help to choose the right method and measuring device [4]. Considering besides the power and some other important characteristics of the laser source, the choice of the most appropriate device can be optimized for accurate and correct measurements of laser power or energy without causing damage to the measuring device for a long time.

We will look at the choice of measurement method in a few steps.

1. To select the correct method for measuring laser power or energy, the operating characteristics of the laser source must be known. The wavelength of the laser must be known because there are measurement devices that can only be used to measure the power of lasers with specific wavelengths, i.e., have a narrow measurement range. Beam diameter - on which the power or energy will be measured, is the next essential element. This parameter will determine the size of the sensor's sensitive area and whether it is necessary to use optical extension lenses for the corresponding length of the laser source. One should not

choose to measure the power or energy at the focal point of the laser beam. It is recommended that the measurement sensor be positioned either before or after the laser focus point.

It is also important to know whether the laser is CW or pulsed and whether power or pulse energy will be measured.

CW Lasers – Continuous wave lasers are measured using average power from µW to kW. When choosing a device to measure CW laser power, one must consider what the average power will be measured. If the laser power variation range is too large, two different measurement sensors may be needed. One for low and the other for high laser power. It is important to choose a device where the power of the laser source is close to the middle of the device's measurement range, not at the lower or upper end of the range, as that is where the sensors have the highest measurement accuracy.

CW Laser – Exposure Time. Another criterion when choosing a device is to know the duration during which the laser beam will be on the sensor. Are only periodic measurements needed or will the laser beam be on the sensor the entire time the laser is running. If the laser beam hits the sensor all the time, either a larger sensor with air fins or one with a built-in fan to continuously cool the sensor will be needed.

Pulsed Lasers. With pulsed lasers, it is important to determine the energy of the pulses to be measured and from there select a measuring device with the appropriate range.

Pulse Width. The determination of the pulse width can also influence the choice of a suitable measurement device, as this parameter can reach the sensor's destruction threshold although the average laser power is less and lies within the measurement range of the device.

Pulse Rate. Another parameter to consider is the pulse repetition rate. From here it can be understood whether a device to measure the pulse energy is needed or whether a device to measure the average power of the laser source will be used. There are already pulse energy sensors on the market that can work up to 20 kHz pulse repetition rate.

2. The type of measurement to be performed must be specified.

Average Power. With most lasers, regardless of whether they are CW or pulsed, a measuring device can be used to measure the power of the laser radiation and as a result we will get a value for the average power of the laser. It is important to say that sensors that are designed to measure average power are slower. When measuring pulsed lasers with an average power sensor, there can be a discrepancy between the actual efficiency of the laser and the resulting measurement results since the energy characteristics of the pulses cannot be measured. When using a pulsed laser with a pulse repetition rate of a few kilohertz, is suitable to use a measuring device with a pyroelectric sensor that can measure the energy of each pulse is used and at even higher frequencies it is advisable to use photodiodes as measurement sensors. For powerful lasers working in CW mode, it is best to use calorimetric measuring devices.

The main result of the comparative analysis is fixed in Table 1 which shows comparison of laser power measurements methods. This table can be useful when choosing a method and device for measuring the power of laser radiation depending on the most important parameters of laser sources.

TABLE 1 COMPARISON OF LASER POWER MEASUREMENT METHODS

Feature	***Thermo-pile***	***Photo-diode***	***Pyro-electric***	***Calori-meter***
Spectral Range	Broad-band	narrow band	narrow band	Broad-band
Power Range	Low to medium	Low	Low to medium	Very high
Signal	Voltage (V)	Current (A)	Voltage (V) or	Voltage (V)
Response time	High	Low	Low	High
Wavelength dependent	No	Yes	No	No
Linear response	Yes	Yes, up to saturation	--	--

V. CONCLUSION

The aim of the paper is to be useful to engineers involved in laser technology in choosing a system for measuring the energy or power of laser radiation.

To achieve this aim in the paper, a comparative analysis of the most used methods for measuring the power of laser radiation is made, depending on the type and power of the laser and the accuracy of measurement. To determine the correct measurement system, it is very important to know which parameters of the laser radiation are to be measured. A methodology has been developed that covers the main criteria for choosing a method for measuring the laser power.

REFERENCES

[1] Y. Klimkov, M. Horoshev, Lazernaya Tehnika, Uchebnoe posobie – M.: MIIGAiK, 2014, UDK 621.375.826 (075.8).

[2] S. Bergman, Laser power measurement: Time is money, Industrial laser solutionst for manufactoring, Santa Clara, CA.

[3] D. A. Jennings, E. D. West, K. M. Evenson, A. L. Rasmussen, and W. R. Simmons, Laser Power and Energy Measurements, Nat. Bur. Stand. (U.S.), Tech. Note 382, 64 pages (Oct. 1969).

[4] [Online]. Available: https://www.ophiropt.com/laser--measurement/laser-measurement

[5] A. Shemyakin, M. Rachkov, M. Yakimov, Izmerenie moshtnosti lazernogo izluchenia tehnologicheskogo kompleksa s nesamostoyatelnyim tleyushtim razryadom, 2009, UDK 681.326.74.

[6] Pulov, D., T. Karadzhov, Optoelectronic Device for Measuring the Power of Laser Radiation. Environment. Technology. Resources. Rezekne, Latvia, Proceedingsofthe 13th International Scientificand

Practical Conference. Volume 3, 286-290, 2021, DOI: 10.17770/etr2021vol3.6590.

[7] J. A. Hadler, C. L. Cromer, and J. H. Lehman, NIST Measurement Services: cw Laser Power and Energy Calibrations at NIST, NIST Special Publication (2007), Vol. 250–75.

[8] [Online]. Available: https://www.findlight.net/blog/laser-detectors-a-primer/

[9] [Online]. Available: https://www.aptechnologies.co.uk/support/SiPDs/circuits

[10] Lazov, L., T. Karadzhov, Methods for Measuring Laser Power. Environment. Technology. Resources. Rezekne, Latvia, Proceedings of the 13th International Scientific and Practical Conference. Volume 3, 173-180, 2021, Online ISSN 2256-070X, DOI: 10.17770/etr2021vol3.6565.

[11] I. Ryger and et al, "MEMS Non-Absorbing Electromagnetic Power Sensor Employing the Effect of Radiation Pressure," in Proceeding at the Eurosensors, Graz, Austria, 2018, DOI: 10.3390/proceedings2130767.

[12] N. Angelov, "Investigation the Influence of the Number of Repetition and Volumetric Energy Density on Laser Marking of Products," Journal of the Academy of Sciences and arts of the Republic of Srpska „Contemporary Materials, vol. V, no. 2, pp. 250-253, 2014, DOI: 10.7251/cm.v2i5.1738.

[13] K. Agatsuma, D. Friedrich, S. Ballmer, G. DeSalvo, S. Sakata, E. Nishida, and S. Kawamura, "Precise measurement of laser power using an optomechanical system," Opt. Express 22(2), 2013–2030 (2014).

[14] S. A. Kuznetsov, A. G. Paulish, M. Navarro-Cía and A. V. Arzhannikov, "Selective Pyroelectric Detection of Millimetre Waves Using Ultra-Thin Metasurface Absorbers," Scientific Reports, vol. 6, 16 Feb 2016, DOI: 10.1038/srep21079.

[15] P. Williams, J. A. Hadler, F. C. Maring, R. Lee, K. A. Rogers, B. J. Simonds, M. T. Spidell, A. D. Feldman and J. H. Lehman, "Portable, high-accuracy, non-absorbing laser power measurement at kilowatt levels by means," Opt. Express , vol. 25, p. 4382–4392, 2017.

[16] Dichev, D., I. Zhelezarov, N. Madzharov. Dynamic Error and Methods for its Elimination in Systems for Measuring Parameters of Moving Objects. Transactions of Famena, volume 45, issue 4, 2021, pp. 55-70, DOI: 10.21278/TOF.454029721.