PROCESSING OF SIGNAL OF PYROELECTRIC SENSOR IN LASER ENERGY METER

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Abstract

In this paper the principles of measuring the energy of pulse light sources (especially pulse lasers), using pyroelectric sensors, are presented. The theoretical principles of operation pyroelectric sensors are described, as well a conversion system of pyroelectric sensor signal, enabling to reduce the influence of acoustic, thermal, and electromagnetic interference, influencing the sensor.

1. Introduction

Pulse radiation sensors may be divided in two basic groups: photon detectors and thermal detectors, in which the radiation absorbed is first converted into heat that, in turn, causes a measurable effect. The main difference between photon and thermal detector lies in the fact that the first measures the radiation power, and the latter – the radiation energy.

Among thermal detectors the following examples may be mentioned: pyroelectrics, thermocouples, thermistors, and bolometers. Particularly important group of elements are pyroelectrics. Pyroelectric detectors have many properties in common with other thermal converters. In particular, they show uniform spectral characteristic in a relatively wide range of radiation wavelength. Unlike other thermal sensors, the output signal of pyroelectric sensors depends on temperature change in pyroelectric material, and not on temperature value. The response speed of pyroelectric detector is limited mainly by electric parameters of equivalent diagram of the sensor and the amplifier circuit. These sensors enable to measure radiation pulse energy in the ranges of time below nanoseconds.

Pyroelectric sensors show high acoustic, thermal, and electromagnetic interference sensitivity, which, consequently, may cause problems in discerning a useful signal at the noise background. The experience of the author pointed out that in some cases the lowest measuring ranges of laser energy meters, manufactured even by recognized producers, are of little use due to the interference background. The use of simple ways to avoid the interference, for example cylindrical screens on the package of pyroelectric sensor, improves the measurement confidence to only slight degree.

2. Working principle of pyroelectric sensors

Pyroelectric sensor as such is a capacitor formed by depositing metal electrodes on a both surfaces of the thin slice of pyroelectric material. The absorption of the radiation pulse of power $P(t)$ by the pyroelectric material results in a change in its temperature with the value of ΔT, which causes a polarisation change, and, consequently, results in displacement of electric charges in the pyroelectric material, hence the displacement current $I_p(t)$ occurs [1]. It is possible therefore to accept the interpretation, that the capacitor of pyroelectric sensor is loaded from current source $I_p(t)$, induced by heat flux absorbed by the sensor [2, 3]. The equivalent circuit in Fig.1 illustrates this interpretation.

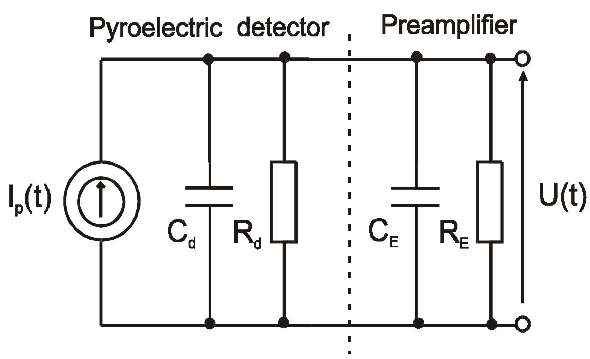

Fig.1. Equivalent circuit of pyroelectric sensor and preamplifier

The equivalent circuit contains current source $I_p(t)$, sensor's capacitance C_E, and leakage resistance of the pyroelectric material R_d of the dielectric. In the diagram also the equivalent parameters of load circuit (of the preamplifier) – capacitance C_E and resistance R_E are placed.

Assuming the uniform structure of the pyroelectric material and uniform heating, the current $I_p(t)$ may be determined from relationship:

$$I_p = p \cdot \frac{dT}{dt} \cdot S \tag{1}$$

where:

– p – pyroelectric coefficient

— dT/dt speed of temperature changes of the pyroelectric material

– S – surface area of the sensor electrode.

Let us assume that there are no additional heat losses, the duration of measured radiation pulse t_I is very short and it meets inequality:

$$t_I \langle\langle \tau_E \langle\langle \tau_C \tag{2}$$

where:

– τ_E – electric time-constant of the whole electric circuit:

$$\tau_E = \frac{R_d \cdot R_E}{R_d + R_E} \cdot (C_d + C_E) \tag{3}$$

– τ_C – thermal time-constant of the sensor.

Then it is possible to assume that the speed of temperature changes of the pyroelectric material is a linear dependence of the power of radiation $P(t)$ falling on the sensor – relationship:

$$\frac{dT}{dt} = \frac{\alpha}{c_d \cdot \rho \cdot S \cdot d} \cdot P \tag{4}$$

where:

– α – absorption coefficient of radiation falling on the sensor

– c_d – specific heat of the pyroelectric material

– ρ – density of the pyroelectric material

– S – surface of the sensor electrode

– d – thickness of the pyroelectric material slice

Putting relationship (4) into relationship (1), we obtain formula (5) describing the intensity of displacement current $I_p(t)$:

$$I_p(t) = \frac{p \cdot \alpha}{c_d \cdot \rho \cdot d} \cdot P(t) \tag{5}$$

Including the coefficient called current sensitivity of the sensor r_I:

$$r_I = \frac{p \cdot \alpha}{c_d \cdot \rho \cdot d} \tag{6}$$

we obtain relationship:

$$I_p(t) = r_I \cdot P \tag{7}$$

From this relationship it follows that displacement current $I_p(t)$ induced with heat flux is proportional to the temporary value P of the radiation pulse.

In practice, time-constant τ_E, determined from relationship (3), will be decided upon detector's capacitance C_d and input resistance R_E of the voltage preamplifier. Fitting an appropriately large value R_E or limiting the maximal duration of the radiation pulse measured, one can assume that inequality (2) is satisfied as far as the relations between the pulse duration and the electric time-constant of the circuit and the thermal time-constant of the sensor are concerned. This means that the value of output voltage signal $U(t)$ is actually decided by the effect of integration of current I_p of the current source, obtained in the effect of loading the equivalent capacitor with capacitance $C = C_d + C_E$. The value of output voltage signal is given by:

$$U = \frac{1}{C} \int_{t_I} I_p(t) dt \tag{8}$$

Putting current $I_p(t)$ described with relationship (7) into formula (8), we obtain relationship (9) describing peak voltage U_{max} after the duration t_i of the radiation pulse:

$$U_{\max} = \frac{1}{C} \cdot r_I \int_{t_I} P(t) dt \tag{9}$$

Accepting energy definition $E = \int_{t_i} P(t)dt$ we obtain finally the relationship of peak input voltage on the radiation energy pulse measured:

$$U_{\max} = \frac{r_I}{C_d + C_E} \cdot E \qquad (10)$$

where:
- E – energy of the radiation pulse measured
- r_I – current sensitivity of the sensor

Fig. 2 shows an exemplary course of voltage response of the pyroelectric sensor to the laser pulse.

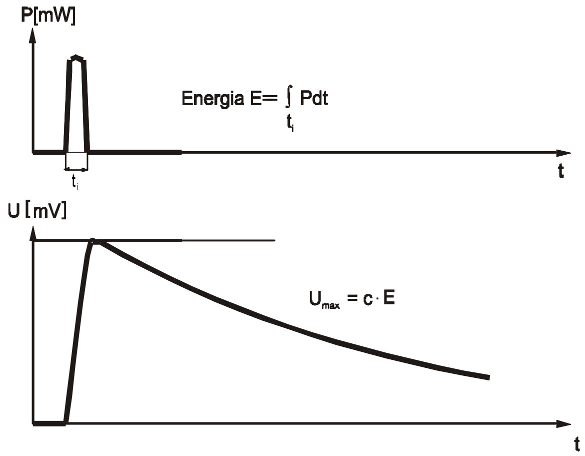

Fig.2. Response of pyroelectric sensor to a short laser pulse

The energy measurement depends on determining the maximal value U_{max} of voltage signal response of the pyroelectric sensor, which is proportional to the energy of the radiation pulse. Reaching the maximal value is followed by exponential decay of the curve of voltage signal with the speed determined by electric time-constant τ_E of the whole circuit, allowing for the equivalent circuit of the sensor and the load circuit.

3. Amplifier-and-converter system of pyroelectric sensor signal

A typical block diagram of conversion system co-operating with the pyroelectric sensor is not complex. The system consists of elements such as preamplifier, amplifier of adjusted amplification, peak sensor, and analog-to-digital converter. The problem of obtaining an appropriate operating quality of such circuit requires, among others, the use of such technical solutions that enable to reduce the influence of interference to which the pyroelectric sensor is sensitive. All pyroelectric sensors are also characterised by piezoelectric properties, and therefore show high sensitivity to acoustic interference. Besides, there is also an influence of thermal and electromagnetic disturbances on the useful signal. Consequently, one can observe great scatters of measurement results, particularly when low measuring ranges of laser energy meters are used.

The research conducted in Institute of Electronics and Telecommunications resulted in the design of a conversion system, which task is to reduce the influence of disturbing factors. The principle of this circuit is the differential measurement in which the value of background signal is stored before the measurement. After the appearance of useful signal added with the background, follows the operation of subtraction of the stored background signal.

The system diagram is shown in Fig. 3. The signal from pyroelectric sensor is amplified by means of an amplifier with adjusted amplification and then it is given to the input of the conversion system. For proper operation of the conversion system it is necessary to deliver information (trigger pulse) about the moment, in which the pulse of the laser occurs. Before the measurement analogues switches K1 and K2 are closed. Therefore the temporary voltage value across capacitor C1 changes together with the changes of background signal. Directly before the laser flash a trigger pulse appears, which causes analogues switches K1 and K2 to be opened through a control system. As a result the voltage value of signal containing information about background component is stored by capacitor C1 in just before the laser flash. After the laser flash a voltage signal of output probe containing the background component and the useful component occurs. Therefore we observe the voltage applied to the input of peak detector being the difference of the both signals, and as a result the background signal is eliminated. The value of the signal stored by the peak detector is converted in digital form by means of A/D converter.

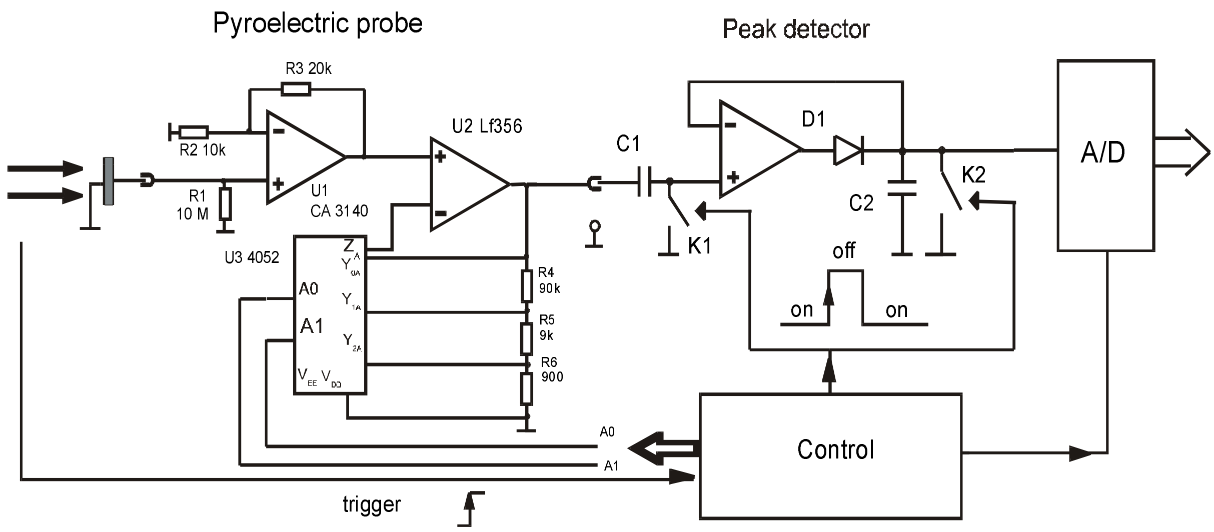

Fig.3. The block diagram of laser energy conversion system

When the conversion into digital form is ended, analogues switches K1 and K2 are closed again.

The elimination of interference by means of the system presented is effective when the interference signal is relatively slow, as compared to the useful signal rise on the pyroelectric sensor output.

The trigger pulse should appear with possibly slight advance in relation to the laser flash, taking into account the delay time of activating the analogy switch co-operating with capacitor C1.

4.Conclusions

The experiments conducted resulted in the development of a model of laser energy meter, which conversion system realises the difference measurement method. The use of this method enables to eliminate the influence of any interference to sufficient degree. No information on similar solutions of energy meter systems are accessible to the author, though the operating idea of such system is not complicated. Very promising results were obtained in comparative studies with several laser energy meters manufactured by well-known factories. The worked out model of this device allowed us to show a much lower level of sensitivity to disturbing factors, particularly to acoustic and thermal interference.

References

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