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SIMPLE PULSE MICROWAVE WAVEGUIDE CALORIMETER WITH TEMPERATURE SENSOR LM 35

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The paper presents the construction of a storage-type waveguide calorimeter designed to measure the energy of a sequence of short microwave pulses. The radiation is absorbed by water or ethanol, then the temperature increase is recorded by the LM 35 sensor. When using 14 cm^3 of water, the energy measurement range is 3…88 J, and when using ethanol 1.3…40 J. The calorimeter is simple, cheap, and reliable.

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INTRODUCTION

Methods of measuring the energy of electromagnetic oscillations are constantly developing, and new measurement methods and designs of energy meters for electromagnetic oscillations appear [1 - 3]. But the calorimetric method of measuring the energy of microwave radiation remains the most widely used. This method is characterized by high accuracy and versatility and is used in the entire radio frequency range to measure the radiation of both low and high power.

The method is based on the conversion of the energy of electromagnetic oscillations, absorbed by the coordinated load, into thermal energy and load temperature rise measurements. In the most common loads, the working substance is water or ethanol. An increase in the temperature of the working substance can be registered directly or indirectly as a change in volume, pressure, or other characteristics.

The calorimeter, proposed in our work, is intended for measuring the energy of microwave radiation, which is formed during the conversion of wake waves in a plasma or in a dielectric structure [4]. Pulses of microwave radiation have a duration of 2 μs. and the repetition rate is 2 s^{-1}.

Our goal was to create a simple and reliable waveguide calorimeter of storage type with an exposure time of 10…20 s and a measurement range from a few joules to several tens of joules. In addition, the calorimeter should be located at a distance of about 20 m from the operator and be resistant to impulses.

In storage-type calorimeters, the increase in the temperature of the working fluid is most often measured by the increase in the volume of the working fluid in the measuring capillary tube using resistance sensors [5] or capacity [6]. But the passage of electric current through water and its solutions leads to electrolysis and decomposition of water [7]. In addition, when the liquid in the measuring tube expands, the effects of uneven wetting of the tube walls appear. These processes lead to the need for complex calibration of the calorimeter and reduce the accuracy of the measurement.

In our work, it is proposed to use the direct method of measuring the temperature sensor LM 35 to measure the energy of pulsed microwave radiation, which allows you to measure minor changes in temperature with a relative accuracy of no worse than 0.05°C.

The direct method of temperature measurement in microwave oscillation calorimeters is quite widely used [8, 9], but the production of previously proposed calorimeters was quite complicated and expensive. Each calorimeter required a separate setup and calibration

Our goal was to design and manufacture a calorimeter that did not require complex or expensive parts, its application would not require additional setup or calibration and would be suitable for measuring microwave energy from a few joules to several tens of joules over a wide frequency range. We believe such a calorimeter can be made using the LM 35 temperature sensor.

The absorption coefficient of the rf calorimeter is not worse than $\alpha \geq 0.9$. Operating frequency range $\Delta f = 2…20$ GHz.

1. CALORIMETER WITH TEMPERATURE SENSOR LM 35

1.1. PARAMETERS OF THE LM 35 SENSOR

The energy of electromagnetic oscillations measured by the calorimeter is defined as $E = m \cdot c \cdot \Delta T$ (where m is the mass of the working fluid, c is the specific heat capacity of the working fluid, ΔT is the temperature change of the working fluid under the influence of radiation). To measure the absorbed energy, a non-absolute temperature value, and the knowledge of the temperature change when a certain energy is absorbed the accuracy of determining the temperature change primarily depends on the linearity of the temperature sensor.

The LM 35 temperature sensor has sufficient linearity for our measurements.

This integrated silicon sensor includes a thermosensitive element – a primary converter and a signal processing circuit made on a single crystal. The output voltage of the LM 35 sensor is proportional to the Celsius temperature scale and is 10 mV/°C. At a temperature of 25 degrees, this sensor has an output voltage of 250 mV, and at 100 degrees, an output voltage of 1.0 V [10].

From the graph presented in Fig. 1, taken from the manufacturer's manual for LM35 and LM35A temperature sensors, it can be seen that the minimum error of the measured temperature value in the middle of the operating range of the sensor corresponding to 25°C is 1 and 0.5°C, and at the edges of the range it is 1.5 and 1°C.

These graphs are valid for measuring the absolute value of temperature. However, in our measurements it is not required to obtain a particularly accurate absolute temperature value, but rather high sensitivity of the sensor is required, which is ensured by the high linearity of the LM35 sensor – the dependence of the output voltage on temperature, in a narrow temperature range ΔT ~ 2°C at 18…28°C.

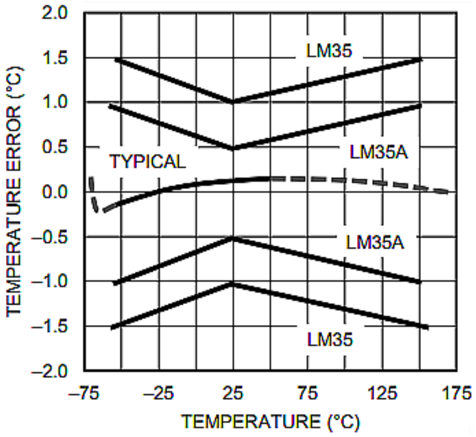

Fig. 1. Dependence of temperature measurement error on temperature

The high linearity of the LM35 sensor is illustrated by the dependence shown in Fig. 2.

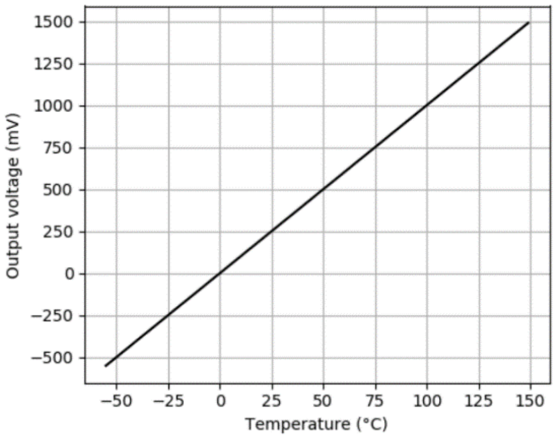

Fig. 2. Dependence of the output voltage of the LM 35 temperature sensor

1.2. CONSTRUCTION OF THE CALORIMETER

We have produced a calorimeter with a three-centimeter wavelength range placed in a circular cross-section waveguide. The E_{01}-type wave excitation is assumed. A calorimeter without external thermal insulation and a temperature sensor are shown in Fig. 3.

Calibration of the calorimeter using an internal heater showed that the sensor detects changes in the temperature of the working fluid by 0.01°C (the output voltage changes by 0.1 mV). But at the same time, the time to establish equilibrium increases, and nonlinearity is observed when the temperature increases by 2…3°C.

During the successive absorption of 3 J of energy by the calorimeter with 14 cm^3 of water as the working fluid, the sensor recorded a linear increase in temperature by 0.05°C (0.5 mV the output voltage changes). Linearity was observed when heated by at least 2°C. Good linearity was also observed when ethanol was used as the working fluid.

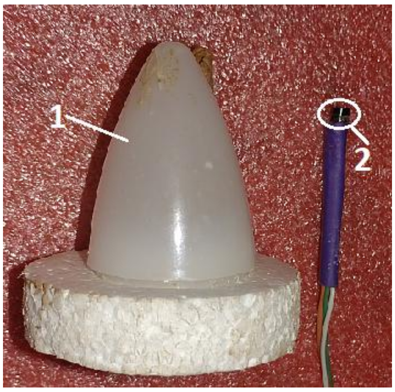

Fig. 3. Waveguide calorimeter: 1 – calorimeter casing without thermal insulation; 2 – temperature sensor LM 35 in a protective tube

As a result of the calibration, it was determined that the calorimeter with 14 cm^3 of water as the working fluid has an energy measurement range from 3 to 88 J, if the increase in water temperature is limited to 1.5°C. For a calorimeter with 14 cm^3 of ethanol (11 g), due to the lower specific heat capacity of ethanol, a temperature increase of 0.05°C occurs with the absorption of 1.3 J of energy, and an increase in the temperature of ethanol by 1.5°C corresponds to the absorption of 40 J of energy.

A special feature of the calorimeter is that it is possible to make several independent measurements in a row, only noting the initial and final temperatures at each measurement without waiting for equilibrium to be established. Of course, the total increase in temperature should not exceed 1.5°C. The temperature sensor connection diagram is shown in Fig. 4.

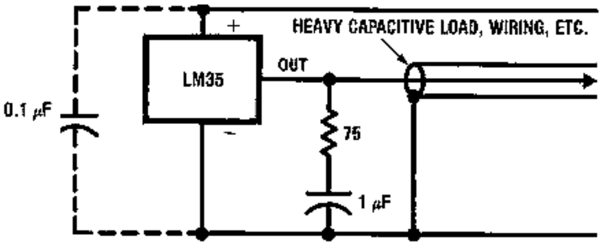

Fig. 4. Connection diagram of the LM 35 temperature sensor

In our case, a battery with a voltage of 9 V was used for power. The calorimeter was connected to the output voltage meter with a coaxial cable about 20 m long. The output voltage was measured by a BT-39C tester.

The calorimeter was tested using a pulse generator with an MI-30 magnetron at an electromagnetic pulse duration of 2 μs and a reference frequency of 2 s^{-1}, a linear increase in the absorbed energy was observed throughout the entire measurement range.

CONCLUSIONS

A calorimeter of a sequence of short pulses of electromagnetic oscillations was manufactured and tested. The calorimeter is placed in a circular cross-section waveguide. Water or ethanol is used as a working substance. The direct measurement of the temperature increase of the working fluid by a precision temperature sensor LM 35 with an integrated circuit and a linear output voltage was used. Preliminary calibration showed its sufficient linearity when measured with a relative accuracy of 0.05°C when the temperature of the working fluid changes by 1.5°C. The calorimeter with 14 cm^3 of water as the working fluid has an energy measurement range from 3 to 88 J. The energy measurement range for ethanol ranges from 1.3 to 40 J.

The absorption coefficient is $\alpha \geq 0.9$. The range of operating frequencies: 2…20 GHz.

The range of energy measurement can be significantly expanded by using a different volume of the working fluid and in other wavelength ranges, provided that the wave resistances of the radiation source and the calorimeter match.

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ПРОСТИЙ ХВИЛЕВОДНИЙ КАЛОРИМЕТР ІМПУЛЬСНОГО МІКРОХВИЛЕВОГО ВИПРОМІНЮВАННЯ З ТЕРМОДАТЧИКОМ LM 35

А.Ф. Лінник, Д.Ю. Залеський

Представлена конструкція хвилевідного калориметра накопичувального типу, призначеного для вимірювання енергії послідовності коротких мікрохвильових імпульсів. Випромінювання поглинається водою або етанолом, потім підвищення температури фіксується датчиком LM 35. При використанні 14 см^3 води діапазон вимірювання енергії становить 3…88 Дж, а при використанні етанолу – 1,3...40 Дж. Калориметр простий, дешевий і надійний.