DOI: 10.46300/9104.2023.17.13 Volume 17, 2023

Development of an optoelectronic system for recording and processing signals from fiber-optic sensors

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Received: April 9, 2023. Revised: June 21, 2023. Accepted: September 18, 2023. Published: October 24, 2023.

Abstract— Natural disasters, in particular earthquakes, can damage bridges, tunnels, dams, high-rise buildings, railways, oil platforms, buildings, and pipelines with catastrophic humanitarian, social, economic, and environmental consequences. Thus, automatic assessment of damage to industrial and civil construction structures after an earthquake in real-time or on request is necessary for early emergency response, effective preparation of rescue plans, and mitigation of these catastrophic consequences. The article presents the use of a system of distributed fiber-optic sensors based on Bragg fiber arrays, which will allow periodic measurements and monitoring of the condition of structures, assessing trends in its technical condition and thereby facilitating the identification of possible threats. The given research presents assembling and testing optoelectronic systems to record and process signals from fiber-optic sensors. The main optoelectronic systems to record and process the signals from fiber-optic sensors are light source controllers and optical power detectors. There was an assembled controller diagram, which apart from the light source includes the current source for its adequate operation, as well as the systems necessary for stabilizing its working point. The scheme was modeled for specifying nominal and maximum operation criteria. Construction has been designed in a way, that the light source controller includes structures of the current regulation and stabilization SLED (super luminescent diode) and temperature stabilization. Apart from that, there was assembled the microsystem of the optical power detector additionally to the light detector, which includes the microsystems of intensification and filtration of the signal measured, processing analog data into digital form, and microcontroller, used for preliminary data analysis. Data of optoelectronic systems diagram to record and process the signals from fiber-optic sensors has high response speed, low noise level, and sufficient progress. type your abstract here.

Keywords— Damage to structures; fiber-optic sensor; optoelectronic system; microcontroller STM32F4, impedance routing analysis.

I. Introduction

MANY bridges around the world are nearing the end of their service life and their condition needs to be assessed to reduce risks, prevent disasters, and optimize maintenance planning. Of particular interest are failure-critical bridges because they have little or no-load path redundancy. Structural health monitoring (SHM) has recently emerged as a branch of technology that aims to improve the assessment of the health of structures. Distributed fiber sensing technology has opened up new possibilities in SHM. The distributed strain sensor (sensor cable) is sensitive at every point of its length to strain changes and cracks, [1]. Mounting the sensor along the monitored object is critical to ensure that voltage is transferred from the structure to the sensor cable. Stress behavior within building structures usually varies depending on material properties, loading conditions, etc. Therefore, sensors must be placed not only in suitable locations but also using suitable installation techniques according to project requirements. Rotation and twisting measurements are important for monitoring various types of cable systems and mechanical structures, [2], [3], and even in textiles, [4]. The article, [5], presents a method using simple and homogeneous Bragg gratings to track the forces acting on metal wires, which are elements of mechanical structures. Figure 1a installation along the reinforcement, figure 1b shows a steel rod reinforced with carbon fiber, the condition of which is monitored by sensors with a fiber Bragg grating (FBG - fiber Bragg grating).

The sensitivity of systems of this type is most often evaluated using static and fatigue tests. Figure 1b shows the so-called smart steel cables with embedded carbon fiber cores and installed FBG sensors. The system proposed in this work was subjected to tensile tests to determine the sensitivity of the measuring system. The obtained results show the stability of the measurements and the accuracy is higher than the measurements using strain gauges.

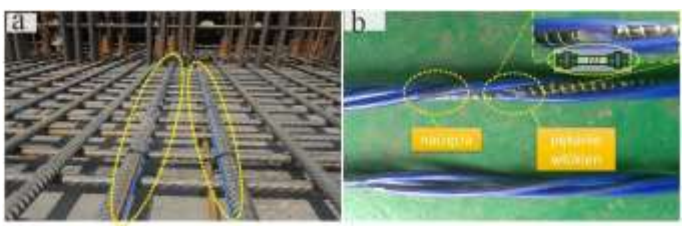

Fig. 1 Sensor installation methods: (a) Application along the rebar. (b) steel cable controlled by FBG sensors

For concrete structures, it can be used both inside the structure and along the surface. However, the monitoring results vary significantly depending on the installation location and the type of cable used with embedded carbon fiber rods and clamp-on FBG sensors.

Currently, there is great interest in developing specific, sensitive, cheap, and portable optoelectronic devices. The latest development of new sensitive and selective materials plays an important role in complex industrial samples and environmental objects. Additionally, fiber-optic technologies are widely applied to many processes of optical measurements due to their important advantages, such as noise immunity and the possibility of their usage for distance and multi-positional measurements.

In [6], the authors developed the light-emitting diode topology, capacity or stress analysis, and diagrams of light-emitting diodes (LED) focus, which are technologies of LED. In the work, [7], there were developed and studied the possibilities of using LEDs and applying solid-state technologies. Work, [8], presents the research on stability, reliability, and use of digital control of LEDs. In the work, [9], there was studied the light intensity, which was controlled using light-emitting diode drivers to manage the light emission, as well as, light-emitting diode sources, which have fixed correlated color temperature (CCT) and color reproduction. For over half a century the LED has been an integral part of everyday life. At first, the LED property was insignificant, but scientific-technical developments have widened their usage in many areas, [10], [11], [12], [13], [14], [15], [16]. The authors in [17], [18], [19], developed LED illuminators, which have a lot of advantages compared to conventional incandescent lamps or gas-discharged light sources. The advantages are the ability to synthesize the colors, wide emission angles, high contrast and light output, low voltage power source, and convenience to a user method of stream control. The works, [20], [21], [22], study LED sources, which have peculiar shortages, such as LED scattering, LED dilapidation, changes in environmental temperature, connections' temperature, and environment humidity. Work, [23], shows, that LEDs' high performance, design advantages, and ease of power supply result in their wider usage. While developing LED technologies first there was regulated the working temperature of separate LEDs and multi-spectral LED's light source, which uses a small spectrometer to control the flow in the real-time system. There was offered the method of optical sensor operation MEMS (Micro-Electro-Mechanical Systems) as a real-time spectrometer. Subsequently there is described the implementation of the sensor control circuit, which shows the reliability of spectral measurements and, consequently, the output stream property. Additionally, there was a customer way to connect the analog part of the flow measurement path with the analog-to-digital conversion and the control system on the base of a programmable logic device (PLD). In [24], there was developed optoelectronic devices for optical chemical (bio) sounding. Particular attention was devoted to chemical sensors themselves, although only a few of them covered the design process of optoelectronic devices. A study of optical devices and optical measurement technologies used in this field was also suggested to provide a thorough understanding of the application areas. The light detector (photodetector) converts the optical signal into an electrical signal. The spectral characteristics of the photodetector are adapted to the emission spectrum of the optical sensor to avoid loss of information at critical wavelengths. In addition, the photodetector design accordingly has a high sensitivity to cover the high signal-to-noise ratio (SNR). In [25], [26], photodetectors with the main components of modern multifunctional technologies capable of converting light signals into electrical ones have been developed and researched.

The aspect of technological novelty of the project is the development of an innovative optoelectronic system for monitoring and diagnosing the state of building structures, based on a combination of conventional fiber Bragg gratings and the so-called tilted fiber Bragg gratings. This concept is

DOI: 10.46300/9104.2023.17.13

the result of a dynamic development in measurement technology that uses passive fiber optic components of this type. The possibility of their use in explosive environments, small size, resistance to electromagnetic interference, and high sensitivity to deformation make fiber Bragg gratings attractive elements for these purposes.

II. Research Methodology

The basic equipment of optoelectronic components connected to optical sensors is simple in principle, because it uses conventional, commercially inexpensive spectroscopic components (optical electronics), normal light sources, optical filters or monochromators, light diverters, and light detectors, the characteristics and cost of which will be determined according to specific needs. The probability of a single choice of any of those parts guarantees a large number of combinations. It is possible to design according to the customer's order in a way that has sufficient characteristics for each specific case.

The purpose of the work is to create an optoelectronic system for recording and processing signals from fiber optic sensors.

-Analysis and selection of electronic components of the light source controller

- Analysis and selection of electronic components of the optical power detector

- Testing of an optoelectronic system for recording and signal processing.

III. Results

A. Assembly of an optoelectronic system for recording and processing signals from fiber-optic sensors. Assembling the light power controller

In this part of the study, an analysis of the used light sources was carried out according to the length of the emitted wavelength, electrical power, and installation feasibility. Figure 2 shows the controller diagram. In addition to the light source, the controller circuit contains a current source necessary for its correct operation, as well as systems necessary to stabilize its operating point.

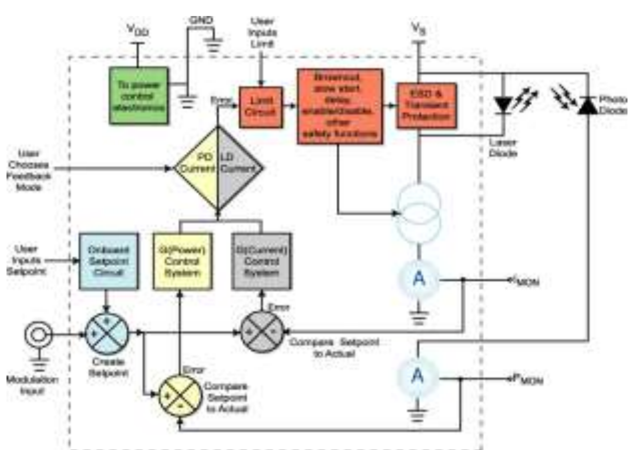

Fig. 2 Control unit diagram

The proposed circuit was modeled to determine the nominal and limiting operating conditions. The system is designed in such a way, that the light source controller contains SLED (super luminescent diode) current adjustment and stabilization units, as well as temperature stabilization. Actuating elements must be made using MOSFET technology (MOSFET -Metal-Oxide-Semiconductor). The diode current was regulated and stabilized using a PID controller. Adjustment and stabilization of the temperature of the diode junction is carried out using the PI controller.

Among the components available on the market, an integrated diode from Thorlabs was chosen. SLD1550S-A2 with the following options:

- Light wavelength δ_c: minimum 1520 nm, maximum 1580 nm (preferred 1550 nm);
- IOP diode current: 600mA maximum;
- PASE optical power: 2.5mW maximum;
- 3dB bandwidth: 90nm maximum (preferred 85nm);
- The effective value of ripple δ_G: preferred maximum 0.25 dB;
- Forward voltage VF: 1.6V maximum;
- TEC maximum ITEC current: 1.5 A;
- TEC allowable voltage VTEC: 3.5 V;

Temperature sensor resistance RTH: 10 kOhm. The characteristics of the selected SLED are shown in Figure 3.

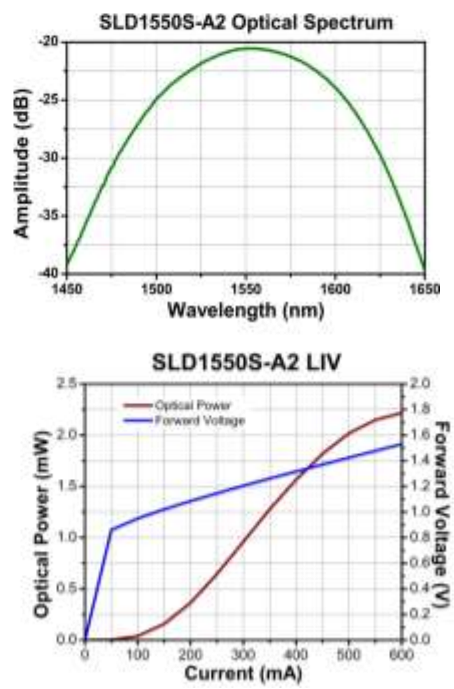

Fig. 3 Characteristics of selected source of SLED

The case and conclusions of the proposed solution are shown in Figure 4.

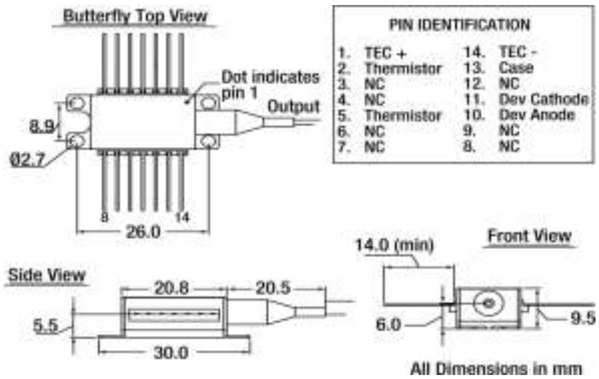

Fig. 4 Selected Light Source – Case and Pinouts

Characterization of the light source to determine the appropriate parameters for the PI (temperature) and PID (current) controllers was performed using a prototype with a digital-analog transformer. The scheme of this circuit is shown in Figure 5.

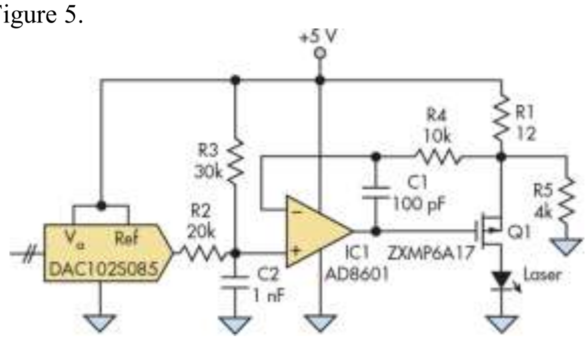

Fig. 5 Preliminary circuit diagram of SLED current-carrying diode

B. Assembly of light power detectors

In this study, an analysis was made of the used detectors of light optical power due to the emitted wavelength, efficiency, and feasibility of installation. Figure 6 shows the optical power detector chip. The optical power detector microcircuit, in addition to the light detector, includes microcircuits for amplifying and filtering the measured signal, a microcircuit for processing analog data into digital form, and a microcontroller used for preliminary data analysis. The proposed scheme was modeled to determine the nominal and limiting operating conditions.

The optical power detector chip is an optoelectronic integrated circuit containing a photodiode and a trans-impedance amplifier, constructed using two operational amplifiers in a single dielectrically isolated silicon structure.

A visual diagram of the proposed solution is shown in Figure 6.

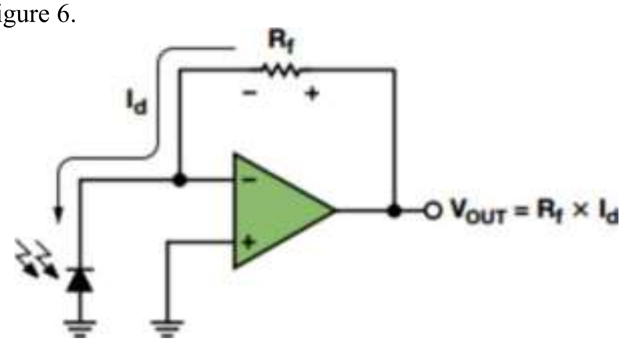

Fig. 6 Suggested trans-impedance amplifier configuration

The first stage of the trans-impedance amplifier is implemented on an operational amplifier with a high-precision field-effect transistor and a built-in resistor with a metal layer. The second stage of the amplifier is divided by a voltage divider, where the output voltage range of the entire detector power system will be regulated.

From the elements available on the market, a Thorlabs photodiode with the Thorlabs FGA01FC symbol and parameters was selected:

1) Light wavelength range λ: minimum 800 nm, maximum 1700 nm;
2) Preferred light wavelength λP: 1550 nm;
3) Photosensitive element diameter: 0,12 mm preferred;
4) Ascent/descent time: (for RL=50 Ω, 5 V) maximum 0,30 ns,
5) Current dark Id: (for 5 V): Preferred maximum 2,0 pF;
6) Connector capacity Cj (for 5 V): Preferred maximum 2,0 pF;
7) Maximum optical power: minimum 18 mW;
8) Case: preferred- TO-46 (FC/PC);
9) Semiconductor detector material: Preferred InGaAs.

The spectral characteristics of the selected photodiode are shown in Figure 7, and the case form output is in Figure 8.

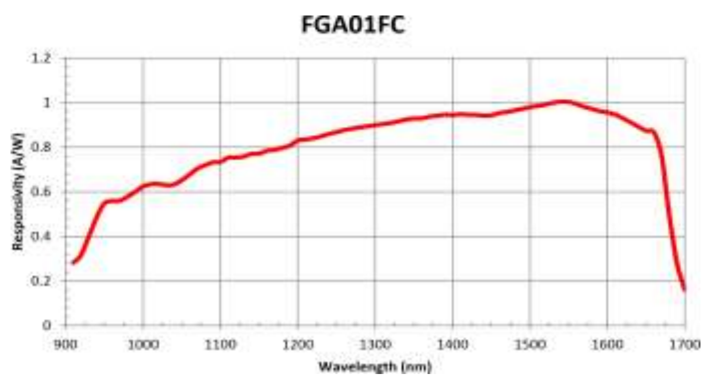

Fig. 7 Spectral characteristics of the selected photodiode

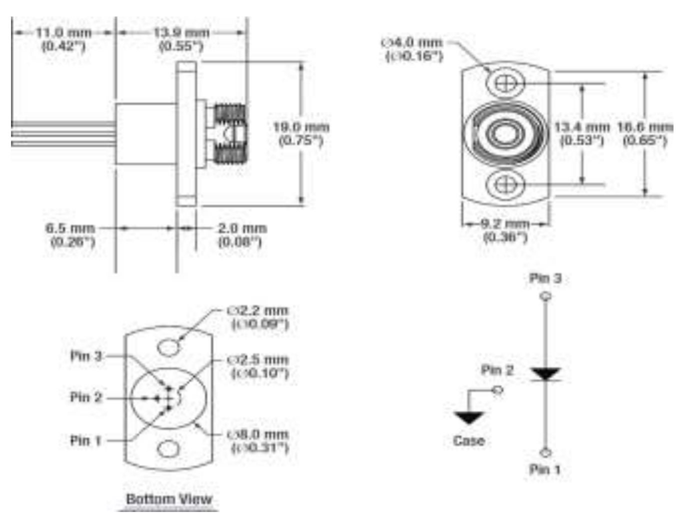

Fig. 8 Housing and pin assignment of the selected

The proposed design of the measuring system ensures the voltage polarization of the receiving diode with almost zero bias current (bias). This solution will significantly improve the processing characteristics of the proposed system, improving its linearity, and will also allow operation at very low values of the dark current of the photodiode. Reducing these settings will greatly reduce the problems, associated with leakage current error, increased noise, and gain peaks caused by random capacitance. An additional advantage of the proposed circuit is a low supply current of about 400 μA.

Testing an optoelectronic system for recording and processing signals from fiber optic sensors. Due to the bit resolution of the converter, the current ripple in the glowing diode circuit is minimized, which amounts to 20 A. Figure 9 shows the selected maximum diode current ripple when setting the current probe 1 mA/1V.

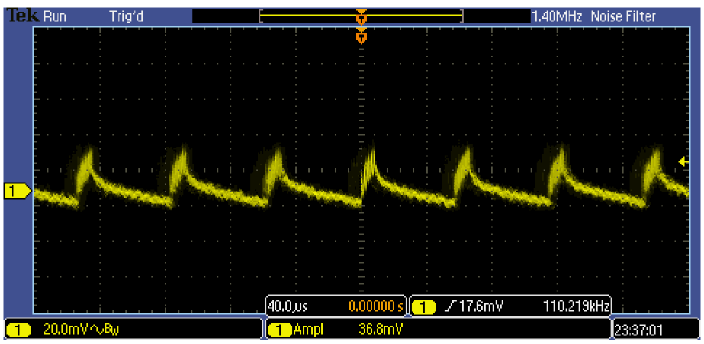

Fig. 9 Maximum current ripple of SLED (1MA / 1V)

The measurement results of the temperature characteristics of the light source are shown below in Figure 10.

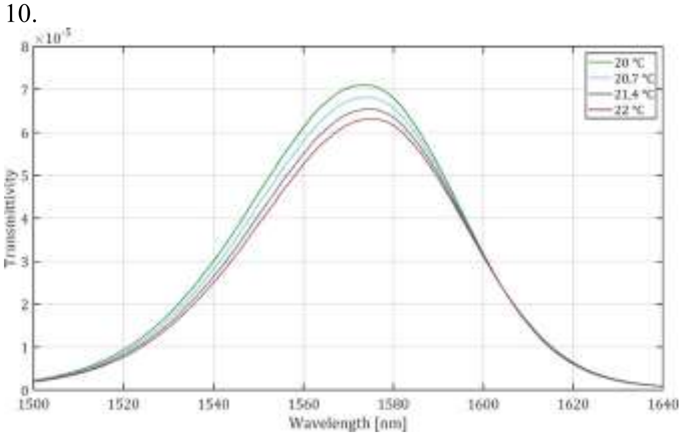

Fig. 10 Temperature dependence of maximum power and radiated wavelength as a function of temperature

As can be seen from Figure 10, changing the temperature of the selected SLED significantly affects the power transmitted by optical thorium. Thus, a three-stage cascade temperature stabilization system is provided. Such a topology is dictated by the need to maintain the temperature of the light source and the optical power detector in the temperature regime of +/- 1 micron. Separate temperature stabilization is subject to a light source with a built-in Peltier module and an optical power detector mounted on its own Peltier module. The third element is the system for stabilizing the temperature of the device body.

IV. Conclusion

In the work herein, there was shown assembling and testing an optoelectronic system for recording and processing signals from fiber optic sensors. When testing the light power controller, it was found, that due to the bit resolution of the converter, the current ripple in the glowing diode circuit is minimized, it amounted to 20 A. Changing the temperature of the selected SLED significantly affects the power, transmitted by optical thorium. Thus, a three-stage cascade temperature stabilization system is provided. When testing a light power detector, the output signals of a trans-impedance amplifier in combination with a test photodiode were investigated for various LED current fill factors. Changing the temperature of the selected SLED significantly affects the power, transmitted by the optical thorium. Thus, a three-stage sequential temperature stabilization system is provided. Such a topology is dictated by the need to keep the temperature of the light source and the optical power detector in the temperature regime of +/- 1 mK. Separate temperature stabilization is subject to a light source with a built-in Peltier module and an optical power detector fixed on its own Peltier module. The third element is the system for stabilizing the temperature of the body of the device.

Acknowledgment

This work is supported by a grant from the Ministry of Education and Science of the Republic of Kazakhstan within the framework of Project No. AP19679153 and No AP09259547.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Aliya Kalizhanova developed the concept and methodology of the study.

Ainur Kozbakova developed the concept and methodology of the study.

Murat Kunelbayev designed the structure and assembled the controller circuit.

Zhalau Aitkulov designed the structure and assembled the controller circuit.

Sources of funding for research presented in a scientific article or scientific article itself

This work is supported by a grant from the Ministry of Education and Science of the Republic of Kazakhstan within the framework of Project No. AP19679153 and No AP09259547

Conflict of Interest

The authors have no conflict of interest to declare that is relevant to the content of this article.