

NEW MAGNETIC LINEAR SENSOR FOR CRACK MONITORING IN STRUCTURES

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Abstract: Due to the recent deployment of new sensing technologies and monitoring devices aiming to control technical condition of structures and its safety, the problem of optimization of data acquisition process and economic expediency during Structural Health Monitoring has arisen. This article presents the design and implementation of a new linear displacement sensor prototype with advanced functionality capable to measure three significant parameters affecting the condition of concrete and brick structures: cracks width, environmental temperature and humidity. The measuring method is based on the efficient principle of converting input values using Hall effect, which is rarely found in structural monitoring. The sensor prototype also includes a hardware set for immediate processing and transmitting data, which ensures efficient remote monitoring. As a result of the work, research and analysis of methods and principles for measuring linear displacements were carried out, selection and justification of the choice of hardware components of the sensor were performed, electronic circuit and functional diagrams were developed. Furthermore, work was done on modeling the structural elements of the sensor and their final production was executed. According to the results of tests of the sensor prototype, numerical characteristics were obtained, its performance was confirmed and, eventually, the ways of further improvement are proposed.

Keywords: Structural Health Monitoring, magnetic sensor, linear sensor, cracks

НОВЫЙ МАГНИТНЫЙ ЛИНЕЙНЫЙ ДАТЧИК ДЛЯ КОНТРОЛЯ ТРЕЩИН В КОНСТРУКЦИЯХ

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Аннотация: В связи с недавним внедрением новых сенсорных технологий и устройств мониторинга, направленных на контроль технического состояния конструкций и их безопасности, возникла проблема оптимизации процесса сбора данных и вопрос экономической целесообразности при проведении мониторинга состояния конструкций. В статье представлена разработка и реализация нового прототипа датчика линейных перемещений с расширенным функционалом, способного измерять три значимых параметра, влияющих на состояние бетонных и кирпичных конструкций: ширину трещин, температуру и влажность окружающей среды. Метод измерения основан на эффективном принципе преобразования входных величин с использованием эффекта Холла, что редко встречается в мониторинге конструкций. В состав прототипа датчика также входит аппаратный комплекс для немедленной обработки и передачи данных, что обеспечивает эффективный удаленный мониторинг. В результате работы были проведены исследования и анализ методов и принципов измерения линейных перемещений, выполнен выбор и обоснование выбора аппаратных компонентов датчика, разработаны электронные принципиальные и функциональные схемы. Кроме того, была проведена работа по моделированию конструктивных элементов датчика и осуществлено их конечное изготовление. По результатам испытаний прототипа датчика получены числовые характеристики, подтверждена его работоспособность и, в итоге, предложены пути дальнейшего совершенствования.

Ключевые слова: Мониторинг состояния конструкций, магнитный датчик, линейный датчик, трещины

1. INTRODUCTION

Currently, most methods of surveying and assessing the technical condition of building structures involve the use of portable technical means and a relatively simple instrumental base with limited functionality. Although highly reliable, these monitoring methods have a significant drawback, namely that they can only be performed during a scheduled survey, repair or reconstruction. In addition, the monitoring methods used today can be very labor-intensive, costly, and thus ineffective when performing tasks at technically complex facilities, which include, for example, seaports, bridges, tunnels, as well as unique facilities for which technical regulations have not been established. Most facilities have individual space-planning and design solutions, and the types of materials used in the structures. Building structures are operated in various conditions and are not always located in easily accessible places (monitoring unique buildings, surveying chimneys, hydraulic structures, bridges and overpasses). [1] The authors are confident that in order to solve such complex engineering problems dictated by the dynamic development of the construction industry, it is necessary to improve the currently used measurement base and introduce new measurement tools that could provide the most accurate results and increase the quantity and quality of information obtained both for applied (for example, within the framework of geotechnical monitoring) and experimental purposes.

2. LITERATURE REVIEW

Detecting cracks in bridge structures is inherently challenging due to the size, complexity, and varied materials of bridges. According to Bao et al. [2], visual inspections, the most traditional method, are often inadequate because they are subjective, labor-intensive, and prone to human error. Advanced methods, such as ultrasonic testing or

thermography, provide more precise detection but face limitations regarding accessibility, especially in hard-to-reach areas of large bridges [3]. Even when cracks are detected, interpreting the data to assess the severity and progression of damage presents another challenge. As noted by Johnson et al. [4], SHM systems generate vast amounts of data, which can overwhelm engineers and lead to delays in decision-making. Additionally, integrating data from different sensors and monitoring systems to provide a comprehensive understanding of bridge health remains a complex task, often requiring advanced algorithms. Environmental and operational conditions greatly affect crack monitoring efforts. Temperature fluctuations, humidity, and vibration from traffic can all influence the readings of crack monitoring sensors, leading to false positives or negatives. According to Kim et al. [5], bridges in regions with extreme weather conditions present unique challenges, as sensors must be resilient to harsh environments while maintaining accuracy.

It is worth noting the importance of a correct and comprehensive assessment of historical buildings. Given the availability of constant, reliable information about both the state of the elements and environmental conditions, it becomes possible to simulate realistic damage scenarios that may occur in the future [6] and prevent structural anomalies. This approach is the key to expanding knowledge of old structures. However, currently used conservative methods for aged buildings have a number of limitations and may be unreliable. For example, they often underestimate the load carrying capacity, which may result in uneconomical or unnecessary mitigation measures being taken to maintain old structures [7]. Therefore the use of more sophisticated methods is needed for old structures maintenance to avoid moving towards its discontinuation and losing benefits of their functioning.

While significant advancements have been made in crack monitoring technologies for bridge SHM, several challenges remain. These

include the limitations of detection technologies, difficulties in data interpretation, environmental influences, and the high costs associated with current monitoring systems. Addressing these challenges requires continued research and innovation, particularly in improving sensor durability, and developing cost-effective monitoring solutions. Recent studies have explored those advancements in wireless sensor networks offer promising avenues for more cost-effective and efficient monitoring solutions [8].

Among the various aspects of Structural Health Monitoring (SHM) discussed in this work, the authors focus on measuring linear displacements that could indicate potential issues, such as crack detection, monitoring expansion joints, and observing changes in the geometric alignment of structural junctions. One promising solution to these challenges involves recent advancements in electromagnetism. Many studies have explored new, advanced sensors for position, displacement, and crack monitoring based on magnetic effects [9-12]. However, the use of magnetic sensors has traditionally been more prevalent in mechanical engineering and the automotive industry. There has been limited research on their application in SHM systems, and their use in current practice remains minimal.

In order to analyse the current state of scientific research in the target area, statistics were collected on the number of publications presented in the international Scopus database in the main areas: "Linear sensor"; "Linear position sensor"; "Linear potentiometer"; "Linear converter"; "Displacement sensor"; "Photogrammetry"; "Crack monitoring".

The highest number of publications is displayed for the keyword "Linear sensor ". So, in the period from 2011 to 2021, 69,336 publications were published, which is of considerable interest to scientists in this field. Figure 1 represents growth dynamics of the number of publications by keywords.

At the same time, within the framework of the presented study, the authors decided to take a

sample for further research, compiled according to the two keywords "Linear sensor" and "Crack monitoring". A total of 205 document search results for the specified keywords are displayed. The distribution of publications by years is shown in Figure 2.

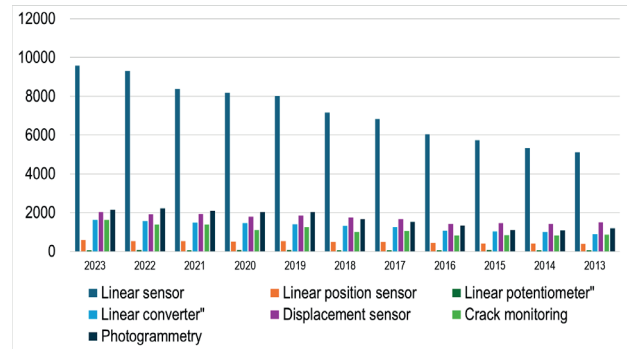


Figure 1. Growth dynamics of publications by keywords: "Linear sensor"; "Linear position sensor"; "Linear potentiometer"; "Linear converter"; "Displacement sensor"; "Photogrammetry"; "Crack monitoring" presented in the international Scopus database in the period from 2013 to 2023

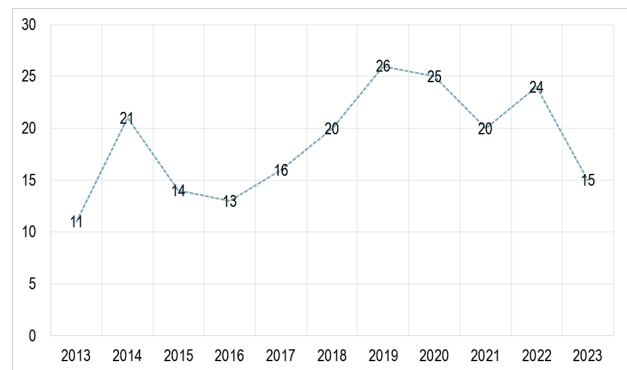


Figure 2. Distribution of publications by years by keywords "Linear sensor" and "Crack monitoring"

The distribution of publications by country is shown in Figure 3 (the first 15 countries), and Figure 4 shows the distribution of publications by branches of knowledge.

As can be seen from Figure 3a, the leaders in the area under consideration are authors from the China (69 publications), the second place is occupied by authors from United States (33

publications), the three leaders are closed by authors from the UK (16 publications). At the same time, the largest number of publications relates to the field of knowledge "Engineering" (39,1%). Thus, considerable attention is paid to the issues of using the sensor in monitoring building structures.

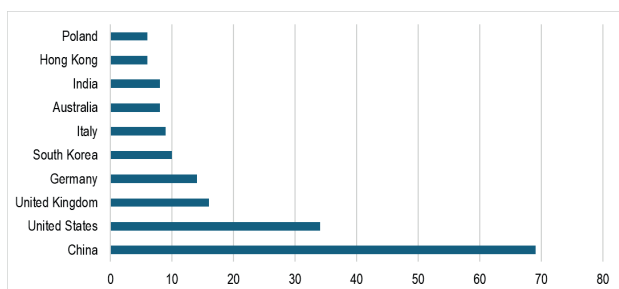


Figure 3. Statistics on the publications of the sample by country

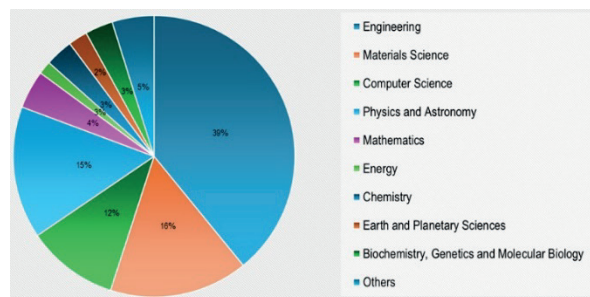


Figure 4. Statistics on the publications of the sample by branches of knowledge

A brief description of the most cited publications from the sample is presented in Table 1.

Table 1. Summary of the most cited publications in the sample

title	year	abstract	citates
[13]	2017	The article addresses the issue of the minimum number of sensors required and their placement for structural health monitoring using the example of an Italian monumental bell tower, which was monitored for over nine months. The correlations between natural frequencies and environmental parameters are examined in detail, and the predictive capabilities of linear statistical regression models based on the use of multiple continuous environmental monitoring sensors are assessed.	186
[14]	2014	Engineering structures are subject to fatigue damage during their service life, which entails early detection and continuous monitoring of fatigue damage from its inception to growth. A hybrid approach for fatigue damage characterization was developed using two types of damage indicators constructed based on linear and nonlinear characteristics of acoustoultrasonic waves. The results showed that nonlinear characteristics of acoustoultrasonic waves outperform their linear counterparts in terms of detectability.	168
[15]	2014	This article presents predictive modeling of nonlinear propagation of guided waves for structural health monitoring using both finite element method and analytical approach. In the study, the nonlinearity of guided waves is generated by interaction with a nonlinear breathing crack.	129
[16]	2015	By means of numerical simulation and subsequent experimental verification, two damage indices are comparatively constructed based on the linear and nonlinear time characteristics of Lamb waves, which are used to localize the fatigue damage near the rivet hole of the aluminum plate.	109
[17]	2016	The renewable energy industry is constantly improving and developing all over the world, wind energy seems to be the most in demand, which leads to the need to ensure a high level of reliability, availability, maintainability and safety of wind turbines. This article is devoted to the issue of ensuring the reliability of wind turbines through the use of a new fault location approach for acoustic emission techniques in wind turbines	85

title	year	abstract	citates
[18]	2015	This article proposes a method to obtain crack initiation, location and width data in concrete structures subjected to bending and equipped with an optical backscatter reflectometer system.	78
[19]	2017	The objective of this review is to demonstrate how acoustic emission (AE) location in loaded polymer composites can be used to gain a deeper understanding of damage onset and growth and associated failure events and sequences.	73
[20]	2019	This article investigates the possibility of using new microwave sensors for crack detection in reinforced concrete structures.	71
[21]	2018	Glass fiber reinforced polymers have attracted increasing attention in recent years, but this material has low elastic modulus, and linear elastic properties compared with steel bars, which leads to different bond characteristics between bars and concrete. In this article, an active sensing approach based on piezoelectric ceramics is proposed and developed to detect the bond failure between glass fiber reinforced polymer bars and concrete structures.	71
[22]	2019	There is a need to develop a structural health monitoring method to evaluate micro-sized fatigue cracks in metallic structures, since cracks are considered as precursors to structural failure. However, traditional linear ultrasound-based technology is insensitive to cracks when they are barely visible in metallic environments. In this paper, we present a nonlinear ultrasonic technology based on crack-wave interaction to study fatigue crack growth.	62
[23]	2014	“Sensor sheets” based on large-area electronics consist of a dense array of single strain sensors. They are an effective and affordable structural health monitoring tool that can detect and continuously monitor crack growth in structures. This paper presents a study of the quantitative relationship between crack width and strain, the latter measured by a single sensor that will be part of the sensor sheet.	62
[24]	2016	This research work assessed the feasibility of using telecommunication single-mode optical fiber (SMF) as a distributed fiber-optic strain and crack sensor in concrete pavement monitoring	56
[25]	2022	Flexible pressure sensors with high sensitivity over a wide pressure range are in great demand, but they are difficult to fabricate to meet the practical application requirements in daily activities and more significantly in some extreme conditions. This work demonstrates a thin, lightweight, and high-performance pressure sensor based on flexible porous phenyl silicone/functionalized carbon nanotube film.	54
[26]	2020	Marine structures are subject to fatigue damage due to fluctuating environmental and operational forces. This article compares the use of mode shapes from a finite element model with that of extended experimental mode shapes. Modal expansion is applied to a scaled offshore platform in a laboratory to evaluate the deformation response using finite element mode shapes and extended experimental mode shapes using different expansion methods. Based on this study, the expansion of experimental mode shapes has the potential to reduce errors in stress/strain estimation. However, the expansion is a fitting process and thus contains case-dependent fitting error. In this research work, finite element mode shapes outperform some mode shape expansion methods due to these fitting errors.	51
[27]	2018	This article presents a study of the features of nonlinear scattering of guided waves from fatigue cracks initiated in rivet holes, considering the state of a rough contact surface.	50

3. MATERIALS AND METHODS

Within this work the authors set the following tasks, solution of which would make it possible to achieve the necessary technical requirements for the sensor:

1. Finding the principle of input signal conversion, the choice of a measuring element.
2. Determination of the set of hardware components, electronic circuit schemes and its primary prototyping;
3. Selection of the required technical characteristics of electronic components;
4. Justification of the set of hardware selected.

3.1. The development of a methodology for input signals conversion

When choosing a method for measuring linear displacements, the following methods were considered:

1. Mechanical-electrical (using microrheostat);
2. Mechanical-optical (using optical encoder);
3. Mechanical-magnetic (using a combination of Hall sensor and permanent magnet).

The third method was chosen as most preferred, because it outperformed the others in all key metrics: simplicity, cost, reliability. Common disadvantages of rheostat sensors are the presence of sliding contact and, consequently, contact resistance, abrasion and possible oxidation of contact surfaces, the possibility of their contamination, the creation of electrical noise. The main drawbacks to optical encoders are its mechanical fragility, and poor reliability in dust-polluted environments. Apart from that, high rate of linearity and the durability to the vibrations, created by the other operating devices, make magnetic sensors preferable [28]. As a magnetic field recorder, a Hall sensor was chosen, analogous to 100G, bipolar, in an SS41 design with the following characteristics:

- output signal, digital;
- sensing type, dipolar;
- turn-on induction, 1000, Gauss;

- switch-off induction, -1000, Gauss;
- temperature range, -40...150 oC;
- weight, 0.09 g.

As it was planned by the authors the magnet and Hall sensor are fixed to the movable sensor parts located on both sides of the crack in building structure. Depending on the distance between the Hall sensor and the magnet, the Hall sensor generates an output voltage level corresponding to the magnetic induction of the current relative position of the measuring pair.

Another task was to find the suitable shape of the magnet. The fact is that the shape of the magnet determines the location of its magnetic lines, the uniformity of distribution and collinearity of which, as well as the linearity of the change in the vector angle of the magnetic flux, directly affect the accuracy of measurements and the complexity of sensor calibration. Within the framework of this work, toroidal and rectangular magnets were considered, their physical properties were determined by measuring the analog signal received from the output of the Hall sensor when interacting with magnets in various positions (see Figures 5).

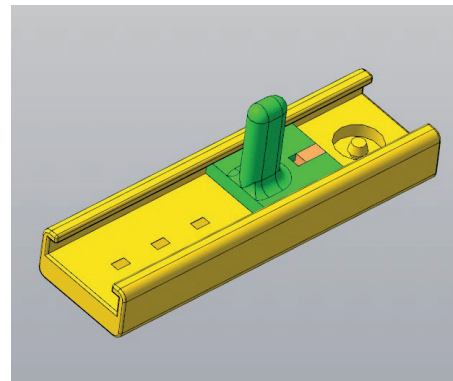


Figure 5. Model of the layout for preliminary tests

Based on the results of initial prototyping and analysis of the received signal, a rectangular magnet with an axial direction of magnetization was chosen as the source of the magnetic field, which made it possible to achieve a measurement range of 20 mm, with the following characteristics:

- Length, 20 mm;
- Width, 10 mm;
- Thickness, 2 mm;
- Weight, 3 g;
- Magnetization: axial;
- Max. temperature 80 Co;
- Degaussing time, 1% per 10 years.

Later, the problem arose of placing a magnet in the Measuring Part (MP) of the linear sensor prototype, which was solved at the stage of design development.

3.2. The development of an electronic control board

The main issues existed on this stage of work were:

1. Formation of requirements to the Electronic Control Board (ECB) and its general technical capabilities;
2. Determination of the list of components necessary to solve the tasks set for the ECB;
3. Design of the housing that should meet the specifics of working environment, determining the locations of the key components of the board, soldering points for connectors;
4. Computer modelling of the ECB;
5. Production of a printed circuit board and soldering of the ECB components;
6. Software and constructive debugging of the ECB components;
7. Finalization of the ECB.

As part of the development, three stages of step-by-step refinement of the ECB took place. The model of the current design is shown in Figure 6.

The electronic control board of the linear sensor prototype is a dielectric printed circuit board included a number of electronic components and measuring unit connected by electronic measuring circuit. The main function of the ECB is to receive, process and transmit a signal generated by the transducer (Hall sensor) with information about the linear displacement of the object under study. The main electronic components of the ECB:

- POA (programmable operational amplifier) with built-in analog-to-digital signal converter PGA280;
- STM32F373CCT6 microcontroller;

- transceiver RS-485 ADM2687EBRIZ;
- LDO voltage regulator LD117AS33TR;
- power supply unit: POWERLINE ICR18650 2200 mAh accumulator;
- GSM-module SIM800;
- temperature and humidity sensor DHT22;
- reference voltage source REF2033AIDDC;
- DC/DC converter EM 0515V;
- quartz resonator HC-49S;
- a set of resistors, capacitors, diodes;
- connecting parts: screw terminal blocks, PLD-40 connectors.

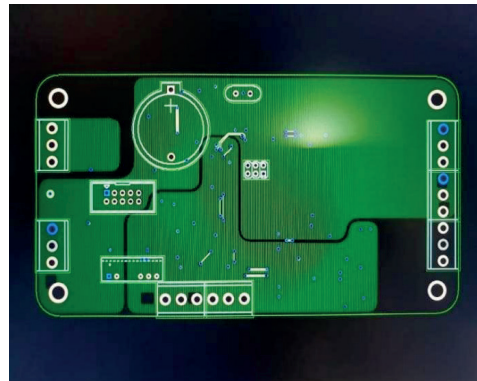


Figure 6. Model of the Electronic Control Board

An analog signal from Hall sensor is supplied to the operational amplifier PGA280. Further, the signal amplified to a certain level is converted into a digital representation using the built-in ADC, and then processed by the microcontroller.

Amplifiers are used to amplify weak DC signals. After analyzing ready-made solutions in the semiconductor market, we settled on the Texas Instruments PGA280 programmable operational amplifier. It is characterized by:

- wide input supply range, $\pm 15.5 \dots \pm 18$ V;
- switchable gain, 128V/V...1/8 V/V;
- low bias level (3 μ V) at gain level, 128 V/V;
- absence of zero drift over a long period of observation;
- small temperature drift 0.5 ppm/ $^{\circ}$ C.

Also, POA (programmable operational amplifier) has a 16-fold margin for the accuracy of the measured signal, low drift, near-zero errors.

The bit depth of an ADC is the bit depth of its output signal, that is, the number of bits in the value at the ADC output. For example, a 16-bit PGA280 ADC can output $2^{16} = 65536$ values (from 0 to 65536 if we are talking about positive numbers). Thus, we can determine the further accuracy of the linear sensor prototype, which the selected ADC can provide. This can be done using the following formula:

$$X = \frac{D}{2^P}, \quad (2)$$

where P is the ADC capacity, bit; D – range of measurement of linear displacements, mm; X is the accuracy of measuring linear displacements (discreteness), mm.

$$X = \frac{20}{2^{16}} = 0,0003 \text{ mm}. \quad (3)$$

Since the measuring range of linear displacement is 20 mm, under ideal conditions, the hardware of the prototype sensor can measure linear displacement with an accuracy of 0.0003 mm.

The STM32 microcontroller is a popular and highly demanded platform that allows you to create professional solutions for automation in a wide variety of areas, based on STMicroelectronics microcontrollers with an ARM processor, various modules and peripherals. The processor frequency is 76 MHz, which is enough to calculate and transfer data almost instantly and provide a reading time of less than 1 second.

Protection of wires and connections is a fundamental task to ensure durability of the SHM system and data quality [29]. Therefore, it is more preferred to utilize wireless communication interface. In linear sensor it is provided by the presence of the SIM800 module in the ECB. This module is in no way inferior to a conventional cell phone in terms of functional

characteristics, and with its help you can send SMS messages, make or receive phone calls, connect to the Internet via GPRS, TCP / IP without distance limitation.

Environmental factors have a significant impact on the parameters of structures, especially concrete [30]. Thus it is also possible to integrate a temperature and humidity sensor into the ECB, for example, DHT22 with the following confirmed technical characteristics:

- humidity measurement range, 0...100%;
- temperature measurement range, -40...+80 C.

3.3. The development of a functional scheme of work and design

The functional diagram of the linear sensor prototype consists of two distinct structural components: the Measuring Part (MP), which includes a Hall sensor, and the Electronic Control Board (ECB) housed in a sealed casing. The MP produces an output signal in response to an input action within the system and sends this signal to the analogue input of the ECB. The analogue signal, which carries information about the linear movement, is then processed, and the resulting data is transmitted over a wireless communication channel.

The linear sensor comprises a Measuring Part (MP) made up of two grooved rails that move linearly in relation to each other. One rail has a Hall sensor mounted on it, while the other features a magnet placed directly beneath the sensor, separated by an air gap of less than 1 mm. The rails are connected by a hinge, which enables them to adjust their position in two planes at the same time, parallel to the object's surface.

The second structural element of the sensor is the housing, installed in close proximity to the MP, with the necessary set of connectors and pressure seals, in which the ECB is located, connected to the Hall sensor by a wired interface. The standard G258C 160x80x55mm enclosure (option with transparent top cover), meeting the IP54 standard, provides protection

of internal electronic components from environmental influences.

The results of designing the MP of the linear sensor prototype for its further production by the FDM printing method (3D printing with PETG polymer) are shown in Figures 7, 8.

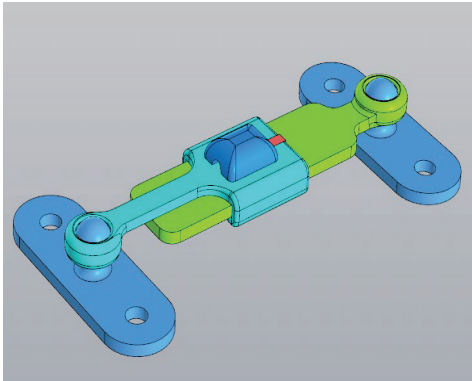


Figure 7. Model of the sensor's MP (zero position)

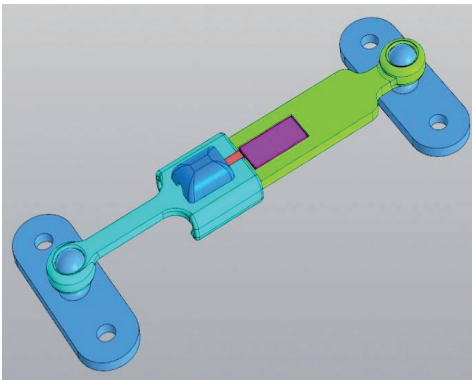


Figure 8. Model of the sensor's MP (extreme positions)

3.4. Production of the linear sensor prototype

The production of a linear displacement sensor prototype took place in three stages:

1. Soldering and mounting of ECB electronic components;
2. Refinement of a typical housing by installing additional connectors, spacers, brackets and installing an ECB inside the housing;
3. Production of the MP by 3D printing and subsequent refinement.

A general view of the finished ECB with mounted elements is shown in Figure 9.

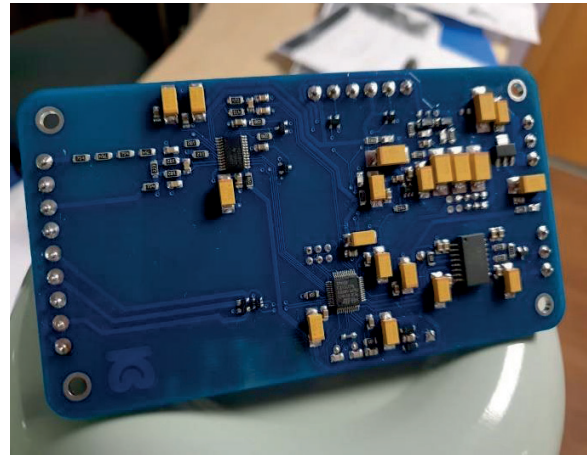


Figure 9. General view of the ECB

It should be mentioned that in addition to the components placed on the board, the circuit involves a separate modem board designed specifically for embedded solutions - SIM800. To locate the modem board inside the case, special bracket was made (see Figure 10). It solves several problems, including convenient location of the modem board (for connecting an external antenna, changing a SIM card), noise immunity of the radio part due to the removal of the board from the rest ECB components.

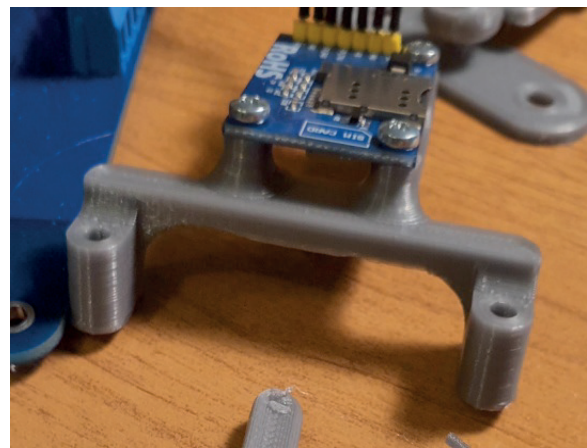


Figure 10. GSM module board bracket and board spacers

Figure 11 shows the attachment of the SIM800 GSM module board to the inner surface of the sensor housing.

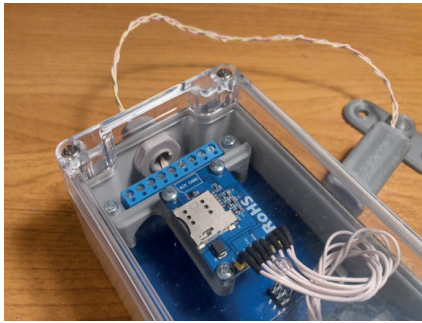


Figure 11. Mounting unit for the SIM800 GSM module board

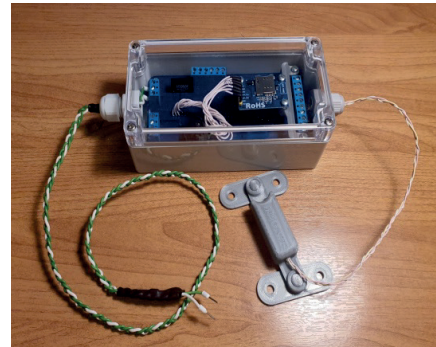


Figure 13. General view of the linear sensor prototype

The manufacturing of sensor's MP was carried out using the FDM printing method (3D printing with PETG polymer).

The finished MP of the sensor is shown in Figure 12.

Summing up the stages of design development and manufacturing of a linear displacement sensor prototype, it became possible to determine the main functional and design characteristics:

1. Execution IP54, due to the selected housing and the organization of the input of cable connections through pressure seals of the appropriate calibre;
2. Possibility to connect to the power supply as from an external source using the appropriate connector or use the built-in battery;
3. Ability to connect two analogue sensors for simultaneous measurement of linear displacements in two planes;



Figure 12. The final version of the Measuring Part

A general view of the linear sensor prototype is shown in Figure 13.

3.5. Laboratory test

Laboratory test of the linear sensor prototype were carried out in order to validate the correctness of the technical solutions adopted, as well as to obtain reliable information about the characteristics of the prototype.

Testing of the linear displacement sensor prototype consisted in studying the amplitude and time characteristics of the electrical signal received from the sensor by connecting an oscilloscope.

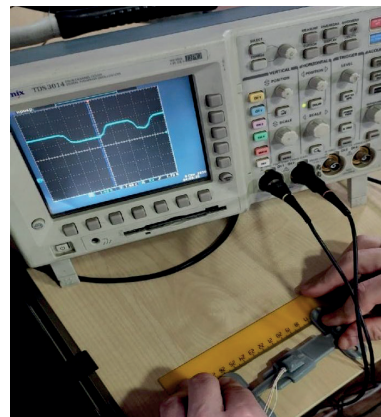


Figure 14. Obtaining an electrical signal from a sensor prototype

4. Results and Discussion

Based on the results of sensor prototype development and testing, the following technical characteristics were achieved:

- measuring range of linear displacements, 0...20 mm (± 10 mm in each direction from the zero position);
- accuracy of measurement of linear displacements, 0.0003 mm;

- measuring base of linear displacements, 110 mm;
- overall dimensions, 160x80x55 mm;
- weight, 350 g.

Experimental results validate the accuracy of the linear displacement sensing with a competitive behaviour. Given that under ideal conditions sensor provides high measurement accuracy, further research needed to determine the sensitivity to electromagnetic interference and signal contamination [31], which is typical for magnetic sensor, and degree of its influence on measurements accuracy in the field conditions needs to be found.

It is also worth noting that data processing, reduction and storage are fundamental SHM issues, in particular having a large number of sensors installed on the monitored structure. The availability of procedures able to reduce then transmission data volumes is a key aspect for reliability and sustainability of SHM systems. The proposed solution where the sensor also acts as a data logger combines two subsystems of the SHM system at once – sensing and data acquisition and transmitting. It may mitigate the necessary data analyses capacity of the system, deployment costs and enhance reliability and resources optimization, which is crucial for the modern SHM systems [32].

CONCLUSION

When investigating the causes of negative processes occurring in the load-bearing structures of buildings and facilities at the stress-strain state, as well as the dynamics of their development, it is crucial to comprehensively measure not only the parameters of visible defects, such as cracks, but also to simultaneously record changes in the parameters of the soil foundation under external dynamic loads. Only in this way can the observer obtain comprehensive information about the current state of the technical object and the natural environment, which together form a geotechnical system whose components are constantly in close interdependence. For this

purpose, the authors propose to add to a load cell [33] determining the stress state of the soil to the measurement system to expand the amount of data received during SHM.

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