# Experimental Outcomes of Comparing Tilted Fiber Bragg Gratings Sensor to Existing Conventional Bragg Sensors

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**Abstract- The study describes sensors with an inclined grid designed to monitor the condition of structures installed on the bridge. The aim of the study is to study the possibility of using the developed sensors with an inclined grid to monitor the condition of structures by checking the deformation of various parts of bridges under highway loads, as well as comparing the characteristics of sensors with an inclined grid with conventional Bragg sensors. In this paper, experimental observations show that the results of using sensors with an inclined grid are in excellent agreement with the results obtained using conventional Bragg sensors. Also, a change in the wavelength of the VBR was detected and a comparison of the deformation characteristics for measuring temperature without deformation and the VBR for measuring deformation characteristics on a sensitive Bragg sensor for 700 seconds.**

**Keywords- Experimental results, sensors with inclined fiber bragg gratings, conventional bragg sensors**

## I. INTRODUCTION

The technology of bridge structural health monitoring attracts wide attention in the transport sector. Probing technology is hardcore and the basis for engineering structures and health system monitoring. Therefore, researches and probing technologies development have an important significance for securing subsequent monitoring of structural health. In the work [1], the technology of measuring FBG is considered and methods of foundation control are being developed quickly, thanks to numerous studies. In [2], corrosion resistance, resistance to electromagnetic influences, waterproofing and high measurement accuracy were calculated using fiber Bragg grating (FBG). In the article [3], periodic changes in optical fibers were studied, at which the refractive index, the refracted Bragg lattice, and its deformation change. Works [4-6] speak about sensor technology, which is, recently, been gradually applied to monitoring the engineering health of different structures and engineering-geological monitoring [7, 8]. Also, it was widely applied to definite application areas, including such objects as roads [9], and bridges [10, 11].

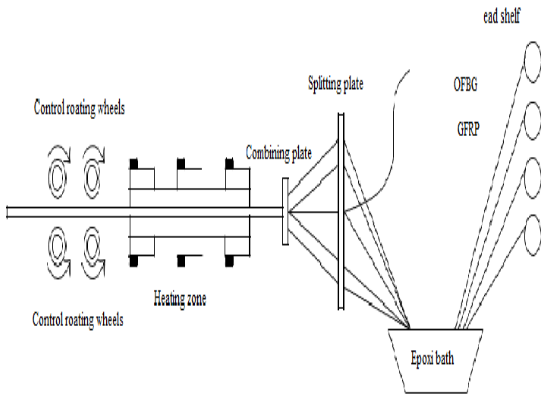
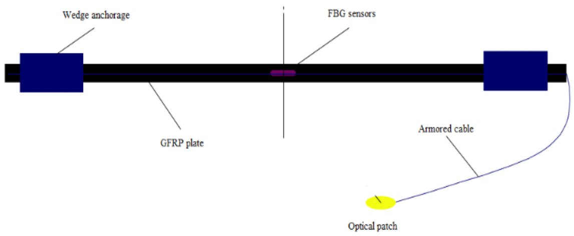



Figure 1. Principal diagram of smart FBG-CFRP fabrication process [11].

Fig.1 presents the configuration scheme and fabrication process of being offered smart plate from carbon fiber reinforced plastic (CFRP) [11], displaced tub by submerged resin at expense of the moving source, created with two sets of contra rotation wheels with constant speed, and afterwards, FBG sensors go through a preliminary designed bore in the middle of separating plate and enter CFRP fibers through multiplexer plates and then are uniformly distributed along the plate's cross-section. Further, the fabrication process was continued with heating fibers, armoured with polymer in the oven, having a heat regulator. Thanks to the high-temperatures effect (about 200 ° C) of the heating machine, a smart, hardened resin. Subsequent to producing a plate from CFRP, a built-in FBG will be expanded at one edge to create front/rear connection elements, melting together additional cladding fibers.




a)

b)

Figure 2. Principal diagram of smart carbon fiber armored plastic (CFRP) [11]

Mechanical information related to the environment, for example, movement, can be obtained using the survey technique. Fig. 2 a, b that a sensitive sensor is offered.
Certain designs and studies were intensive in the article [12], a surface displacement sensor was used to successfully monitor the range of traffic and its changes on the motorway through the channel due to the load pressure of the vehicle. Kesavan et al. [13] offered FBG sensor application to measure interphase deformation, armoured polymer, hardened with proved, matrix defines the start separation.

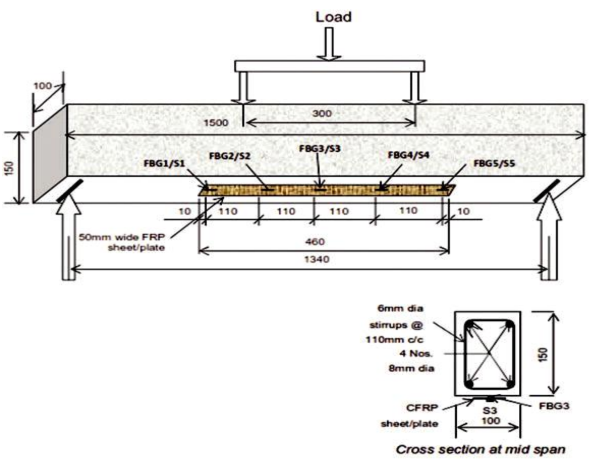



Figure 3. Standard scheme of test instruments for beams. All sizes are in mm. FBG1 – FBG5 denote fiber Bragg grating sensors (length 10 mm) at the boundary between CFRP and concrete. S1 – S5 point at resistive-grain sensors of electric resistance (length 10 mm) on the sheet/plate from CFRP [13].

Matrix FBG sensor [13] consisted of five 10 mm length gratings, located at 100 mm distance along fiber length. Total on the interface for each beam there were switched on five sensors. There were studied two beams and both were equipped with similar devices. Electrical resistance tensometers of 10 mm length were attached to CFRP sheet surface in five places, as it is shown in Fig.4. FBG humidity probe has also been developed for controlling corrosion speed of sewerage networks concrete walls [14].

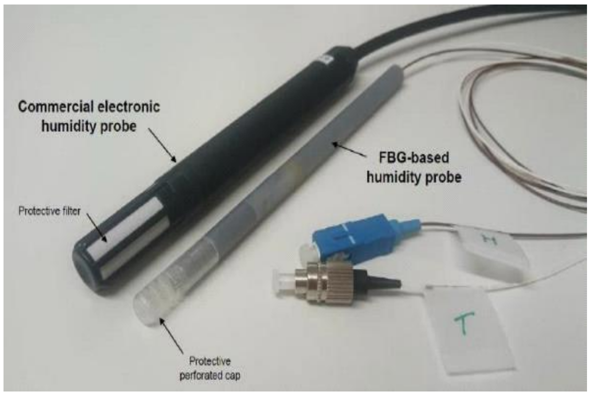



Figure 4. developed sensor, 3D-seal epoxy package (with fiber-optic communication lines with the polling system) [14].

That approach was selected, as it was cheap, and fast in fabrication. Construction [14] consisted of bar fiber. Fiber area, containing active subjected influence at the edge, perforated cap, on 3D-printer, which is easily removed for checking (or redesigning or replacing in case of mud accumulation). That sensor package is illustrated in Fig. 6, where also can be seen compared with commercial electrical sensors (used in assessment tests in sewerage).

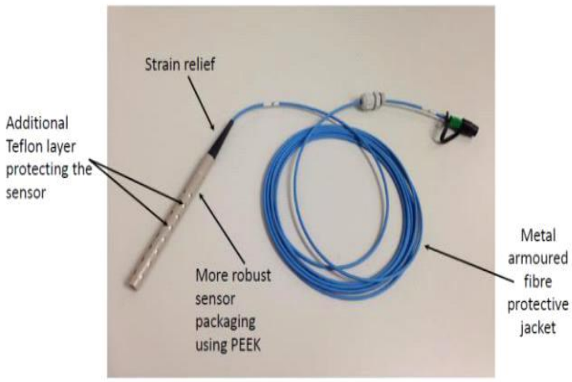



Figure 5. Sensor system, developed, using packages [14].

These sensors [14] perforation bars from fiber-optic connections with interrogation system, got at the market, while in the walls of the cylindrical form (developed in the boring result) there were drilled the holes, allowing the atmospheric gases in sewerage. That package drilled bars 2 layers from PEEK, followed with layer, inner bar, further again is protected with the second drilled bar from PEEK. It creates a reliable configuration of the sensor system for aggressive media, and an outside appearance of the package can be seen in Fig.5.
It was verified, that the FBG sensor secures a long life duration, perfect response time and sustainability within the long period in aggressive media of gaseous hydrogen sulfide with high humidity. Consequently, it was shown, that the FBG sensor has wide perspectives for applying to severe environmental conditions [15].

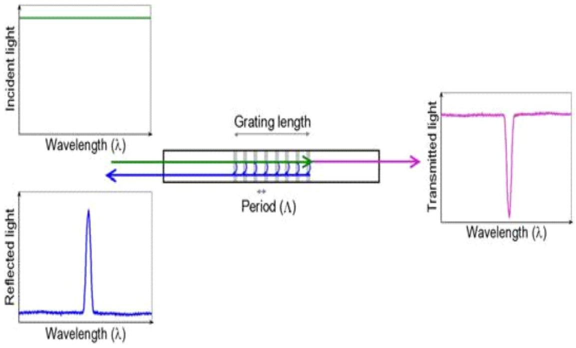



Figure 6. Basic sensor system on the basis of Bragg grating with ability to transmit or reflect [15]

It is embedded in an optical fiber by exposing it to intense ultraviolet radiation. This effect creates periodic fiber changes. The results of the experiment showed that both sensors can support accurate deformation measurements. It was proposed to use FBG and their design was demonstrated, which makes it possible to reduce structural damage by increasing the voltage applied to the FBG sensor by about 36 times [16].

The article [17] presents an experimental application of the measurement method based on a reflectometer for monitoring deformation curves. It was demonstrated that the proposed method provides results corresponding to the results of direct spectral measurements. To accurately measure the physical and mechanical properties of the soil, a probing technique was proposed [18]. To study the law of deformation and the evolutionary characteristics of the internal stresses of overlying layers after the development of shallow and powerful coal seams, a model of fiber Bragg physical similarity sensors embedded in the model for tracking the deformation of overlying layers during coal mining was developed and built. The research results are of great importance for promoting the use of fiber-optic sensors in the mining industry [19]. In the study [20], an inversion model of tunnel precipitation based on the measurement of deformations of a distributed optical fiber was proposed, and the feasibility of the model was confirmed by laboratory tests. Based on field observations, the characteristics of deformation of the distribution of optical fibers and changes in the mechanical properties of the tunnel were analyzed taking into account the destruction process. The article [21] proposes an innovative intelligent multi-layer deformation monitoring system for the inverted arc of a tunnel made of salt-bearing rocks, which combines a laser deformation level monitor and a Bragg grating with a tender fiber for careful control of filling and internal deformation of the inverted arc of the tunnel. The article [22] shows the results of the application of engineering examples and proves that the method of detecting singular flash values can effectively analyze local singular features of data and better detect singular values. The article [23] describes experimental monitoring of structural deformations using ground-based laser scanning and ground-based radar interferometry. The procedures of measurement, analysis of the obtained spatial data and the results of deformation monitoring are explained and described. The objective of the given work is comparison of FBG sensor with tilted grating to existing conventional Bragg sensors.

## II. PROBING PRINCIPLE, BASED ON FBG

Fiber-optic sensors are a fragment of an optical fiber subjected to a certain modification. When using optical fibers as sensing elements, there is no influence on the measurement result of electromagnetic fields, random electromagnetic radiation or crosstalk interference, there are no problems associated with the grounding circuit and displacements at the joints of dissimilar conductors, electrical safety is sufficiently increased, there are no problems with sparking. and sparkling. Fiber-optic sensors are highly resistant to dangerous environmental influences; they have small size and weight, high mechanical strength, resistance to high temperatures, vibrations, etc., as well as high data transfer rate. In addition, fiber-optic sensors can be used in explosive environments due to their absolute explosion safety. They are chemically inert, have a simple design and are highly reliable. Fiber Bragg gratings turned out to be different due to differences in the structure and photosensitivity of the fibers used, as well as the peculiarities of the recording conditions and the lasers with which the recording is performed. The recording features are the exposure time and the recording dynamics, that is, the radiation density. There are many methods for constructing sensor systems based on Bragg lattices in Fig. 3.

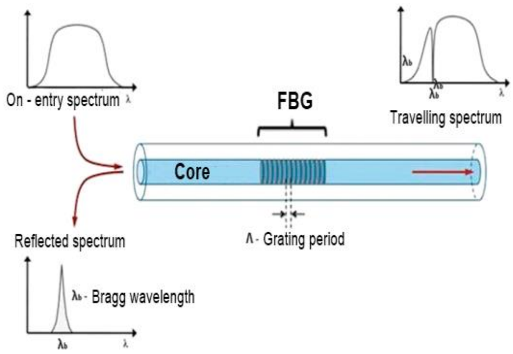


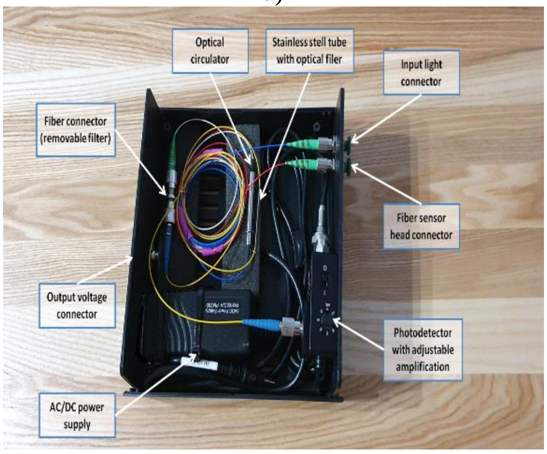

Figure 7. Scheme of sensor

Signal from the source is reflected by sensor element. Reflection wavelength is fixed with an analyzer block. As a rule, analyzer represents a narrow-band spectrometer.

## III. MANUFACTURING TILTED GRATING FBG SENSORS

We have developed and experimentally investigated a sensor with inclined fiber Bragg gratings.

a)




b)

Figure 9. Sensor a) mockup; b) sensor interiority

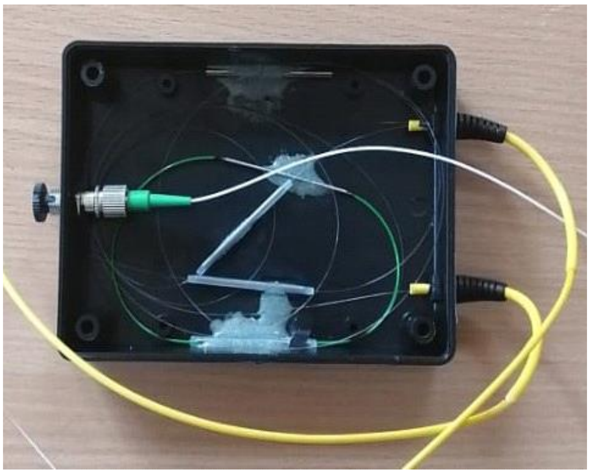


Figure 10. Conventional Bragg fiber-optic sensor

## IV. RESEARCH OUTCOMES

Experimental tests were carried out on the river.

Figure 11. **R**iver bridge


Figure 12. **L**aboratory stand for measuring TFBG temperature

Fig. 12 demonstrates the temperature measuring system, in which TFBG structures have been placed into climatic chamber.

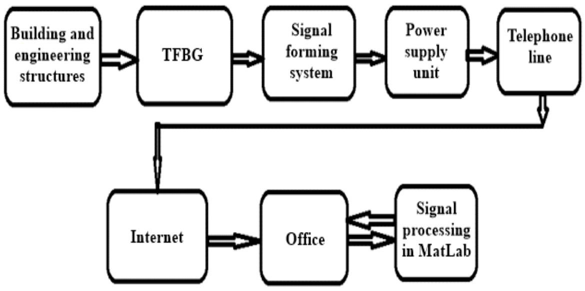



Figure 13. Remote system for distant monitoring

Offered system of distant monitoring operates as follows. Built-in fiber optic sensors with tilted Bragg grating transfer data to the own system of signal conditioner along fiber-optic cables, located in the channels for protecting from the environment. The signal from the power unit is reliably connected via telephone to the Internet, from where the data can be easily extracted and processed from the office by means of MatLab software.

The purpose of this study is to monitor the bridge, various measurements were carried out, including night measurements with a duration of hours, sampling near which will detect the dynamics during the movement of the car. Results, obtained, using G sensor with tilted grating were, as well, compared to the outcomes, obtained

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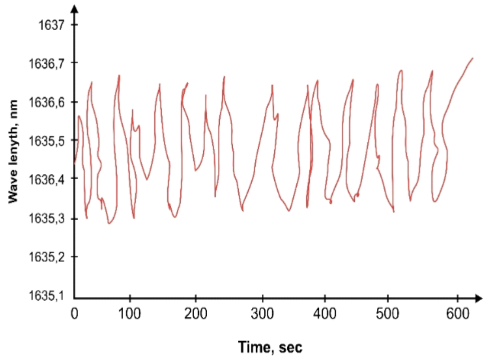
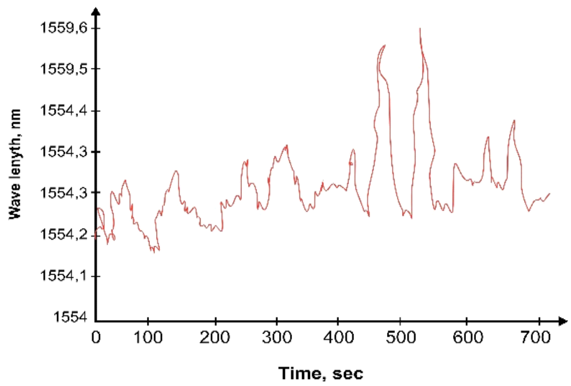
by means of existing optical sensors with direct Bragg grating.



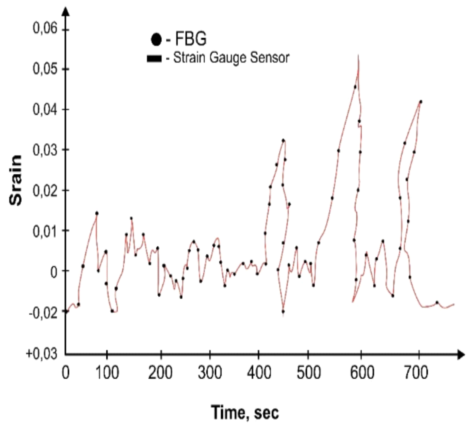

a)




b)

Figure 14. (a, b) wavelength changes and comparison of deformation characteristics, measured with tilted grating (point) FBG sensor and conventional Bragg sensor (line), accordingly

Fig. 14 (a) and (b) show the change in the wavelength of the FBG and a comparison of the characteristics of deformation without deformation of the FBG, which was affected by both thermal and deformation effects.




c)

Figure 15. (c) comparison of deformation responses at sensitive point

Fig.15 (c) gives a comparison of deformation responses at sensitive with the Bragg sensor within 700 seconds. Approximately during 425, 567 and 678 seconds about 10 vehicles moved along the bridge. Experimental data shows, that FBG outcomes well match.

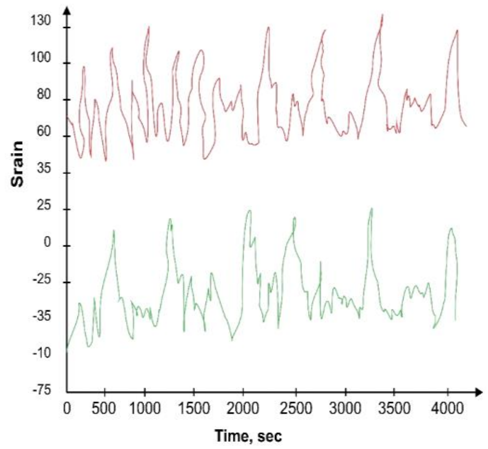



Figure 16. Comparison of FBG sensors (lower) and conventional ones (upper), installed on the bridge.

FBG sensors with tilted grating and conventional Bragg sensors turned out to be very similar and automobiles motion might be clearly revealed.

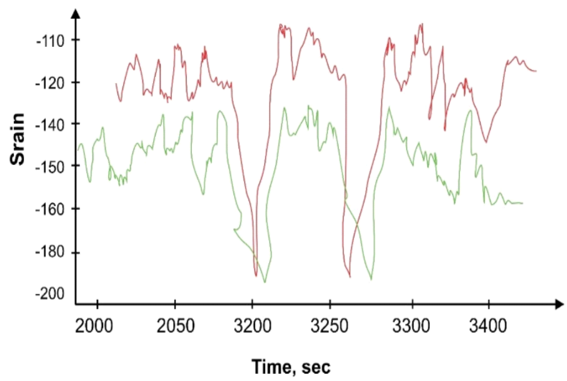



Figure 17. Comparison of the bridge bar

FBG sensor sampling time constitutes 0,0612 ms. Filter, with sliding average FBG sensor and spectral bandwidth, is decreased approximately to 2 Hz. There is detected a big similarity between the sensors.

## V. CONCLUSIONS

The given work presents the technology of fiber Bragg gratings. There has been developed a new fiber-optic sensor with tilted Bragg grating. There have been successfully conducted experimental tests with FBG sensors on the bridge of Issyk river, Almaty region, Republic of Kazakhstan. There have been applied FBG sensors and interrogation systems for monitoring the dynamic load on the bridge. Offered methodology for applying to structural health monitoring, which can perfectly and correctly define dynamic deformational bridge's reactions, caused by automobile movement on the bridge. Outcomes of interrogation system measurements were in excellent acceptance with the results, obtained by means of measurements. FBG sensors with tilted gratings possess many advantages, compared to conventional Bragg sensors. They are remote probing, ease of installation, corrosion absence and much lower expenditures on technical maintenance.

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**Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

-Aliya Kalizhanova, Murat Kunelbayev carried out the simulation and the optimization.

-Ainur Kozbakova, Didar Yedilkhan has implemented the Construction

-Zhalau Aitkulov, Zhassulan Orazbekov

has organized and executed the experiments of Section 4.