ANALYSIS OF PHOTOCONVERSION CHARACTERISTICS
AND PARAMETERS OF A HOLOGRAPHIC CONCENTRATOR
FOR AN ENHANCED EFFICIENCY SOLAR CELL

Abstract. The article describes the microprocessor method for measuring parameters and characteristics of conversion of solar radiation using a holographic concentrator at its production for an enhanced efficiency solar cell. The measurement is done using the Arduino Nano microprocessor controller, the HC-SR04 ultrasonic distance sensor, the TCS34725 color sensor, and the BH1750 light sensor. Information from the digital measuring system is transmitted via a serial USB port to a laptop where it is processed using the Excel spreadsheet.

The developed system for determining the quality parameters and characteristics of the holographic concentrator ensures the obtainment of rational parameters for converting light flux and the necessary level of dispersion and focusing of solar radiation, which contributes to reaching the maximum efficiency of the solar cell.

Key words: microprocessor method, measurement, photoconversion characteristics, holographic concentrator, solar cell, microcontroller, distance sensor, light sensor, color sensor.

Introduction. Microprocessor-based measurement and control systems are widely used in research by scientists from different countries [1-5].

The solar energy engineering is developing a sector related to the conversion of solar radiation into electrical energy using a holographic concentrator [6-8].

The principle of operation of the enhanced efficiency solar cell in line with the RK patent No. 31796 is described in detail in the article [9] and is shown in figure 1.
Figure 1 shows that the holographic concentrator is the most important element of the enhanced efficiency solar cell. It decomposes the light flux of solar energy on the optical axis into spectral components and focuses various wavelengths at a certain distance.

In the process of manufacturing a holographic concentrator with the required level of dispersion and focusing, it is necessary to determine qualitative characteristics of manufactured samples. To this end it is necessary to measure physical parameters of the light flux conversion.

For this, a digital measuring system was developed. It is shown in figure 2.

The digital measuring system contains an 8-bit Arduino Nano microprocessor controller and three digital sensors:

1. The HC-SR04 sensor for measuring the distance from the holographic concentrator;
2. The TCS34725 RGB sensor for measuring the color of a focused beam at the measurement point;
3. The BH1750 sensor for measuring the irradiance of the light flux transmitted through a holographic concentrator without spectral decomposition.

The HC-SR04 digital distance sensor employs acoustic ultrasonic radiation to determine the distance to the object. This contactless sensor ensures high accuracy and stability of measurements. The measurement range is from 2 cm to 400 cm. Solar radiation and electromagnetic noise practically do not affect sensor readings. The principle of operation of the digital sensor measuring the distance to the object is based on measuring the time delay of the reflected 40 kHz ultrasonic signal and is presented in figure 3.

The HC-SR04 distance sensor is connected to the digital pins D2 and D3 that are responsible for TRG (trigger signal) and ECHO (echo signal) respectively.

The TCS34725 RGB color sensor measures the total light intensity, the light intensity of the red, green and blue spectral range.

The TCS34725 color sensor reads data from a set of photodiodes arranged in the form of an 8×8 matrix, which includes 16 photodiodes with blue filters, 16 photodiodes with green filters, 16 photodiodes with red filters and 16 photodiodes without filters. Four types of color photodiodes alternate to minimize the effect of uneven intensity of incident radiation [10].
The BH 1750 sensor measures the visible light intensity in the range from 380 nm (violet) to 780 nm (red) [11].

The TCS34725 and BH1750 sensors are connected via a two-wire I2C interface, and supplied from +5 V. The I2C interface in Arduino boards is implemented on analog pins A4 and A5, which are responsible for SDA (data bus) and SCL (clock bus) respectively [12, 13].

**Research Method.** Figure 4 shows the electrical circuit diagram of a digital system for measuring the qualitative characteristics of holographic concentrator samples.

![Figure 4 - The electrical circuit diagram of a digital system for measuring the qualitative characteristics of holographic concentrator samples](image)

The program code recorded in the microprocessor controller using a laptop initializes digital sensors, reads the measured parameters and transfers data to the laptop for storage and analysis.

The obtained data are recorded on a laptop in an Excel spreadsheet, where the radiation intensity graphs in lux are analyzed and plotted depending on the distance to the holographic concentrator for: C - full-color spectrum, R - red spectrum, G - green spectrum and B - blue spectrum.

The digital system for measuring the qualitative characteristics of holographic concentrator samples is shown in figure 5.

![Figure 5 - The digital system for measuring the qualitative characteristics of holographic concentrator samples](image)

**Research Results and Discussion.** Using a digital system for measuring quality characteristics, three samples of holographic concentrators were analyzed. The measurements were performed on February 24, 2020 from 15.00 to 16.00 p.m. in the city of Almaty, the Republic of Kazakhstan. The light beam focused by the holographic concentrator was manually pointed at the photosensor matrix. This explains the spike in intensity.

Table below shows the results of measuring the illumination of the light flux transmitted through holographic concentrators disregarding the spectral decomposition.
Results of measuring the illumination of the light flux transmitted through holographic concentrators disregarding the spectral decomposition, %

| No | Light Sun, lux | Light in, lux | %  |
|----|----------------|---------------|----|
| 1  | 20,653         | 7,233         | 35 |
| 2  | 20,653         | 5,775         | 28 |
| 3  | 20,653         | 8,467         | 41 |

Here, ‘Light Sun’ is the input intensity of the light flux, and ‘Light in’ is the light intensity of the light flux transmitted through holographic concentrators disregarding the spectral decomposition.

Figures 6, 7 and 8 show diagrams of the qualitative characteristics of holographic concentrators No. 1, No. 2 and No. 3 respectively.

![Figure 6](image1.png)

**Figure 6** – Spectral decomposition of the light flux and its intensity (holographic concentrator No. 1):

- Интенсивность, люкс – Intensity, lux;
- Расстояние от голографического концентратора, см – Distance from the holographic concentrator, cm

![Figure 7](image2.png)

**Figure 7** – Spectral decomposition of the light flux and its intensity (holographic concentrator No. 2)
The diagrams of the qualitative characteristics of holographic concentrators No. 1, No. 2 and No. 3 show that the manufacturing parameters affect the quality of dispersion and focusing. In particular, sample No. 1 decomposes the light flux more evenly. While concentrator No. 2 is characterized by the best light flux conversion coefficient and the worst dispersion. All parameters of the third concentrator are lower than in the first one.

**Conclusion.** The developed digital system for measuring the parameters and qualitative characteristics of the holographic concentrator ensures the determination of physical parameters of the light flux conversion and achievement of the required dispersion and focusing of solar radiation, which contributes to the maximum efficiency of the solar cell.

Н. С. Буктуков, К. А. Васин

**ПАЙДАЛЫ ЭСЕР КОЭФФИЦИЕНТІ ЖОГАРЫ КУН БАТАРЕАСЫ УШІН ГОЛОГРАФИЯЛЫҚ КОНЦЕНТРАТОРДЫҢ ФОТОТУРЛЕНДІРІЛІШ СИПАТТАМАЛАРЫН ТАЛДАУ**

**Аннотация.** Макалада пайдалы эсер коэффициенті жогары кун батареасы ушін оны дайындау кезінде голографиялық концентратордың құн радиациясының түрлісіліру параметрлері мен сипаттамаларын әлшудің микропроцессорлық тәсілі сипатталады. Әлшуде "Arduino Nano" микропроцессорлық контроллерінің, "HC-SR04" қашықтықтық ультрадыбыстық белгі берпіш, "TCS34725" түс қашықтығының және "BH1750" жарық белгісінің комегімен жүргізіледі. Ақпарат әлшуды жүйесінің тәзбекті USB порты арқылы ноутбукқа беріліп, "Exel" кестелік процессорды оқылыңызға алынады.

Сандық әлшудің жүйенің комегімен әлшудың сипаттамалары анықтау ушін голографиялық концентраторлардың үш ұлттық талданды. Әлшуде Қазақстан Республикасы Алматы қаласында 2020 жылы 24 акпаға сәт 15-00-ден 16-00-ге дейін жүргізілді. Фотобелгі беріш мітрическими аумағына жарық салуынан голографиялық концентраторлары төмді көрсету қолмен жүргізілді. Бұл қарқындылығы құрылға оңай түсінірлеседі.

Кестеде спектр бойынша әдір сәк醚ілмеген голографиялық концентраторлар арқылы откен жарық ағымының жарқытандырылу әлшеу нәтижелері көрсетілген.

| No | Light Sun, люкс | Light in, люкс | % |
|----|----------------|----------------|---|
| 1  | 20653          | 7233           | 35|
| 2  | 20653          | 5775           | 28|
| 3  | 20653          | 8467           | 41|
Анализ фотопреобразовательных характеристик и параметров голографического концентратора для солнечной батареи с повышенным коэффициентом полезного действия

Аннотация. В статье описывается микропроцессорный способ измерения фотопреобразовательных характеристик голографического концентратора при изготовлении его для солнечной батареи с повышенным коэффициентом полезного действия. Измерение проводится с помощью микропроцессорного контроллера «Arduino Nano», ультразвукового датчика расстояния «HC-SR04», датчика цветности «TCS34725» и датчика освещенности «BH1750». Информация с цифровой измерительной системы передается через последовательный USB порт в ноутбук, где обрабатывается с помощью табличного процессора «Excel».

При помощи смонтированной цифровой измерительной системы определения качественных характеристик были проанализированы три образца голографических концентраторов. Измерения проводились 24 февраля 2020 года с 15-00 до 16-00 часов в городе Алматы Республики Казахстан. Наведение сфокусированного голографическим концентратором светового луча на область матрицы фотодатчиков проводилось вручную. Это объясняет резкие скачки интенсивности.

В таблице приведены результаты измерения освещенности светового потока прошедшего через голографические концентраторы без учета разложения по спектру.

Результаты измерения освещенности светового потока прошедшего через голографические концентраторы без учета разложения по спектру, %

| №  | Light Sun, люкс | Light in, люкс | % |
|----|----------------|----------------|----|
| 1  | 20653          | 7233           | 35 |
| 2  | 20653          | 5775           | 28 |
| 3  | 20653          | 8467           | 41 |

Здесь Light Sun – входная интенсивность светового потока, а Light in – интенсивность освещенности светового потока прошедшего через голографические концентраторы без учета разложения по спектру.

По результатам измерения составлены графики качественных характеристик соответственно для трех различных голографических концентраторов.

Полученные графики качественных характеристик голографических концентраторов показывают, что в зависимости от параметров изготовления имеет место различный уровень качества диспергирования и фокусировки, в частности, первый образец более равномерно разлагает световой поток по спектру. Так, у второго концентратора лучший коэффициент преобразования светового потока, но худшее диспергирование. В третьем варианте все показатели ниже, чем в первом варианте.

Разработанная система определения качественных параметров и характеристик голографического концентратора позволяет получить рациональные параметры преобразования светового потока и...
необходимый уровень диспергирования и фокусировки солнечной радиации, который способствует получению максимального коэффициента полезного действия солнечной батареи.

**Ключевые слова:** микропроцессорный способ, измерение, фотопреобразовательные характеристики, голографический концентратор, солнечная батарея, микроконтроллер, датчик расстояния, датчик освещенности, датчик цветности.

Работа выполнена в рамках программы BR05236263 «Создание основ серийного производства казахстанских источников возобновляемой энергии мирового уровня».

**Information about the authors:**

Buktukov Nikolaj Sadvakasovic, Academician of the NAS of the Republic of Kazakhstan, Honored Inventor of the Republic of Kazakhstan, Doctor of Technical Sciences, Professor, Director of the Mining Institute named after D.A. Kunayev, Almaty, Kazakhstan; n.buktukov@mail.ru, https://orcid.org/0000-0001-6370-8557

Vasin Konstantin Andreevich, Senior Researcher, Mining Institute named after D.A. Kunayev, Almaty, Kazakhstan; kvas2500@mail.ru, https://orcid.org/0000-0002-4257-2061

**REFERENCES**

[1] Sinha N.K. Microprocessors in Control Systems. In: Sinha N.K. (eds) Microprocessor-Based Control Systems. International Series on Microprocessor-Based Systems Engineering. Vol. 4. Springer (1986), Dordrecht. https://doi.org/10.1007/978-94-009-4708-51

[2] Shoureshi R., Kubota N. Microprocessor-Based Control Systems: A First Step in Teaching Mechatronics, IFAC Proceedings Volumes. Vol. 25, Issue 12, June 1991. P. 103-107. https://doi.org/10.1016/S1474-6670(17)50097-X

[3] Yi Xianjun, Liu Cuimei. Development of high-Precision Temperature Measurement System Based on ARM, 2009 9th International Conference on Electronic Measurement & Instruments. DOI: 10.1109/ICEMI.2009.5274028

[4] Yuan Sannan, Wang Shaoru. Parameter Measurement through Network Based on Embedded System, 2011 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring. DOI: 10.1109/CDCIEM.2011.463

[5] Isembergenov N., Taissariyeva K., Seidalieva U., Danilchenko V. Microprocessor control system for solar power station // News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences. Vol. 1, N 433 (2019). 107 – 111. ISSN 2224-5278. https://doi.org/10.32014/2019.2518-170X.13

[6] Hull J., Lauer J., Broadbent D. Holographic solar concentrators, Energy. March–April 1987. Vol. 12, Issues 3–4. P. 209-215. https://doi.org/10.1016/0360-5442(87)80079-X

[7] Wagemann Ermit & Frohlich Ing & Schulat J. & Schuette Hartmut & Stojanoff Christo (1993) Design and Optimization of a Holographic Concentrator for Two-Color PV Operation. Proceedings of SPIE - The International Society for Optical Engineering. 2017.

[8] Ferrara M.A. & Striano Valerio & Coppola Giuseppe (2019) Volume Holographic Optical Elements as Solar Concentrators: An Overview. Applied Sciences. 9. 193., DOI: 10.3390/app9010193.

[9] Buktukov N.S., Vasin K.A. Experimental Research of New Generation Solar Cells // Reports of The National Academy of Sciences of the Republic of Kazakhstan. Vol. 5, 2019. ISSN 2224-5227. https://doi.org/10.32014/2018.2518-1483.19

[10] TCS34725 Color Light-to-Digital Converter with IR Filter - TAOS Inc., August 2012. [electronic resource] access mode: https://cdn-shop.adafruit.com/datasheets/TCS34725.pdf

[11] BH1750, BH1750 Digital 16bit Serial Output Type Ambient Light Sensor IC TAOS Inc., July 2009 – [electronic resource] - access mode: https://www.alldatasheet.com/datasheet-pdf/pdf/350139/ROHM/BH1750FV1.html

[12] Gonzalez R., Vuds R. Digital Processing of Inventions. Tehnosfera, 2012. 1104 p. ISBN 9785948363318 (in Russ.).

[13] Petin V.A. Projects Involving the Use of Arduino Controller. BHV-Peterburg, 2014. 400 p. ISBN 9785977533379 (in Russ.).