The Radiation Detection Equipment Comprising the Sensor Matrix

Darina Matisková [1], Daniela Marasová [1], Stella Hrehová [1], Renáta Cenková [2]

[1]Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Slovakia
[2]Pavol Jozef Safarik University of Kosice, Philologies and Communication, Slovakia

***Abstract* –The present article describes the technical design of a sensory system used for the detection and localisation of radiation direction in space using a photosensitive component, a sensor matrix. At present, there are a number of systems that use accumulated solar energy. The solar energy is used in heating systems, for water heating, as well as technological purposes and production of electrical energy. The most frequent applications include heating drinking water and energy accumulation in form of a usable (perceivable) heat in hot water containers. However, there are still certain limitations to these systems, as to heating and seasonal accumulation purposes, in terms of their efficiency and financial return.**

***Keywords* – sensory system, radiation, photovoltaic cell, solar energy.**

1. Introduction

From the theoretical point of view, solar radiation represents an enormous source of thermal energy. The radiation received at the Earth's atmosphere represents approximately 174 PW (1 PW = 10^{15} W). As it reaches the Earth's surface, the intensity of the radiation decreases due to reflection and absorption in the atmosphere (6 % reflection; 16 % absorption) and also due to the effect of clouds above the Earth's surface (20 % reflection; 3 % absorption). As a result, approximately 89 PW of the remaining solar radiation reaches the Earth's surface. [9],[11], [12]

Within the accumulation of the usable (perceivable) heat, the thermal energy is stored during the process of heating a substance possessing the properties suitable for such purposes. Accumulation of thermal energy in form of usable (perceivable) heat is most frequently carried out using water as it has a high heat capacity (4.8 kJ/(kg.K) where K represents the Kelvin unit. This method is applied especially for the accumulation of heated drinking water in residential buildings. [9], [13]

There are three main criteria applicable to designing systems for the heat energy accumulation which must be taken into account, i.e., technical parameters of each component, return on investment, and environmental impact. The key factors in designing the heat storage system are the optimal technical properties. [9]

When designing an accumulation system, the following properties that need to be considered are defined by the following parameters:

- high heat capacity (kJ/(kg.K);
- high thermal conductivity (W/(m.K);
- reversibility;
- stability;
- chemical compatibility;
- low toxicity, flammability; and
- affordability.

Ways and technical solutions for heat accumulation

In terms of heat energy storage methods, from a chemical point of view there are three ways of heat storage for later use:

1. Accumulation of sensible heat;
2. Latent heat accumulation;
3. Heat accumulation in the form of a chemical reaction; [9]

DOI: 10.18421/TEM83-09
https://dx.doi.org/10.18421/TEM83-09

Corresponding author: Darina Matisková,
Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Slovakia
Email: *darina.matiskova@tuke.sk*

Received: 28 March 2019.
Revised: 21 July 2019.
Accepted: 04 August 2019.
Published: 28 August 2019.

In each method, there is has a different heat capacity, depending on the volume of the substance that accumulates the heat while the lowest capacity displays the sensible heat and the highest capacity of the heat bound in the form of a chemical reaction. These methods also differ in the difficulty of operation and implementation, and each one of the methods is suitable for a different application. [1], [6]

From the physical point of view, the accumulation of usable (perceivable) heat is based on the principle of the calorimetric equation defined by the following formula:

$$Q = \int_{T_i}^{T_f} v.\rho.c.dT = V.\rho.c.\left(T_f - T_i\right) \qquad (1)$$

where:

Q is the heat transferred to/removed from a substance (W);

v is the volume of the substance (m^3);

ρ is the density of the substance (kg/m^3);

c is the specific heat capacity of the substance (kJ/(kg.K);

T_f is the final temperature of the substance (°C); and

T_i is the initial temperature of the substance (°C).

Latent heat (heat of combustion) is the heat energy released from the substance and generated during the process of changing the state (liquid/solid, liquid/gaseous) of such substance. With this form of accumulated energy, greater heat capacity can be achieved at a smaller volume and a constant temperature.

The physical nature of the latent heat accumulation is defined by the formula (2).

$$Q = V.\rho\left[C_{sp}\left(T_m - T_i\right) + a_m \Delta h_m + C_{sp}\left(T_f - T_i\right)\right] \qquad (2)$$

where:

Q is the heat delivered/removed by the substance (W);

V is the substance volume (m^3);

ρ is the substance density (kg / m^3);

C_{sp} is the average thermal capacity between T_i and T_m (kJ/(kg. K);

T_m is the melting point (° C);

T_i is the initial temperature of the substance (° C);

T_f is the final temperature of the substance (° C);

a_m is the amount of the substance subjected to the change (kg);

Δ_{hm} is the heat released during the fusion process (kJ/kg); and

C_{sp} is the average thermal capacity between T_m and T_f (kJ/(kg.K).

This method of heat accumulation is mainly used for the long-term storage of heat energy and in processes requiring strict temperature compliance. However, the heat accumulation through latent heat has a considerable disadvantage, i.e., low thermal conductivity of the materials (0.20.7 W/(m). [7], [9], [10]

Increasing thermal conductivity, and hence improving overall efficiency, can be achieved by using substances with high thermal conductivity (carbon, metal) that are integrated directly into the heat storage substance. This method employs, for example, carbon fibers (thermal conductivity of 470 W/(m)K) or metal foams that increase the thermal conductivity by 60 to 150 %. In general, materials capable of changing their state are used and they are integrated into the heat reservoirs to improve their overall efficiency. The method of latent heat storage is still being subjected to the research aimed at technology improvement for practical applications.

2. Background of the Technological Equipment

The equipment that is currently used for measuring direction, intensity and gradient of radiation is designed as separate devices, mostly as laboratory apparatus. As for single-purpose sensors used in stationary devices, the curve of their sensitivity is rather flat; it means they are also sensitive to reflect and diffuse radiation components. Such sensors do not guarantee sufficient measuring accuracy of a radiation direction and do not provide a signal that is sufficiently strong for the assessment of the correction of a sensor's direction towards the radiation source. [1], [2], [4]

In systems where the direction of the surfaces of solar collectors or photovoltaic cells is controlled, accurate adjustments are crucial for the optimal energy consumption and for the overall efficiency of such expensive equipment. The practical experience shows that the equipment used for the detection of the direction and intensity (and gradient) of radiation should be of the highest possible sensitivity as it rapidly changes due to declination between the sensor axis and the radiation direction. [3], [4], [10]

Systems for the detection of the position of a radiation source still represent a topical issue as more and more sources of radiation are being discovered (first radiation sources were discovered by H. Becquerel; later these issues were discussed by scientists such as Marie Curie and Pierre Curie, as well as G. Bémont, P. Villard, W. Kaufman, and the spouses F. Joliot-Curie and I. Joliot-Curie). The issues regarding the detection of the position of a radiation source are still topical, as demonstrated by the published patent applications, for example 288494, 50027-2016, 5002-2017. The technical literature dealing with these issues is rather rich, for example the research works by A.G. Frodesen, O. Skjeggestad, Probability and Statistics in Particle Physics, Universitets forlaget, Bergen, 1979,Taylor J.R., An Introduction to Error Analysis, University Science Books, 1997, Cooper J.R., Randle K., Sokhi R.S. : Radioactive Releases in the Environment - Impact and Assessment, J. Wiley& Sons, Ltd., 2003.

3. Detailed Description of the Proposed Technology

The above described drawbacks are eliminated in the proposed technical design as it is based on the fact that a sensory system for the detection of the position of a radiation source comprises the set of four sensors arranged as a separate monolithic unit containing the sensors arranged in a matrix of two lines and two columns. This sensor matrix is placed at the end of the profile bar (with an X or + profile). Individual sensors are arranged so that they fill one of the quadrants of such bar. In this arrangement, the maximum values of readouts from the sensors are achieved when the axis of the profile bar is directed exactly towards the radiation source and in the direction of inclination (elevation) as well as angular rotation (angle of switch). Otherwise, there is an imbalance between the readouts from the sensors. On the basis of the comparison thereof, a relevant control unit is able to identify the magnitude and direction of the position correction (e.g., in solar collectors). This correction is actually carried out by positional servo systems; they accept the differences between the sensor readouts as regulation variations, and in conformity with their function they are active until they reach the zero value. [10], [15]

The system for the detection of the position of a radiation source and the radiation direction using a sensor matrix consists of a base plate, profile bar, sensor matrix, transparent cover, shaping unit, multichannel communication link, and joints. The profile bar is attached to the sensor matrix which is further attached to the base plate. Radiation sensors are placed in the four corners. [9], [10], [14]

On the other side of the base plate, there is a shaping unit with the multichannel communication link. A transparent cover covers the base plate, the profile bar, and the sensor matrix. The sensor matrix is interconnected with the shaping unit through the joints leading through the base plate. The shaping unit adjusts the readouts from the sensor matrix, i.e., amplification, filtration, or conversion into the digital form (A/D conversion), and performs a number of other adjustments. The shaping unit is positioned in the system structure so that its connection with the sensor matrix is as short as possible and the joints are shielded (shielding, and shielding by a metal base plate). The directional accuracy of the system for the detection of the radiation source position and the radiation direction using a sensor matrix depends on the technical parameters of the used sensor matrix, the width of blades, the length of the profile bar, and the shaping unit parameters. It is higher than the accuracies of individual or grouped sensors, without the directional structural components. [8], [15]

The system for the detection of the radiation source position and the radiation direction using a sensor matrix may comprise a sensor matrix for various types of radiation (e.g., light, UV, IR, X-ray, etc.). The sensor matrix contains a set of semiconductor photodiodes, phototransistors, or other radiation sensors.

4. Description of the Proposed Technological Equipment

The technical design is explained in more details in the drawings; Figure 1. shows the sensory system from the view of the radiation source and specifies the functional parts of the equipment. Figure 2. depicts the side view of the sensory system and shows the arrangement of the functional parts of the equipment. [10] ,[11], [5]

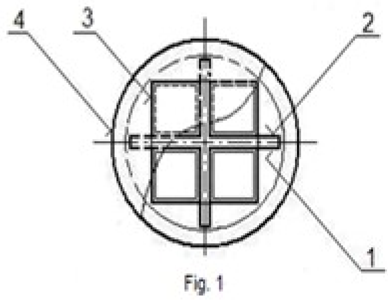

Figure 1. Sensory system from the view of the radiation source

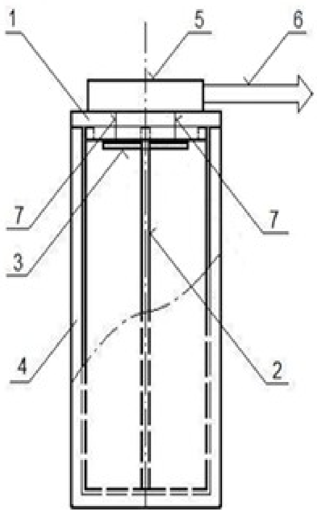

Figure 2. Side view of the sensory system

Keys to Figure 1. and Figure 2. [8]

1- *base plate*
2- *profile bar*
3- *sensor matrix*
4- *transparent cover*
5- *shaping unit*
6- *multichannel communication link*
7- *connection*

Figures 1. and 2. show an example version of the technical design – the arrangement of all functional parts of the equipment. The system for the detection of the radiation source position and the radiation direction using a sensor matrix consists of the base plate (1), profile bar (2), sensor matrix (3), transparent cover (4), shaping unit (5), multichannel communication link (6), and joints (7). The profile bar (2) is attached to the sensor matrix (3) which is further attached to the base plate (1). Radiation sensors of the sensor matrix (3) are placed in the four corners. On the other side of the base plate, there (1) is a shaping unit (5) with the multichannel communication link (6) coming out of it. A transparent cover (4) covers the base plate (1), the profile bar (2), and the sensor matrix (3). The sensor matrix (3) is interconnected with the shaping unit (5) by the joints leading through the base plate (1). The shaping unit (5) adjusts the readouts from the sensor matrix (3), i.e., amplification, filtration, or conversion into the digital form (A/D conversion), and performs a number of other adjustments. The shaping unit (5) is positioned in the system structure so that its connection with the sensor matrix (3) is as short as possible and the joints (7) are shielded (shielding, and shielding by a metal base plate).

5. Conclusion and Industrial Applications

The equipment described in the proposed design may be used for short-term and long-term applications in the apparatuses (functional units) which use the functional units that require position adjustment in order to achieve the optimal value of the selected parameter that depends on the position of the radiation source. An example of such application is adjusting positions of solar collectors and photovoltaic cells during the day. The equipment may also be used separately for the measuring purposes. Alternatively, some of these devices may be mechanically combined into more complex units.

Acknowledgement

This article was prepared with the support from the VEGA 1/0822/16 project and the project from the State Fund of the EU, ITMS Code: 26220220103.

The basis of the technical solution of the above described problem represents the subject of the utility model registered with the Industrial Property Office of the Slovak Republic SR in Banska Bystrica under No. 50035-2018.

References

[1]. Hennessy, J. L., & Patterson, D. A. (2012). *Computer architecture: a quantitative approach*. Elsevier.

[2]. Cabeza, L. F. (Ed.). (2014). *Advances in thermal energy storage systems: Methods and applications*. Elsevier.

[3]. Sørensen, B. (2015). *Solar energy storage*. Academic Press.

[4]. Smil, V. (1991). *General energetics: energy in the biosphere and civilization* (Vol. 369). New York, NY, USA: Wiley.

[5]. Dupláková, D., & Flimel, M. (2017). Layout Effect of Manufacturing Workplace to Illumination of Working Position. *International Journal of Engineering Technologies*, *3*(1), 11-13.

[6]. Tian, Y., & Zhao, C. Y. (2013). A review of solar collectors and thermal energy storage in solar thermal applications. *Applied energy*, *104*, 538-553.

[7]. De Gracia, A., & Cabeza, L. F. (2015). Phase change materials and thermal energy storage for buildings. *Energy and Buildings*, *103*, 414-419.

[8]. Zhou, Z., Zhang, Z., Zuo, J., Huang, K., & Zhang, L. (2015). Phase change materials for solar thermal energy storage in residential buildings in cold climate. *Renewable and Sustainable Energy Reviews*, *48*, 692-703.

[9]. Gašparík, M.(2016). *Akumulácia tepelnej energie v solárnych systémoch*, TZB Houstechnik.

[10]. Matisková, D. at all .(2018). *Device for detection of radiation source position by sensor matrix*, Industrial utility pattern no. PÚ 50035-2018, Registered at the Industrial Property Office of the Slovak Republic in Banská Bystrica.

[11]. Matiskova, D. (2013). Working process optimization and minimization of production costs. *Strojarstvo: časopis za teoriju i praksu u strojarstvu*, *55*(3), 231-235.

[12]. Andrejiova, M., Grincova, A., & Marasova, D. (2016). Measurement and simulation of impact wear damage to industrial conveyor belts. *Wear*, *368*, 400-407.

[13]. Mižáková, J., Piteľ, J., Hošovský, A., Kolarčík, M., & Ratnayake, M. (2018). Using Special Filter with Membership Function in Biomass Combustion Process Control. *Applied Sciences*, *8*(8), 1279.

[14]. Rimár, M. at all.(2016). *Dependence of hardness of continues die-casting products on Fe content. MM Science Journal*, *2016*(11), 1201-1204.

[15]. Panda, A., Duplak, J., Jurko, J., & Behún, M. (2013). New experimental expression of durability dependence for ceramic cutting tool. In *Applied Mechanics and Materials* (Vol. 275, pp. 2230-2236). Trans Tech Publications.