2. Khairnasov, S. Solar Collectors of Buildings Facade Based on Aluminum Heat Pipes with Colored Coating [Text] / S. Khairnasov, B. Rassamakin, R. Musiy, A. Rassamakin // Journal of Civil Engineering and Architecture. — 2013. — Vol. 7, No. 4(65). — P. 403–409.
3. Rassamakin, A. The heat recovery exchanger based on the heat pipes technology for the domestic boilers [Text] / A. Rassamakin, D. Kozak // These were the World Sustainable Energy Days conference. — Wels, Austria, 2014. — Vol. 1. — P. 156–158.
4. Mostafa A. Abd El-Baky. Heat pipes heat exchanger for heat recovery in air conditioning [Text] / Mostafa A. Abd El-Baky, Mousa M. Mohamed // ASME-ATI, «Energy: Production, Distribution and Conservation». — Milan, Italy, 2006. — Vol. 2. — P. 659–668.
5. Семена, М. Г. Тепловые трубы с металло-волокнистыми капиллярными структурами [Текст] / М. Г. Семена, А. Н. Гершуни, В. К. Зарипов. — Київ: Вища школа, 1984. — 214 с.
6. Reay, D. Heat Pipes [Text] / D. A. Reay, P. A. Kew. — Ed. 5. — Butterworth-Heinemann, 2006. — 374 p.
7. Zhuang, J. Prospects of heat pipe technology for year 2010 [Text] / J. Zhuang, H. Zhang // Chemical Engineering and Machinery. — 1998. — Vol. 25, No. 1. — P. 44–49.
8. Исаченко, В. П. Теплопередача [Текст] / В. П. Исаченко, В. А. Осипова, А. С. Сукомел. — Москва: Энергоиздат, 1981. — 416 с.
9. Цветков, Ф. Ф. Тепломассообмен [Текст] / Ф. Ф. Цветков. — Москва: МЭИ, 2006. — 550 с.
10. Тепловой расчет котлов. Нормативный метод. — Изд. 3-е. перераб. и доп. — СПб.: НПО ЦКТИ-ВТИ, 1998. — 257 с.
11. Гершуні, О. Н. Порівняльний аналіз теплопередаючої здатності теплообмінників випаровувально-конденсаційного типу та рекуперативних трубчатих теплообмінників [Текст] / О. Н. Гершуні, О. П. Ніщик // Промышленная теплотехника. — 2010. — Т. 10, № 3. — С. 28–36.

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ТЕПЛООБМЕННИКА НА ОСНОВЕ ТЕПЛОВЫХ ТРУБ

Приведены результаты экспериментального исследования теплообменника на основе тепловых труб для котлов малой мощности. Проанализированы полученные результаты на соответствие данным других авторов. Также проведен сравнительный анализ исследуемого и рекуперативного теплообменников. Показано, что при одинаковой тепловой мощности сравниваемых утилизационных теплообменников, теплообменник на тепловых трубах имеет в 4...5 раз меньшую площадь теплопередающей поверхности по отношению к обычному рекуперативному теплообменнику.

Ключевые слова: тепловые трубы, утилизационный теплообменник, рекуперативный теплообменник, экспериментальные данные, теплопередающая поверхность.

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ВДОСКОНАЛЕННЯ ЗАСОБІВ ТЕЛЕВІЗІЙНОЇ ПІРОМЕТРІЇ

У статті проаналізовано проблему вдосконалення телевізійної пірометрії шляхом визначення діапазону лінійності світлосигнальної характеристики телевізійної системи. В ході досліджень накопичено значний обсяг експериментальних матеріалів. Результати досліджень можна використати для формування сигналів як телевізійної системи визначення параметрів зонної плавки, так і в телевізійних системах іншого призначення.

Ключові слова: *телевізійна пірометрія, телевізійна інформаційно-вимірювальна система, ПЗЗ-матриця, телевізійна камера, вимірювання, температура.*

1. Introduction

Effectiveness of the most high-temperature technologies can be ensured on the stipulation that all the technological requirements for temperature are met. However, adherence to the requirements is basically impossible without proper measuring equipment, namely pyrometers. In such a case, technical facilities must both meet current demands on temperature measurement accuracy during a technological cycle and have a significant potential for improvement of their performance.

A television pyrometry meets the specified requirements in full. The television pyrometry is a set of methods and temperature measurement devices by analyzing self-radiation in a full spectral range (monospectral pyrometry) or by comparing flows in multiple spectral ranges (multispectral pyrometry), which covers an area of measuring equipment that includes theory and practice of high temperature measurement by television means. Moreover, it is a very promising tool for thermal nondestructive testing.

2. Analytical overview of periodicals relating to work

We researched the results, which were obtained by leading experts in the field of television pyrometry (Yu. Ch. Gaydukevich [1, 2], A. P. Dostanko [2], V. A. Poryev [3, 4], V. A. Karachinov [5], A. V. Kuznetsov [6] and others), on the basis of literature sources and have made the following conclusions.

Firstly, up-to-date television information and measurement systems allow simultaneously provide such performances in maximal sampling format, minimum time of its formation and spatial differentiation, which are the highest among other information and measurement equipment, making them indispensable when a set of performances shall be determinative.

Secondly, a non-competitive advantage of television facilities in their application to control over the high-temperature technologies is a unique opportunity to provide temperature measurement along any trajectory in real time.

Thirdly, presence of a computer as part of the television pyrometer allows you to implement and flexibly use a powerful arsenal of methods of formation, processing and analysis of images to improve exact performances of the up-to-date radiation pyrometry.

It is known that a significant limitation on a scope of application of the monospectral television pyrometry is a fundamental dependence of measurement results on a priori knowledge about a facility radiative capacity coefficient and its behavior in the range of measurements. The multispectral television pyrometer (MTP), being under the same conditions, provides potentially higher accuracy. Clearly, it opens up new possibilities to increase probability of control over the temperature modes, and hence, to improve product quality in the high temperature technologies, e. g. electron-beam technologies of obtaining ultrapure materials and materials with desired properties, as well as other related technologies [7, 8].

At the same time, a large number of problems in the multispectral television pyrometry, being important both in theoretical and practical aspects, have not received an adequate coverage at the moment. Particularly, the scientific and technical literature does not have systematic data on technical means of the multispectral television pyrometry, accurate results of their use in scientific or technological practice. Some publications on this topic [3, 9] is not well-grounded and have any substantiation by research of specifications, evaluation of potential opportunities, etc.

The main reasons for such a situation to be created include as follows.

3. Problem statement

Firstly, there are no mathematical models of bispectral pyrometer (BSP) signal measurement, being adequate to physical processes, on the basis of which new measurement techniques and error estimation methodologies can be developed. Clearly, there are no reliable estimates of BSP errors.

Secondly, attempts to enjoy benefits of the unproductive pyrometry by television means simultaneously with improvement of the temperature measurement accuracy are accompanied by errors in measurement of linear dimensions of the temperature fragments. Therefore, it is necessary to review both existing approaches to creation of the television BSP and development of new models and improvement of the temperature measurement methods.

Today, there are no reliable data on such fundamentally important characteristics of the television BSP as an equivalent wavelength and noise equivalent temperature difference of spectral ratio.

Thus, today the problem is not to provide multispectral control over the high temperature by means of television, but to analyze and solve new problems, arising in the case.

This means that today we have not actually created potentially the most effective methodology for temperature control, which capabilities would fully meet the needs of up-to-date high temperature technologies, in particular, needs of the float zone melting.

The above facts shall determine relevance and academic novelty of researches, aimed at creation of non-spectral television zone melting performance measurement means and to provide control of temperature fields of different origin.

4. Problems of using television equipment for the analysis of optical fields

A choice of means for measuring the important process parameters is determined by requirements of the process. Firstly, if you are to cover problems as to the possibility and feasibility of using the television system technique, you should start with an analysis of a paradigm of using the television facilities for the analysis of optical fields.

The paradigm of using the television equipment for the analysis of optical fields is based on the ratio of possibility and expediency of use of a television facility to address a specific problem and is illustrated in Fig. 1.

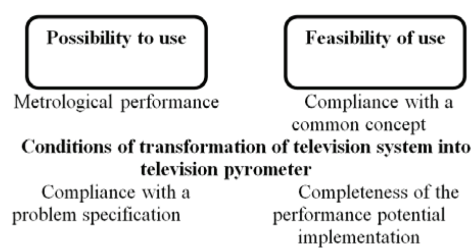

Fig. 1. Use of the television facilities for the analysis of optical fields

This paradigm defines conditions of transformation of the tremendous opportunities of the television system technique into characteristics of the television measurement equipment.

We have formulated a list of conditions that determine possibility and feasibility of using the television facilities in a particular task.

Firstly, the spectral ranges of a radiation object $\Delta\lambda_o$ and measurement facility shall overlap, i. e. $\Delta\lambda_e$. Hence, we can speak of the primary importance of determining the television information-measuring system spectral characteristics (or working area of spectral characteristics).

When determining the luminous-signal characteristics, we shall use a wavelength λ_m for which the signal has a maximum value, i. e. to choose an end point of the spectral characteristics. If shifting in the spectral characteristics to the right or left, then we will get different measuring signals with the same value of illumination and on the CCD target [8].

Thus, taking into consideration the above facts, the basic television information-measuring system characteristics shall contain the spectral characteristics, which make the measured temperature range.

Secondly, it is clear that the illumination of the target E_M must be greater than some threshold $E_{\text{пор}}$, i. e. $E_M \geq kE_{\text{пор}}$. Thus, the second important characteristic, ensuring possibility to use the television means for coverage of a specific problem, is the television information-measuring system luminous-signal characteristic and more precisely the range of linearity of input signals, within which a conceptual condition as to the whole of independent microsensors is created.

It is also possible that the spectral ranges had overlapped and illumination exceeds the threshold. But, a requirement to overlapping of an object's spatial spectrum and the spatial-frequency characteristics of the measurement equipment is not fulfilled. Therefore, we can say that a modulation transmission function (MTF) television information-measuring system is also the very important for studies.

We must add that the general concept of using the television equipment to analysis the optical fields is based on the assumption of that light-electric transducer is an ordered matrix of the identical independent microsensors, which independently create signals at the same level of illumination [3, 9].

Identity means that all microsensors create the same signal, if there is even illumination.

Independence means that a signal, generated at any converters, does not flow into a neighboring converter.

Note, that an order requirement is not relevant today, because inherently CCD is an ordered set of pixels.

This approach permits to use the television equipment for measurement of the geometric, amplitude and dynamic parameters of the image, but taking into account certain cautions. Particularly, [3] evidences that reasonableness of the concept is ensured only when working within the range of linearity and provided that there is compensation of uneven sensitivity of a pixel, which is the result of a number of reasons (minor violations of a matrix production technology, leading to a spread of values of the pixel sizes and electrode transmission coefficients, transfer inefficiency, charge spreading, etc.) [10].

5. Analysis of the television pyrometry improvement ways

Nowadays, despite considerable progress in the television pyrometry development, accompanied by its global recognition and confirmed by the latest achievements, we are to solve some problems that are important from the point of view of improving the accuracy of the high temperature measurement by the television means.

The first problem shall be creation of bispectral pyrometer, which potentially have significant advantages over monochromatic, namely in the accuracy of temperature measurement.

If there is no data on the radiative capacity values, bispectral pyrometer provides the higher accuracy of measurements and new opportunities to increase reliability of control over the temperature modes in high technologies.

However, the scientific literature does not have any reliable and systematic data on technical means of the bispectral television pyrometry. Some publications on the use in scientific or technological practices are unable to form a reasoned opinion on the possibilities of bispectral pyrometer.

Thereat, expansion of a range of scientific and technological tasks, which are covered by using bispectral pyrometer, shall increase demands on the accuracy of their performance, which is possible only by improving the measurement capabilities. Obviously, first of all you are to determine performance, which is not categorized by a manufacturer of the television equipment.

A list of such characteristics (luminous-signal characteristic, uneven sensitivity). This list should be added with an equivalent wavelength and temperature difference of spectral ratio, being equivalent to noise. We could not find suitable materials in the contemporary scientific and technical literature.

It is clear, that development of new methods of measurement and improvement of the existing television pyrometry facilities is impossible without development of the adequate physical and mathematical models.

It shall also include problems of creating the new error estimation methods. It is obvious that well-known techniques, used in the monospectral pyrometry, cannot be used in the multi-spectral pyrometry.

Improvement of accuracy of the temperature measurement can be achieved both by improving the bispectral pyrometer characteristics and by improving methods of their application. It is clear, that improvement of the bispectral pyrometer characteristics, in particular, requires enhancement of accuracy of the temperature measurement, especially, it requires improvement of the metrological support.

We shall not forget that a television equipment production technology is being continuously improved. Therefore, the new factors (variables) appear. They affect the measurement facilities performance.

So, metrological support of television information-measuring system, in general, and bispectral, in particular, cannot be changed. A proof thereof can be results of the recent studies of spatial separating capacities of the television measurement facilities, which have substantially changed a vision of their potential.

If we consider characteristics, that determine accuracy of the temperature measurement in methods of the television bispectral pyrometry, the main characteristics shall be equivalent wavelength, effective to the noise difference of color temperatures and luminous-signal characteristic. Clearly, accuracy of the temperature measurement is affected by a dark signal range of the specific device. First of all, in such a case it is necessary to make experimental studies of performance of the facilities, which are used today or evaluated from the perspective of their use in the bispectral television pyrometry.

However, the contemporary scientific literature practically does not have any materials on the relevant research methods or their results. It places special emphasis on the importance of the problems, laid down in this article.

You are to take into consideration that the existing methods for determination of performance, used in the traditional pyrometry and monospectral television pyrometry, also need revision and improvement.

6. Conclusions

The television measurement equipment, providing such performances in maximal sampling format, minimum time of its formation and spatial differentiation, which are the highest among other information and measurement equipment, shall be the only way to control the dynamic temperature fields of an irreg shape.

Thereat, an error in the temperature measurement can exceed the permissible number of errors by an order of magnitude greater within the temperature range, which corresponds to the range of temperatures and technological parameters of zonal melting. We also know that appropriateness of the concept of using the television measurement equipment to control over the temperature parameters shall be ensured only, when operated in the range of linearity on condition that uneven sensitivity of the matrix is compensated.

Therefore, determination of the range of linearity of the television information-measuring system luminous-signal characteristics will fulfill one of the conditions of the concept.

We have also accumulated a considerable amount of experimental materials in course of the experiments. They concern formation of signals both in the television information-measuring system parameters of zonal melting, and in the television equipment of another destination, particularly, in the television pyrometers that can be used for control over the temperature conditions for pipe rolling technologies, in the television devices for food product quality control, environmental monitoring, in the television microscopy etc.

References

1. Gajdukevich, Yu. Ch. Sistemy jeffektivnogo teplovizionnogo kontrolja vysokotemperaturnyh polej v proizvodstve izdelij jelektronnoj tehniki [Tekst]: avtoref. dis. ... kand. tehn. nauk: 05.27.07 / Yu. Ch. Gajdukevich. — Minsk: Minsk. radioteh. inst., 1991. — 20 s.
2. Gajdukevich, Yu. Ch. Teplovizionnaja pirometricheskaja sistema [Tekst] / Yu. Ch. Gajdukevich, N. I. Domarjonok, A. P. Dostanko i dr. // Jelektronnaja promyshlennost'. — 1987. — № 3. — S. 59–62.
3. Poriev, V. A. Konceptual'ni aspekti vikoristannja priladiv z elektronnim rozgortannjam zobrazhennja dlja analizu optichnih poliv [Tekst] / V. A. Poriev, G. V. Poriev // Naukovi visti NTUU «KPI». — 2001. — № 1. — S. 56–61.
4. Markin, M. O. Mul'tispektral'ni televizijni priladi kontrolju visokotemperaturnih tehnologij [Tekst] / M. O. Markin, G. M. Zgurovs'kij, V. A. Poriev, Ye. O. Bielorusov, I. V. Bojko // Vostochno-Evropejskij zhurnal peredovyh tehnologij. — 2006. — № 4/2(22). — S. 24–26.
5. Karachinov, V. A. Issledovanie harakteristik televizionnogo pirometra so vstroennym kalibratorom temperatury [Tekst] / V. A. Karachinov, D. V. Karachinov, S. B. Toricyn // Izmeritel'naja tehnika. — 2007. — № 7. — S. 42–44.
6. Kuznecov, A. V. Ocenka diapazona izmerenij televizionnogo monohromaticheskogo pirometra [Tekst] / A. V. Kuznecov // Opticheskij zhurnal. — 2008. — T. 75, № 1. — S. 39–42.
7. Hubel, P. Spatial Frequency Response of Color Image Sensors: Bayer Color Filters and Foveon X3. [Text] / P. M. Hubel, J. Liu, R. J. Guttosch // Proceedings of SPIE. — 2004. — Vol. 5301, EI'04. — P. 402–407. — Available at: \www/URL: doi: 10.1117/12.561568.
8. Lyon, R. Eyeing the Camera: Into the Next Century [Tekst] / R. Lyon, P. Hubel // IS&T/TSID 10th Color Imaging Conference Proceedings. — Scottsdale, AZ, USA, 2002. — P. 349–355. — Available at: \www/URL: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.102.6377.
9. Hauer, W. High-temperature dual-band thermal imaging by means of high-speed CMOS camera system [Tekst] / W. Hauer, G. Zauner // SPIE 8661, Image Processing: Machine Vision Applications VI. — 2013. — P. 866103. — Available at: \www/URL: doi: 10.1117/12.2002357.
10. Estevadeordal, J. Multi-Color Imaging Pyrometry Techniques for Gas Turbine Engine Applications [Tekst] / J. Estevadeordal, N. Tralshawala, V. Badami // ASME 2013 Fluids Engineering Division Summer Meeting. American Society of Mechanical Engineers. — July 2013. — ASME 2013 Fluids Engineering Division Summer Meeting. — P. V002T11A007. — Available at: \www/URL: doi:10.1115/FEDSM2013-16369.

УСОВЕРШЕНСТВОВАНИЕ СРЕДСТВ ТЕЛЕВИЗИОННОЙ ПИРОМЕТРИИ

В статье проанализирована проблема совершенствования телевизионной пирометрии путем определения диапазона линейности светосигнальной характеристики телевизионной системы. В ходе исследований накоплен значительный объем экспериментальных материалов. Результаты исследований можно использовать для формирования сигналов как телевизионной системы определения параметров зонной плавки, так и в телевизионных системах другого назначения.

Ключевые слова: телевизионная пирометрия, телевизионная информационно-измерительная система, ПЗС-матрица, телевизионная камера, измерения, температура.

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