ISSN 1726-5479

SENSORS & TRANSDUCERS

11 vol. 16 Special /12

Intelligent Data Acquisition and Information Process Technologies and Their Applications

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 16, Special Issue
November 2012

www.sensorsportal.com

ISSN 1726-5479

Guest Editors: Gongfa Li, Tinggui Chen and Hegen Xiong

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and on CD.

Sensors & Transducers Journal

Contents

Volume 16
Special Issue
November 2012

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

International Frequency Sensor Association (IFSA).

The Fourth International Conference on Sensor Device Technologies and Applications

SENSORDEVICES 2013

25 - 31 August 2013 - Barcelona, Spain

Tracks: Sensor devices - Ultrasonic and Piezosensors - Photonics - Infrared - Gas Sensors - Geosensors - Sensor device technologies - Sensors signal conditioning and interfacing circuits - Medical devices and sensors applications - Sensors domain-oriented devices, technologies, and applications - Sensor-based localization and tracking technologies - Sensors and Transducers for Non-Destructive Testing

Deadline for papers: 30 March 2013

http://www.iaria.org/conferences2013/SENSORDEVICES13.html

The Seventh International Conference on Sensor Technologies and Applications

Deadline for papers: 30 March 2013

SENSORCOMM 2013

25 - 31 August 2013 - Barcelona, Spain

Tracks: Architectures, protocols and algorithms of sensor networks - Energy, management and control of sensor networks - Resource allocation, services, QoS and fault tolerance in sensor networks - Performance, simulation and modelling of sensor networks - Security and monitoring of sensor networks - Sensor circuits and sensor devices - Radio issues in wireless sensor networks - Software, applications and programming of sensor networks - Data allocation and information in sensor networks - Deployments and implementations of sensor networks - Under water sensors and systems - Energy optimization in wireless sensor networks

http://www.iaria.org/conferences2013/SENSORCOMM13.html

The Sixth International Conference on Advances in Circuits, Electronics and Micro-electronics

CENICS 2013

25 - 31 August 2013 - Barcelona, Spain

Deadline for papers: 30 March 2013

Tracks: Semiconductors and applications - Design, models and languages - Signal processing circuits - Arithmetic computational circuits - Microelectronics - Electronics technologies - Special circuits - Consumer electronics - Application-oriented electronics

http://www.iaria.org/conferences2013/CENICS13.html

Sensors & Transducers Journal, Vol. 16, Special Issue, November 2012, pp. 61-67

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Influence of Expansion Joint of Bottom Lining in Ladle Composite Construction Body on Thermal Stress

Guozhang Jiang, Gongfa Li, Jianyi Kong, Liangxi Xie and Siqiang Xu
College of Machinery and Automation,
Box 242, Wuhan University of Science and Technology, Wuhan, 430081, China
Tel.: +86-027-68862283
E-mail: whjgz@wust.edu.cn

Received: 11 September 2012 /Accepted: 11 October 2012 /Published: 20 November 2012

Abstract: Expansion joint has an important effect on the thermal stress of ladle composite construction body. The thermal expansion stress is one of important reasons that lead to damage, so it is of great practical value to calculate the thermal expansion stress. Expansion joint question between the inside linings could be summed up as a kind of contact question, whose physical model was set up, and the finite element model of expansion joint of bottom lining in ladle composite construction body was built. The contact stress of expansion joint in each layer was researched. The results illustrate that setting 2 millimeters expansion joint can reduce the contact stress which is equate to 1/6 ~ 1/5 of crushing strength of the lining. *Copyright © 2012 IFSA.*

Keywords: Ladle composite construction body, Bottom lining, Expansion joint, Finite element method, Thermal stress.

1. Introduction

The ladle is in the metallurgical industry an important vessel to contain and transfer molten steel whose service life directly affects the normal production and cost of incorporations. When the ladle is put into service, its lining temperature distribution has a vital effect on the lining thermomechanical stress distribution, even service life. Thus, it is necessary to comprehend the ladle stress distribution [1].

Research of the ladle temperature and stress deepens continuously with the development of refractory material and advance of steel-making process. Its main purpose is to analyze reasons of the shell temperature increase, refractory material erosion and structure instability as well as to look for measures

[2]. G. S. Sarmiento [3] developed software TEMPCU specialized in analysis of the ladle temperature field and stress field. The software adopted the finite element method to establish two dimensional model of the ladle. The temperature field and stress field could be analyzed in all stages of ladle preheating, Subjected steel, refining and conveyance, pouring as well as cooling; Non-local damage approaches to account for the coarse nature of the refractory micro-structure have only been used in Nazaret and Barrau [4]; Jianyi Kong [5] researched influence of the ladle working lining thickness and heat transfer coefficient on its temperature; Guozhang Jiang [6] researched the influence of refractory material physical parameters and various working lining thickness on distribution of stress field of ladle wall during the process of receiving steel and offered some references for the ladle design; Zhigang Wang [7] used the finite element method to implement numerical simulation on ladle bottom temperature and stress field. The calculation result indicated that the ladle is still in the state of absorbing heat after preheating and reached to "quasi-steady state" after several heat recycles; After preheating, stress value of working layer of the ladle bottom reached to the maximum at the instance of pouring molten steel; stress in the ladle bottom working layer hot surface near to the ladle wall is higher than that near to the center. The insulated device is installed near to the ladle wall to diminish its stress.

From above, it can be seen from research of the ladle at home and domestic that their study mainly focuses on control of ladle temperature and influence of various lining material on ladle temperature and stress distribution. In such research, researchers utilize preferably a 2-D axisymmetric or simplified model. As a matter of fact, the 2-D axisymmetric or simplified model can not thoroughly reflect the actual ladle. The stress field of the ladle, as a composite construction body, is further studied.

The thermal stress is one of important factors which lead to the ladle damage as ladles operate under conditions of high temperature and overload. The thermal expansion arises in the ladle lining and shell which are associated with high temperature. When the deformation arising from the thermal expansion in the ladle lining and shell is subjected to mutual constraint each other, the thermal expansion stress was generated. The most effective approach of adjusting the ladle thermal expansion stress is to set up the expansion joint. Whereas, if the expansion joint is too large, it easily results in "molten steel seepage" and causes serious accidents; if the expansion joint is too little, the thermal stress expands, which diminishes the service life of the shell and refractory bricks. Therefore, calculation of the thermal expansion stress is of great practical value.

The lining expansion joint value is defined during the ladle construction. Flanks on the ladle lining bricks requiring the expansion joint are added up with normal thickness papers. The papers combust as a result of high temperature when the ladle enters the working condition of subjected molten steel at the end of heating the ladle. And then the expansion joint appears in the paper location. The expansion joint value of the ladle lining determined, the thermal stress of the ladle lining decreases. At the same time, the accident of steel seepage of the ladle is avoided occurring. So the expansion joint left in the lining expansion joint is just filled with expanded lining bricks in order to guarantee production safe when the ladle is transferred into the working condition of subjected molten steel after heating the ladle.

The approach that the thermal stress in the ladle with the expansion joint was defined by the finite element method was: choosing the thermal-structural coupled element could obtain both: the temperature field and thermal stress as well as the normal pressure not only between lining bricks but also on the contact surface between lining bricks and the shell.

2. Physical Model of Contact Problems

The contact problem is one type of complex nonlinear problems, which belongs to nonlinear problems of the boundary condition. The complexity mainly derived from change of system states, separate and contact between objects namely. In contact problems, the contact surface between two contacts is

commonly unknown beforehand, and the boundary condition is not prescribed before calculation but is given by the computation result. Area and pressure distributions of the contact surface between two contacts depend on change of the applied load and initial gap and are related to the contact stiffness. There are primarily the penalty method and penalty method combined with Lagrange multiplier method for dealing with contact problems. When gap between the contact and target surface is greater than zero, the contact status is closed; otherwise it switches to open. The contact penetration is denoted by the gap value. As the contact node penetrates the target surface, the contact occurs. The relation between normal force F_n which the contact section is subjected to and gap value is represented as [5]:

As for the penalty method, the normal contact force is denoted by:

$$F_n = \begin{cases} k_n \times g & g \le 0 \\ 0 & g > 0 \end{cases}, \tag{1}$$

where K_n is the contact stiffness; g is the contact gap.

For the penalty method combined with the Lagrange multiplier method, Lagrange polynomial of force is iterated repeatedly in each element. The normal contact force is indicated as:

$$F_n = \min(0, F_n \times g + \lambda_{i+1}), \tag{2}$$

where λ_{i+1} is the Lagrange multiplier force in the i+1 iteration, which is represented by:

$$\lambda_{i+1} = \begin{cases} \lambda_i + \alpha \times K_n \times g & |g| \ge FTOLN \\ \lambda_i & |g| < FTOLN \end{cases}, \tag{3}$$

where $FTOLN$ is the allowable penetration tolerance defined by users; α is the inner calculation factor (α<1).

The friction force on the contact surface, the tangential force of the contact surface namely, is introduced owing to increasing frictions which contact nodes coming together and moving towards target nodes result in.

For three types of friction forms (Free friction, elastic Coulomb friction and rigid Coulomb friction), note that the friction force is given by:

$$F_s = \begin{cases} 0 \\ F_t \times u_s^e < \mu \times F_s^1 \\ F_s^1 \end{cases}, \tag{4}$$

where F_t is the adhesive stiffness. u_s^e is the elastic tangential deform. μ is the adhesive force limit in the Coulomb friction mode. F_s^1 is the ratio of coefficient of static-dynamic friction.

3. Finite Element Model of Expansion Joint of the Ladle Bottom Lining

The expansion joint of the ladle bottom lining is similar to the expansion joint of the ladle wall lining in the treatment method, except being set along the direction of the ladle height. Finite element models of the working layer and permanent layer as well as the permanent layer and outer shell were shown as

Figs. 1-2. Where a＝120 mm, b3＝4.5 mm, b4＝1 mm, h1＝230 mm, h2＝162 mm, h3＝75 mm.

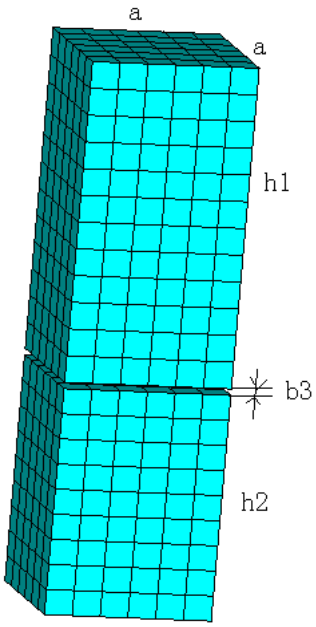


Fig. 1. Finite element model of the working layer and permanent layer.

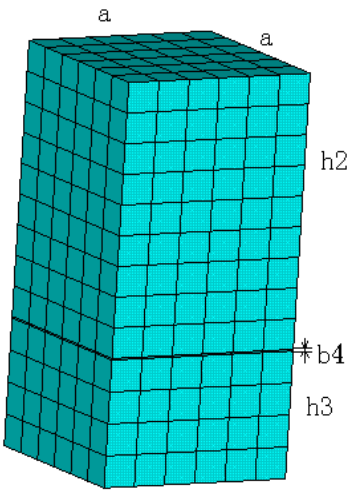


Fig. 2. Finite element model of the permanent layer and shell.

4. Numerical Simulation of Contact Stress in Expansion Joint of Each Layer

4.1. This is a Subtitle Example Contact Stress between the Working Layer and the Permanent Layer

Fig. 3 gave the contour of temperature field distribution in the working layer and permanent layer. The temperature distributed between 253~1560 °C. Fig. 4 illustrated the plot of contact stress varying with expansion joint change. From Fig. 4, note that the contact stress generated on the contact surface by setting 2 mm expansion joint was 12.2 MPa; the contact stress introduced on the contact surface without the expansion joint was 21.5 MPa. It was seen that the contact stress on the contact surface declined gradually, which decreased 9.3 MPa at most as the expansion joint increased.

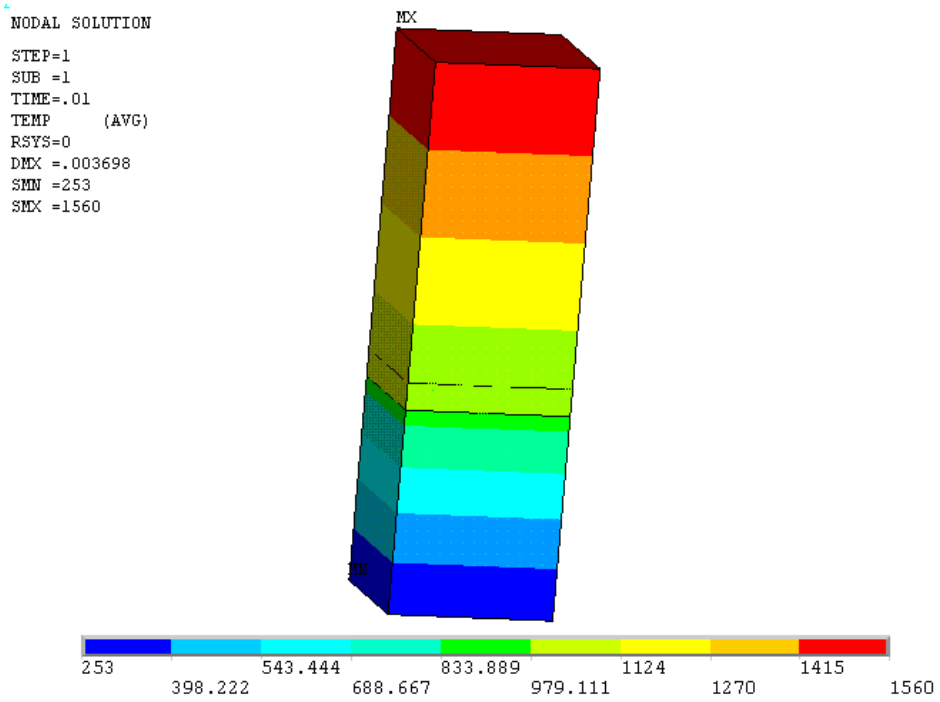


Fig. 3. Contour of temperature field distribution in the working layer and permanent layer.

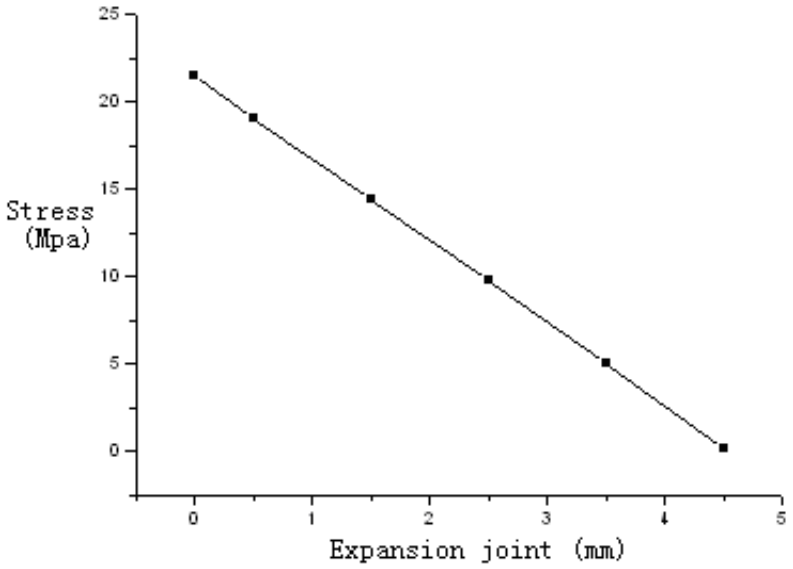


Fig. 4. Plot of contact stress between working layer and permanent layer varying with expansion joint change.

4.2. Contact Stress between the Permanent Layer and Shell

Fig. 5 illustrated the contour of temperature field distribution of the permanent layer and shell and the temperature was between 249~988 °C. Fig. 6 exhibited the plot of contact stress varying with expansion joint change. From Fig. 6, note that the contact stress which was induced on the contact surface of the refractory lining of the permanent layer when 1mm expansion joint was set was 3.3 MPa and the contact stress on the contact surface of the shell was 13.5 MPa; whereas, the contact stress which was generated on the contact surface of the refractory lining of the permanent layer when no expansion joint was set was 17.5 MPa and the contact stress on the contact surface of the shell was 75.7 MPa.

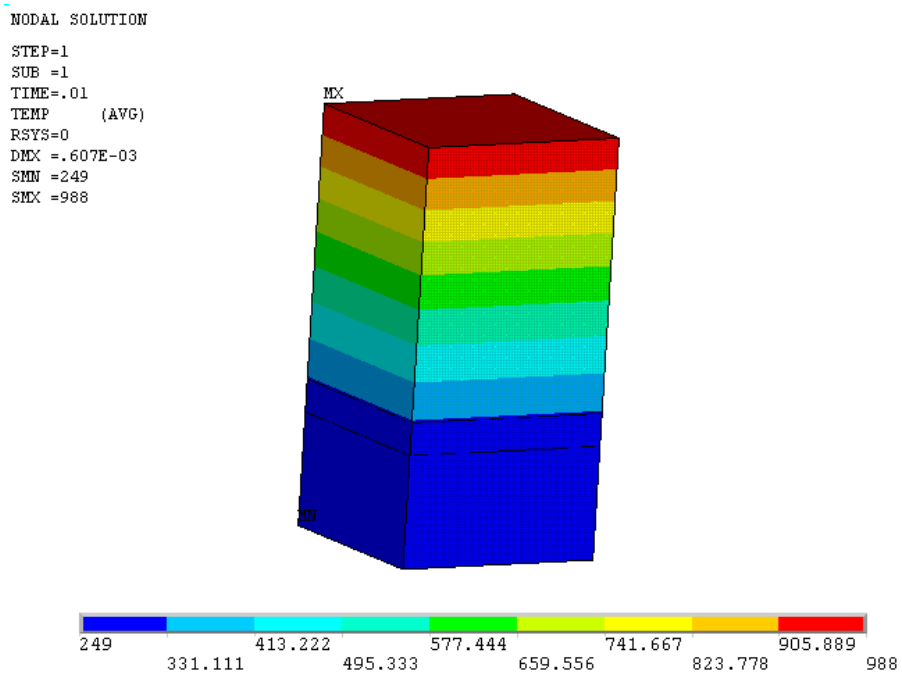


Fig. 5. Contour of temperature field distribution of the permanent layer and shell

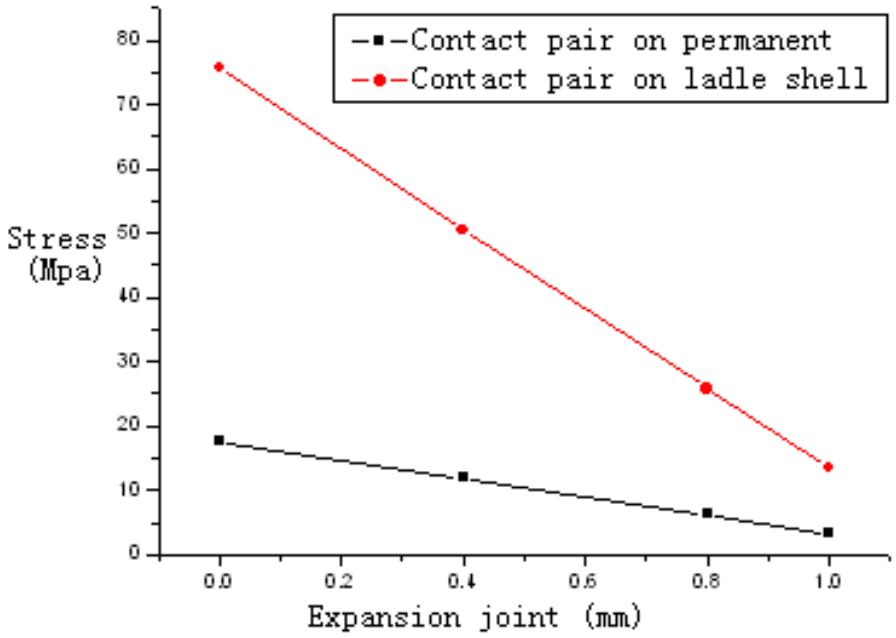


Fig. 6. Contour of contact stress between permanent layer and shell varying with expansion joint change.

Crushing strengths of the magnesia-carbon brick, alumina-magnesia-carbon brick, high alumina brick were 48 MPa, 56.2 MPa, and 50.1 MPa, respectively. From the calculation above, note that the maximum contact stress on the contact surface 12.2 MPa when 2 mm expansion joint was set between the working layer and the permanent layer; nevertheless, the maximum contact stress on the contact surface increased by about 10 MPa and its increment occupied 1/6~1/5 of crushing strength of the refractory material. It was of extreme disbenefit to the service life of refractory bricks.

5. Conclusions

It was obtained through simulation of effect of axial expansion joint of the ladle bottom on the ladle stress field that the difference of the contact stress between unsetting expansion joint and setting 2 mm expansion joint took up 1/6~1/5 of crushing strength of the refractory material. It was extraordinarily detrimental to the service life of refractory bricks. The effect of the lining expansion joint on the ladle stress field could not be negligible.

Acknowledgements

This research reported in the paper is supported by Natural Science Foundation of Hubei Province of China (2010CDA023), National Natural Science Foundation of China (51075310) and The Hubei Province Key Laboratory of Refractories and Ceramics Ministry-Province jointly-Constructed Cultivation Base for State key Laboratory (G201007). This support is greatly acknowledged.

References

[1]. Li Gongfa, Xu Siqiang, Jiang Guozhang, Wu Zehao, Kong Jianyi, Xie Liangxi, Influence of working lining parameters on stress field of ladle composite construction body, *Applied Mechanics and Materials*, Vol. 121, 2012, pp. 800-804.

[2]. Shijie Chen, Guozhang Jiang, Jianyi Kong. Optimizing the structure of ladle bottom based on finite element method, in *Proceedings of the International Workshop on Modern Science and Technology*, 2006, pp. 492~495.

[3]. G. S. Sarmirnto etc., Thermal and stress analysis of casting ladles by an integrated FEM code, *Unitecr*, pp. 327-336.

[4]. F. Nazaret, O. Barrau, Damage modeling in a fiber reinforced refractory castable, in *Proceedings of the Unified International Technical Conference on Refractories,* Salvador, Brazil, 13-16 October 2009, pp. 154-161.

[5]. Jianyi Kong, Nan Li and Yourong Li, Application of finite element to simulation of the ladle temperature field, *Journal of Hubei Institute of Technology*, Vol. 17, Issue 2, 2002, pp. 6-7.

[6]. Guozhang Jiang, Jianyi Kong and Gongfa Li. Simulation and analysis of stress field of ladle wall under a subjected molten steel case, *Metallurgical Equipment*, Vol. 5, Issue 5, 2006, pp. 8-12.

[7]. Zhigang Wang, Nan Li and Jianyi Kong, Numerical simulation of temperature and stress field of the ladle bottom, *Metallurgy and Energy*, Vol. 23, Issue 4, 2006, pp. 16-19.

[8]. Guozhang Jiang, Jianyi Kong and Gongfa Li, Research on temperature distribution model of ladle and its test, *China Metallurgy*, Vol. 16, Issue 11, 2006, pp. 30-32.

[9]. Jiang Guozhang, Kong Jianyi, Li Yourong, Calculation of temperature distribution of ladle lining. The Chinese ceramic society, in *Proceeding of the 4th International Symposium on Refractories,* Beijing, 2003, pp. 289-292.

[10]. Zhiqiang Guo, Xueping Ren. Effect of lining expansion joint on contact pressure between lining and shell, *Iron Steel Vanadium Titanium*, Vol. 24, Issue 3, 2003, pp. 42-45.

[11]. Dihua Qiu, Mechanics of Materials, *Higher Education Press*, Bejing, 2004. pp. 56-72.

[12]. Shijie Chen, Guozhang Jiang, Jianyi Kong. Optimizing the structure of ladle bottom based on finite element method, in *Proceedings of the International Workshop on Modern Science and Technology*, 2006, pp. 492-495.

[13]. Shijie Chen, Research on thermomechanical stress in ladle composite construction body and its service life prediction, *College of Machinery and Automation in Wuhan University of Science and Technology,* Wuhan, 2007, pp. 2-12.

Sensors & Transducers Journal

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

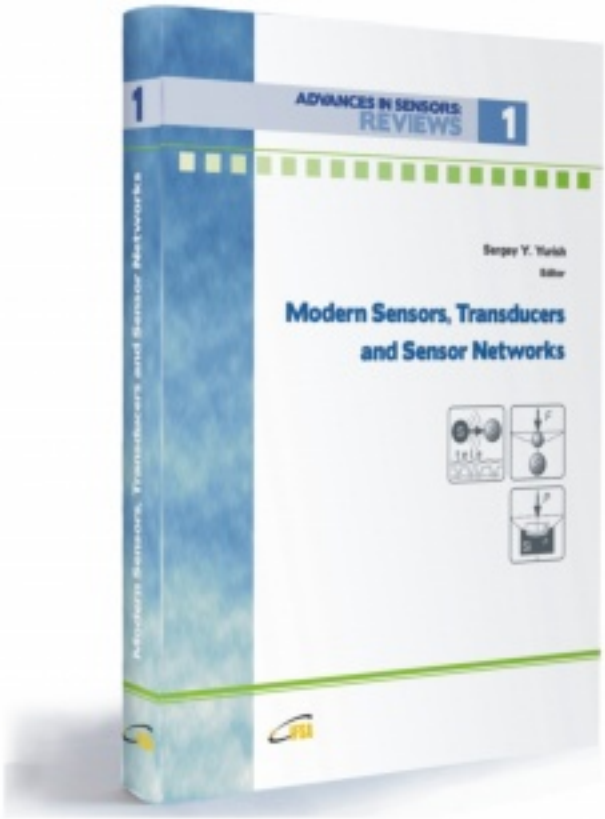
Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2012.pdf

International Frequency Sensor Association Publishing

ADVANCES IN SENSORS: REVIEWS 1

Sergey Y. Yurish
Editor

Modern Sensors, Transducers and Sensor Networks



Modern Sensors, Transducers and Sensor Networks is the first book from the Advances in Sensors: Reviews book Series contains dozen collected sensor related state-of-the-art reviews written by 31 internationally recognized experts from academia and industry.

Built upon the series Advances in Sensors: Reviews - a premier sensor review source, the *Modern Sensors, Transducers and Sensor Networks* presents an overview of highlights in the field. Coverage includes current developments in sensing nanomaterials, technologies, MEMS sensor design, synthesis, modeling and applications of sensors, transducers and wireless sensor networks, signal detection and advanced signal processing, as well as new sensing principles and methods of measurements.

Modern Sensors, Transducers and Sensor Networks is intended for anyone who wants to cover a comprehensive range of topics in the field of sensors paradigms and developments. It provides guidance for technology solution developers from academia, research institutions, and industry, providing them with a broader perspective of sensor science and industry.

Order online:
http://sensorsportal.com/HTML/BOOKSTORE/Advance_in_Sensors.htm

www.sensorsportal.com