

ISSN 1726-5479

SENSORS & TRANSDUCERS

12^{vol. 123}/10



Sensor Market Trends

International Frequency Sensor Association Publishing



Editors-in-Chief: professor Sergey Y. Yurish, tel.: +34 696067716, fax: +34 93 4011989, e-mail: editor@sensorsportal.com

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editors for North America

Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific

Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

- Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Northern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygtantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesha, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Motors Transnational, USA
Baolian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Bruzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Human University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerde Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, N.I. Center for Higher Education. (N.I. University), India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiang, Jeffrey (Cheng-Ta), Industrial Technol. Research Institute, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Université de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjević, Alexander, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, Univ. of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Granel, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcalá, Spain
Hernandez, Wilmar, Universidad Politécnica de Madrid, Spain
Homencovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiang, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khelfaoui, Rachid, Université de Bechar, Algeria
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Kyungpook National University, Korea South
Ko, Sang Choon, Electronics. and Telecom. Research Inst., Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA

Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Laenjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Nabok, Aleksey, Sheffield Hallam University, UK
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, Cherif, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politécnico de Setúbal, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S. National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincaré, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politècnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politècnica de Catalunya, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shah, Kriyang, La Trobe University, Australia
Sapozhnikova, Ksenia, D.I.Mendeleev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Seif, Selemeni, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University, USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore,
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thirunavukkarasu, I., Manipal University Karnataka, India
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vanga, Raghav Rao, Summit Technology Services, Inc., USA
Vaseashta, Ashok, Marshall University, USA
Vazquez, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Pacific Northwest National Laboratory, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung Univ. of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Shuang-Hua, Loughborough University, UK
Yang, Wuqiang, The University of Manchester, UK
Yang, Xiaoling, University of Georgia, Athens, GA, USA
Yaping Dan, Harvard University, USA
Ymeti, Aurel, University of Twente, Netherland
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
Yufera Garcia, Alberto, Seville University, Spain
Zakaria, Zulkarnay, University Malaysia Perlis, Malaysia
Zagnoni, Michele, University of Southampton, UK
Zamani, Cyrus, Universitat de Barcelona, Spain
Zeni, Luigi, Second University of Naples, Italy
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhang, Xueji, World Precision Instruments, Inc., USA
Zhong, Haoxiang, Henan Normal University, China
Zhu, Qing, Fujifilm Dimatix, Inc., USA
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Contents

Volume 123
Issue 12
December 2010

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Development of Electromechanical Architectures for AC Voltage Metrology <i>Alexandre Bounouh, François Blard, Henri Camon, Denis Belieres.....</i>	1
Design of Piezoelectric PZT Cantilever for Actuator Application <i>Abhay B. Joshi, Dhananjay Bodas and S. A. Gangal</i>	16
Investigation Effect of Residual Stress On Pull-In Voltage of Circular Micro Plate Subjected to Nonlinear Electrostatic Force <i>Farzad Choobdar Rahim</i>	25
Numerical Analysis of Thin Film Junctionless pH-ISFET Sensor <i>Fayçal Djeflal, Mohammed Meguellati, Nedhal Abdelmalek and Toufik Bendib.....</i>	35
Investigation of Squeeze Film Effect on Dynamic Characteristics of Electrically Actuated Fully Clamped Micro-Beam <i>Ali Asghar Keyvani Janbahan, Ahmad Ghanbari, Jafar Keyghobadi.....</i>	41
Novel Method for Static Dielectric Constant Measurement of Liquids <i>Anil Tidar, S. P. Kamble, S. S. Patil, B. R. Sharma, P. W. Khirade and S. C. Mehrotra.....</i>	52
Development of (Aluminium) U Tube Type Vibration Based Electromechanical Mass Flow Sensor <i>Pravin P. Patil, Satish C. Sharma, S. C. Jain.....</i>	60
Accuracy and Metrological Reliability Enhancing of Thermoelectric Transducers <i>Bogdan Stadnyk, Svyatoslav Yatsyshyn, Bogdan Yatsyshyn.....</i>	69
Mathematical Models of Methodical Error for Noise Thermometers <i>Bogdan Stadnyk, Ihor Mykytyn.....</i>	76
Electrical Pressure Transducers Based on Graphene Oxide Polysiloxane Composites <i>Antonio Peluso, Mariano Palomba, Gianfranco Carotenuto, Francesca Nicolais.....</i>	84
Humidity Sensing Characteristics of Bi₂O₃- added TiO₂ Composites <i>Vedhakkani Jeseentharani, John Pragasam, Arunachalam Dayalan, Karachalacheruvu Seetharamaiah Nagaraja, Boniface Jeyaraj.....</i>	91
Photoconductive Phenomenon Observed from ZnS Layer Deposition for a Potential of IR Sensor Applications <i>Hariyadi Soetedjo and Gunawan S Prabowo.....</i>	100
Fourier Analysis of Normal ECG Signal to Find its Maximum Harmonic Content by Signal Reconstruction <i>Satish chandra Bera, Rajan Sarkar.....</i>	106

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/Submission.htm

International Frequency Sensor Association (IFSA).

IMU Market 2007-2012

Yole's IMU market report

IFSA offers a SPECIAL PRICE

Competitive market analysis of the RLG – FOG – DTG - Quartz and MEMS based Inertial Measurement Units

This report not only describes the market at the player and application level, but it provides a global view of the IMU market allowing the report user to build diversification strategies taking into account technical requirements.

http://www.sensorsportal.com/HTML/IMU_Markets.htm



Emerging MEMS 2010

Technologies & Markets 2010 Report

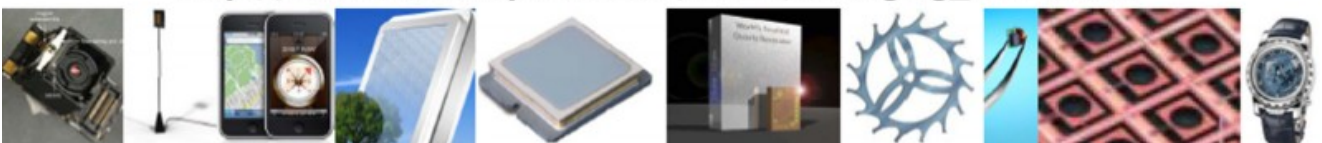
Innovative developments in MEMS devices will add more than \$2B to the total MEMS market by 2015 !

This report presents a market and technical overview for MEMS-based Auto Focus, Electronic Compass, Energy Harvesting, Micro-bolometers, Micro displays, Micro fuel cells, Micro speakers, Micro structures, Microtips, Oscillators and RFID.

Estimated to be \$550M in 2009 a few % of the total MEMS business, Emerging MEMS markets have the potential to add \$2.2B to the overall MEMS market by 2015.

IFSA offers a SPECIAL PRICE

http://www.sensorsportal.com/HTML/Emerging_MEMS.htm





The Third International Conference
on Bioinformatics, Biocomputational Systems and Biotechnologies

BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy



Tracks:

A. Bioinformatics, chemoinformatics, neuroinformatics and applications

- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

B. Computational systems

- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

C. Biotechnologies and biomanufacturing

- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaia.org/conferences2011/BIOTECHNO11.html>



The Seventh International Conference
on Networking and Services

ICNS 2011

May 22-27, 2011 - Venice, Italy



Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaia.org/conferences2011/ICNS11.html>

Tracks:

- ENCOT: Emerging Network Communications and Technologies
- COMAN: Network Control and Management
- SERVI: Multi-technology service deployment and assurance
- NGNUS: Next Generation Networks and Ubiquitous Services
- MPQSI: Multi Provider QoS/SLA Internetworking
- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks



The Sixth International Conference on Systems

ICONS 2011

January 23-28, 2011 - St. Maarten,
The Netherlands Antilles



Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
Camera ready	November 5, 2010

<http://www.iaia.org/conferences2011/ICONS11.html>

Tracks:

- Systems' theory and practice
- System engineering
- System instrumentation
- Embedded systems and systems-on-the-chip
- Target-oriented systems [emulation, simulation, prediction, etc.]
- Specialized systems [sensor-based, mobile, multimedia, biometrics, etc.]
- Validation systems
- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- Safety in industrial systems
- Complex Systems

Development of (Aluminium) U Tube Type Vibration Based Electromechanical Mass Flow Sensor

*Pravin P. PATIL, Satish C. SHARMA, S. C. JAIN

Department of Mechanical and Industrial Engineering,
Indian Institute of Technology Roorkee, India-247667.

Tel.: *91-976001201

*E-mail: pravinppatil2004@gmail.com

Received: 19 October 2010 /Accepted: 21 December 2010 /Published: 28 December 2010

Abstract: The Vibration based mass flow sensors offers unprecedented accuracy, robustness and reliability in measuring materials flow in wide range of applications like process industries over more than 20 years. This measures mass flow directly and is not affected by other factors as compared to conventional volume flow measurement techniques such as the density or viscosity of the fluid, or the profile or Reynolds number of the flow. It is a nonintrusive type of sensor, has no moving parts thus reducing maintenance problems. Despite the successful industrial utilization, the performance of such type of sensors is still not fully understood. Therefore, the primary objective of present work is aimed to develop and calibration of the mass flow sensor prototype. This prototype is designed on Pro Engineer Wildfire modeling software and later developed on the basis of theory of vibrating beams, fluid structure interaction and Coriolis technology in the laboratory. This prototype is calibrated successfully for water giving linear relationship between phase shift and mass flow rate as per the classical relationship found in the published literature for various sensor locations as well as drive frequencies. *Copyright © 2010 IFSA.*

Keywords: Mass flow rate, Aluminium vibrating tube, Coriolis force, Laser sensors.

1. Introduction

The accurate and quick measurement of mass flow rates of fluids is considered an “enabling technology” in various process industries. Flow sensors based on the Coriolis effect offer the most direct sensing of the mass flow rate, and for this reason do not need complicated translation or linearization tables to compensate for other physical parameters (e.g. density, state, temperature, heat

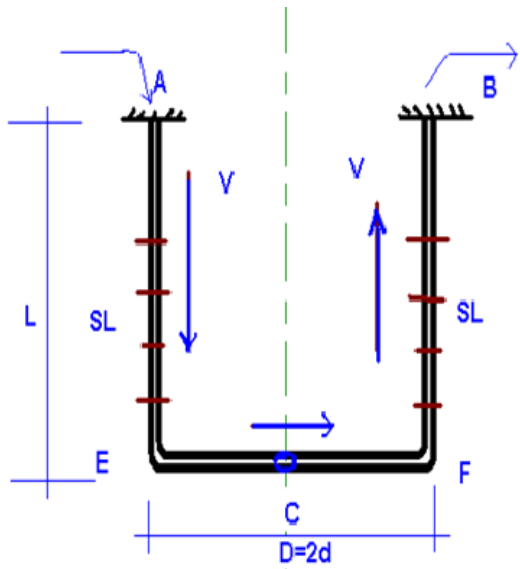
capacity, viscosity, etc.) of the medium that they measure. This also makes Electromechanical mass flow sensors [EMMFS] versatile – the same instrument can, without the need for factory calibration, measure diverse fluid media – liquids as well as gases. Additionally, EMMFS have a quick response, and can principally afford an all-metal-no-sliding-parts fluid interface. Various researchers have been carried out experimental as well as theoretical research on the dynamics of vibrating tube Coriolis mass flow sensors since the 1950s. The major thrust of those studies were to investigate the effects of the fluid velocity, pressure, density, tube geometries and boundary conditions on the natural frequency and the stability of the pipe systems [1-3]. In order to study the measuring and other effects of Coriolis flow sensors, several models, both analytical and numerical were employed/ developed, for the description of the fluid–structure interaction phenomena in the measuring tube. The dynamics of the tube was mostly described by beam models (Euler and Timoshenko models) and the fluid flow in the measuring tube was modelled as a one-dimensional flow [4-9]. A method of modelling the Coriolis mass flowmeter using theory of vibrating beams can be seen in [5]. It is assumed that the tube is made of straight and circular lengths joined together. The use of finite element (FE) models to predict the performance of Coriolis mass flowmeters has become established practice [7-9]. A more comprehensive fully coupled model (with three-dimensional fluid flow) of a Coriolis flow sensor, capable of capturing the actual measuring effects is reported in [8].

A linear variation of time lag with the flow velocity for Coriolis flowmeter having stainless steel U tube with working fluids as kerosene and water has been observed [5]. The Ti-based glassy alloy sensor tube exhibits excellent measurement sensitivity as compared to the conventional flowmeter manufactured using stainless steel (SUS316) tube which revealed the possibility of using others materials having good properties compared to conventional tube materials like aluminium, copper, titanium etc [10]. The experimental studies reported in [11] also gave the same direction of possibility of using other materials but their study was limited to horizontal orientation only. Thus there is a need to develop Coriolis mass flow sensors using others materials like copper, aluminium etc.

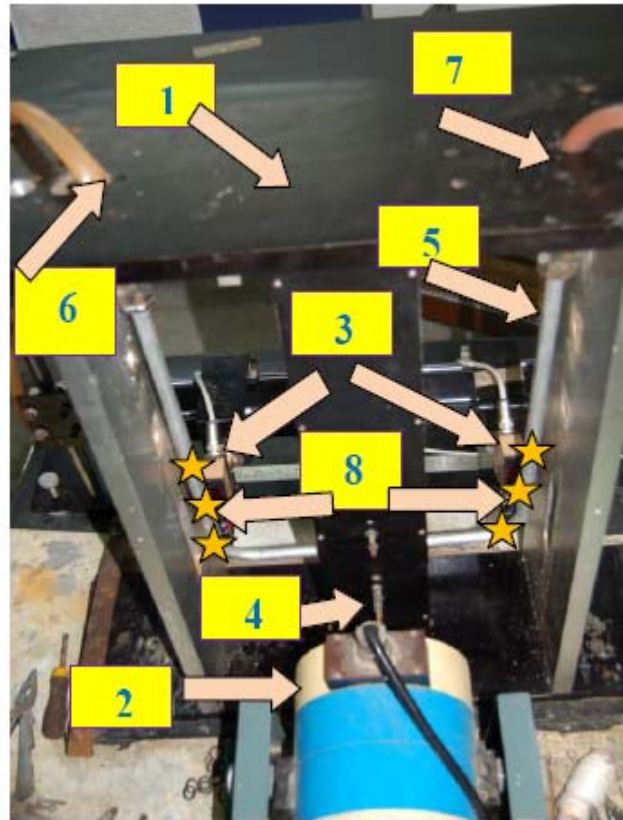
The author in his previous study [12] developed the experimental setup and evaluated the performance of vibration based copper U tube Coriolis mass flow sensor. Now the author would like to extend his previous study by using vibrating tube of aluminium tube material with the primary objective to develop and calibration of the U tube aluminium type mass flow sensor prototype by verification of linear relation between time lag and mass flow rate. This involves the development of experimental set up integrated with virtual instrumentation and installed upon a specially designed and constructed foundation using Passive Shock & Vibration Isolation technique [13]. Aluminium has been selected as a tube material because it offers some unique advantages like it is corrosion resistant, has good surface finishing properties compared to conventional used materials. Being more ductile it lends itself to easy fabricability into ‘U’ shaped tubes. The present study has been carried out with water as a fluid because it generates maximum Coriolis Effect at lower flow rates [1].

2. Working Principle

A Coriolis mass flowmeter measures mass flow directly, using the Coriolis principle, which is based on the conservation of angular momentum, as it applies to the Coriolis acceleration of a given fluid. In principle, as shown in Fig. 1 a Coriolis mass flowmeter consists of a tube with a fixed inlet and outlet, which is vibrated about the axis, formed by the inlet and outlet ends. The tube used in this study is aluminium U shaped, and is vibrated using an electro-dynamics vibration shaker attached at point C as shown in figure. Proximity sensors are mounted as indicated in figure and is labelled as SL on two limbs of tube to measure velocity signals from the vibrating tube. This means that liquid flow is measured by transferring vibrational energy from the meter tubing to the flowing liquid and back to the meter. To appreciate this principle, imagine a vibrating tube as shown in Fig. 1.



A - Inlet flow
 B - Outlet flow
 SL - Sensor Location
 C - Exciter position



1 - Test bench
 2 - Vibration driver
 3 - Laser sensors
 4 - Vibration driver rod
 5 - U tube
 6 - Inlet pipe
 7 - Outlet pipe
 8 - Sensor locations

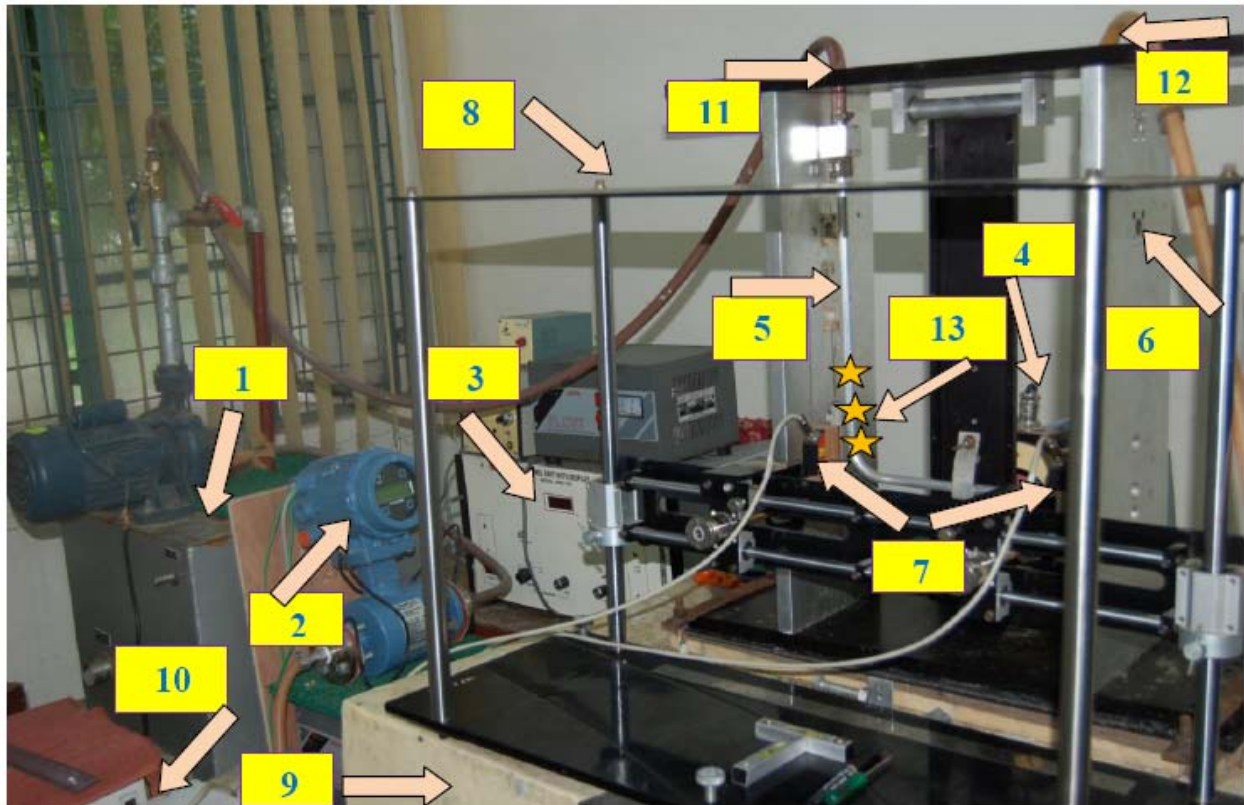
Fig. 1. Oscillating tube conveying fluid along with actual photographic view.

If no liquid is flowing, the excitation in the middle of the tube will cause both arms to vibrate in phase. Mass flowing into the tube starts to receive vibrational energy from the tube walls as it enters the first bend. In this process, the tube loses the same amount of energy. The result is that the phase of the vibrational cycle lags at sensor location of one limbs, the reverse will happen at the location of another limbs. The liquid is vibrating as it enters the bend, but transfers this energy to the pipe. The result is that the mass flow advances the vibrational phase at the sensor location of another limb. When combined, these two changes in vibrational phase produce a twisting of the flow tube. The amplitude of this twist is directly proportional to the mass flow rate and is nearly independent of the temperature, density, or viscosity of the liquid involved.

3. Experimentation

The Experimental set up used in the present study has been designed on Pro Engineer Wildfire modeling software and later manufactured at the Instrumentation laboratory of Mechanical and Industrial Engineering Department, IIT, Roorkee. The block diagram of the experimental setup has been shown in Fig. 2, which consists of the several functional elements such as: Hydraulic bench for providing regulated water supply to the flowmeter. Test bench for supporting the tubes of the Coriolis mass flow sensor. Excitation system for providing mechanical excitation to the Coriolis mass flowsensor, consists of an Electrodynamics shaker, control unit, accelerometer and vibration sensor.

Virtual instrumentation comprising of non-contact inductive proximity sensors, and a signal conditioning unit as shown in Fig. 2.



Various design components are as follows:

- | | | | |
|-------------------------------|--------------------------|---------------------------|-----------------------|
| 1 - Hydraulic bench | 5 - U tube | 9 - Foundation | 13 - Sensor locations |
| 2 - Electromagnetic flowmeter | 6 - Test Bench | 10 - Data Acquisition box | |
| 3 - Vibration Control unit | 7 - Laser sensors | 11 - Inlet pipe | |
| 4 - Vibration driver | 8 - Sensor holding stand | 12 - Outlet pipe | |

Fig. 2. The photographic view of the experimental setup.

3.1. Experimentation Scheme

The design parameters varied in this study are flow range between 0 to 0.3 kg/sec, the details of these have been shown in Table 1 as below. Inductive proximity sensors have been used for motion sensing as these are sensitive to metal objects, they are helpful in eliminating any unwanted noise generated from the surroundings and inherently resistant to dust, humidity and oil in industrial environment. The vibration shaker used in the present study which provides the desired excitation to the Coriolis Mass Flow Sensor. This is having amplitude of 5 mm peak to peak and an excitation frequency in the range of 1 Hz to 1 kHz. In order to make a contact a mild steel rod of 5 mm diameter is used as a stinger to transfer the motion to the knife edge support. As the exciter uses a lot of power and generates a lot amount of vibrations, a strong isolated base was provided so as to damp the vibration and thus avoid movement of exciter or transfer of stray vibrations to the sensor stand or the testing bench [1, 2, 13]. The present work utilizes the concept of Virtual instrumentation platform to perform the fast data analysis. Data acquisition and its processing can be conveniently implemented on a digital platform. For ease of coding, a PC platform is chosen as the processing hardware. For acquiring the signal from the sensors to the PC, NI DAQ card (USB-6211) is used. It consists of two 32 bit counters operating at

80 MHz. It also consists of a 16 bit A/D converter operating at 250 kS/s which continuously samples the signal. A visual programming language (LabView) is used for processing the data in real time.

Table 1. Input Parameters.

Tube shape	U type
Tube material	Aluminium (E =70 GPa, k = 0.3)
Tube dimensions	Do=12.7 mm ; Di=10.9 mm
Height of vertical arm of tube	L = 40 cm
Distance between two arms	D = 40 cm
Sensor Location range	SL = 6 to 12 cm
Drive Frequency range	DF = 32.7 to 34.7 Hz
Mass flowrate range kg/s	0.1 to 0.3
Fluid	Water

3.2. Experimental Procedure

The details of the experimental procedure used to conduct the present study have been described in Fig. 3 as shown below. The hydraulic unit for providing regulated water supply to the mass flow sensor. The hydraulic unit derives its power from the constant voltage transformer (CVT) to maintain constant flow rate. The U-tube is made to vibrate using an electronic shaker. An accelerometer is attached to the shaker which measures the velocity, amplitude and acceleration of the vibration induced by the electronic shaker. The accelerometer gives the feedback to the vibration meter which is observed for maintaining the constant amplitude.

A pair of proximity sensors has been placed on the mechanical positioning attachment facing the two limbs of the U-tube. The output terminals of the sensors have been connected to the input of the NI-DAQ through a signal conditioner. NI-DAQ has inbuilt counters which operates at 80 MHz. These counters measure the frequency and the edge separation between the two incoming waves. The edge separation between the rising edges of the two waves is the time lag (Δt) required for calculating the mass flow rate. The processing of the signals, calculation of the mass flow rate and displaying of the results is processed in LabView. The LabView takes the parameters of the U-tube and other settings as inputs from the user and calculates the mass flow rate which is displayed on the screen. Accuracy and repeatability for each experiment was achieved with the same input conditions until stabilized output was achieved.

4. Results and Discussion

The primary objective in the present study is to verify the linear relation for Phase shift and mass flow rate therefore experimentation was carried out for the set of input design parameters as mention in Table 1. All these results have been explained in details in the following paragraphs through Figs. 4 to 7. The Fig. 4 depicts the variation of experimental phase shift Vs mass flow rate at various drive frequencies from 32.7 to 34.7 Hz for sensor location 6 cm. It may be noticed that there exists an accurate linear relation between phase shift and mass flow rate for drive frequency 33.7 Hz compare to two other closer frequency with maximum phase shift.

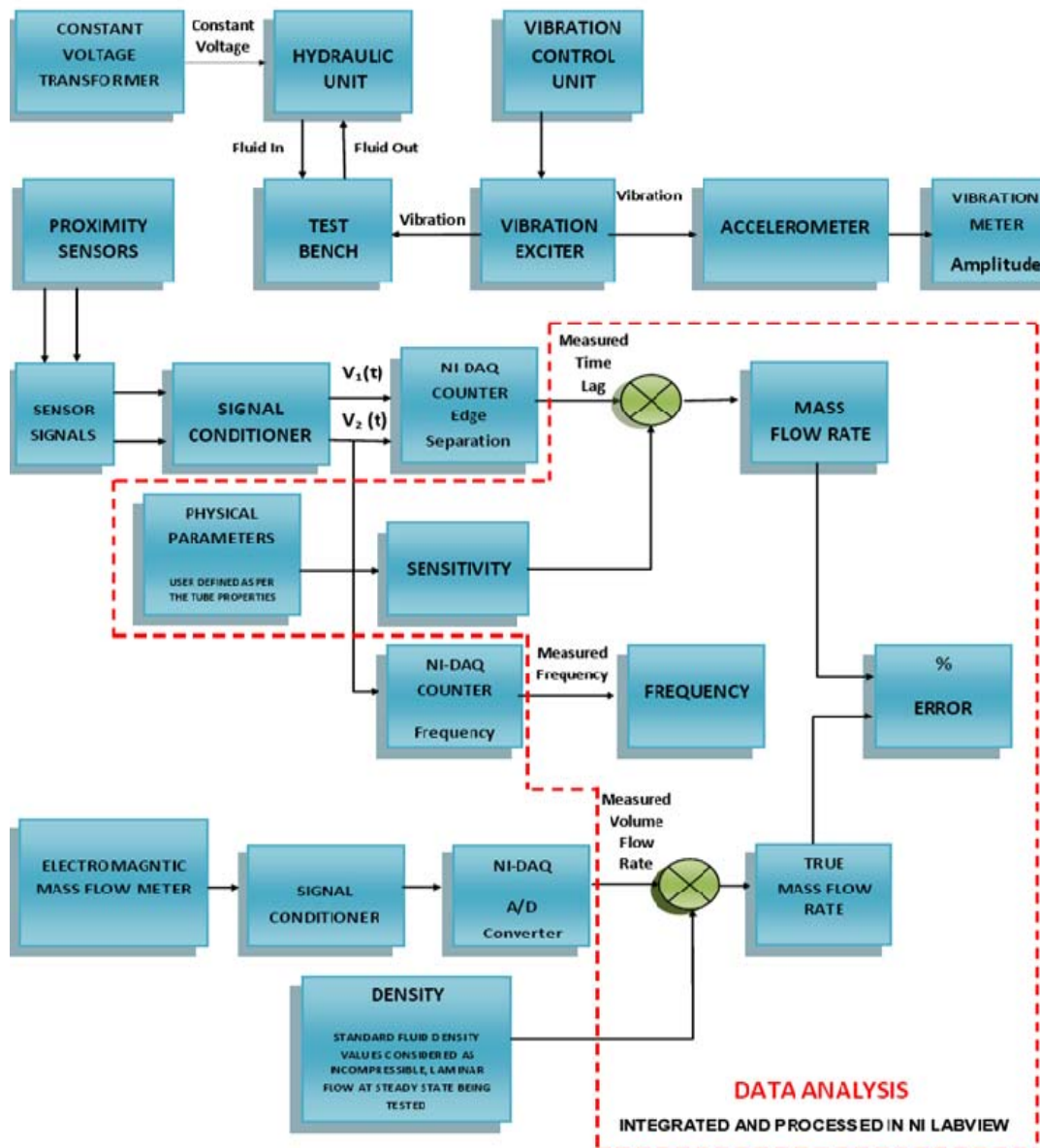


Fig. 3. Flow diagram describing experimental procedure.

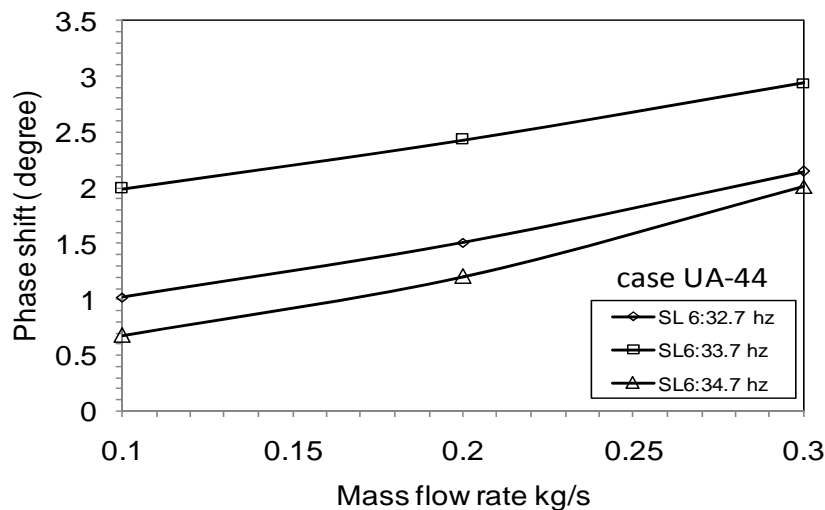


Fig. 4. Phase shift versus mass flow rate for SL 6 cm at various drive frequencies.

The Fig. 5 explained the variation of experimental phase shift Vs mass flow rate at various drive frequencies from 32.7 to 34.7 Hz for sensor location 9 cm. It may be noticed that there exists linear relation between phase shift and mass flow rate for drive frequency 32.7 Hz compare to two other frequency.

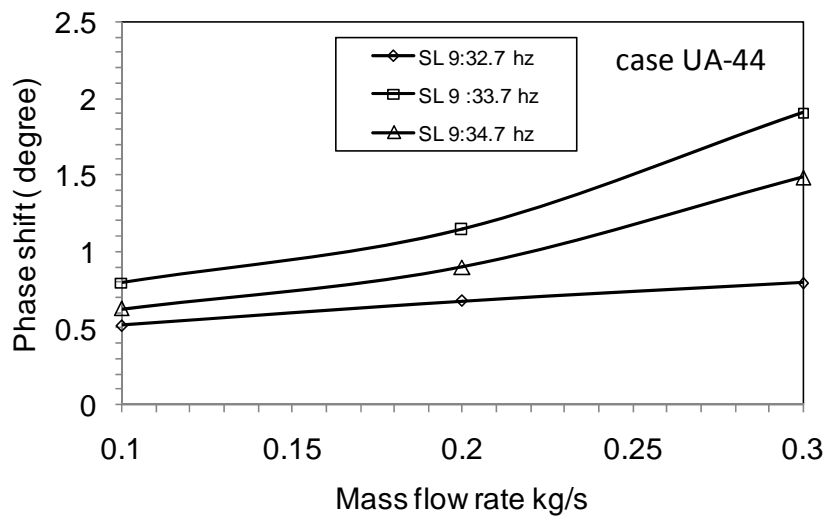


Fig. 5. Phase shift verses mass flow rate for SL 9 cm at various drive frequencies.

The Fig. 6 showed the variation of experimental phase shift Vs mass flow rate at various drive frequencies from 32.7 to 34.7 Hz for sensor location 12 cm. It may be noticed that there exists linear relation between phase shift and mass flow rate for all drive frequencies however maximum phase shift is observed for 33.7 Hz.

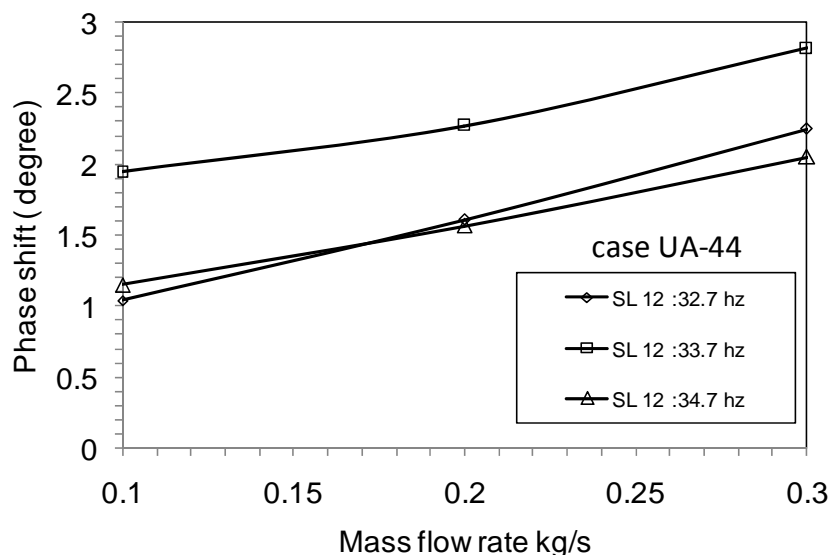


Fig. 6. Phase shift verses mass flow rate for SL 12 cm at various drive frequencies.

Thus from the above discussions and Fig. 7 it may be observed that linearity is exits between phase shift and mass flow rate which is consistent with the results of earlier reported literature [5 and 11]. The more linearity as well as phase shift may be observed as shown in Fig. 7 for 33.7 Hz drive frequency at 6 cm from the bottom of the tube in vertical direction compare to other drive frequencies

and sensor locations. From Fig. 7 it may also be observed that less linearity exists for frequencies less or more value of natural frequency in present case 32.7 and 34.7 Hz at different sensor locations giving lesser phase shift compare to fundamental natural frequency suggesting that there is a need for proper selection of these parameters for accurate mass flow sensing.

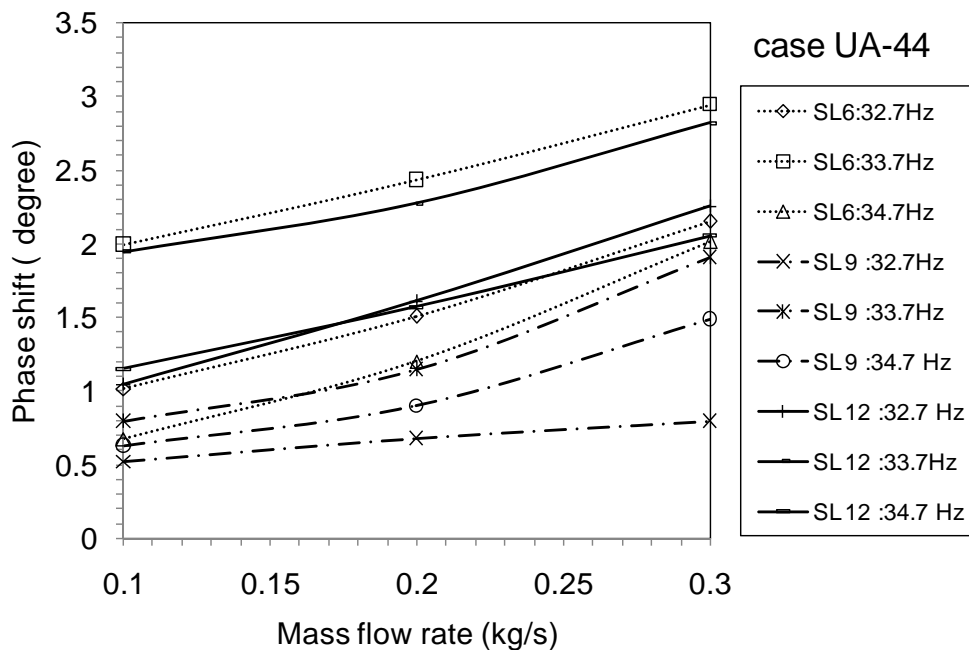


Fig. 7. Phase shift versus mass flow rate at various drive frequencies for all SL.

5. Conclusions

The experimental set up is designed on Pro Engineer Wildfire modeling software and later developed on the basis of theory of vibrating beams, fluid structure interaction and Coriolis technology in the laboratory integrated with virtual instrumentation. Further using the Passive Shock & Vibration Isolation technique the setup installed upon a specially designed and constructed foundation. The calibration of the U tube aluminium type mass flow sensor prototype by verification of linear relation between phase shift and mass flow rate is carried out for fluid as a water as per the classical relationship found in the published literature for various sensor locations and drive frequencies.

Acknowledgements

The authors would like to thank the Department of Science and Technology (DST) Government of India for providing the necessary funding to carry out this research work.

References

- [1]. Roger Baker, Coriolis flowmeters, industrial practice and published information, *Flow Measurement and Instrumentation*, Vol. 5, No. 4, 1994, pp. 229-246.
- [2]. Martin Anklin, Wolfgang Drahm, and Alfred Rieder, Coriolis mass flowmeters: Overview of the current state of the art and latest research, *Flow Measurement and Instrumentation*, 17, 2006, pp. 317-323.
- [3]. D. W. Spitzer, Flow Measurement—Practical Guide for Measurement and Control, *Industrial Society of America*, 1991.

- [4]. H. Raszillier, F. Durst, Coriolis effect in mass flow metering, *Archive of Applied Mechanics*, 61, 1991, pp. 192–214.
- [5]. G. Sultan, J. Hemp, Modeling of the Coriolis mass flowmeter, *Journal of Sound and Vibration*, 132, 3, 1989, pp. 473–489.
- [6]. J. Kutin, I. Bajsic, An analytical estimation of the Coriolis meter characteristics based on modal superposition, *Flow Measurement and Instrumentation*, 12, 2002, pp. 345–351.
- [7]. Wang, T., Baker, R. C., Manufacturing variation of the measuring tube in a Coriolis flowmeter, *IEEE Proceedings: Science, Measurement and Technology*, Vol. 151, No. 3, 2004, pp. 201-204.
- [8]. G. Bobovnik, N. Mole, J. Kutin, B. Stok, I. Bajsic, Coupled finite volume/ finite-element modeling of the straight-tube Coriolis flowmeter, *Journal of Fluids and Structures*, 20, 2005, pp. 785–800.
- [9]. R. Cheesewright, Simon Shaw, Uncertainties associated with finite element modelling of Coriolis mass flow meters, *Flow Measurement and Instrumentation*, 17, 2006, pp. 335–347.
- [10]. Chaoli Ma, Nobuyuki Nishiyama and Akihisa Inoue, Fabrication and characterization of Coriolis mass flowmeter made from Ti-based glassy tubes, *Materials Science and Engineering A*, 407, 2005, pp. 201–220.
- [11]. Pradeep Gupta, K. Srinivasan and S. V. Prabhu, Tests on various configurations of Coriolis mass flow meter, *Measurement*, 39, 2006, pp. 296–307.
- [12]. Satish C. Sharma, Pravin P. Patil, Major Ashish Vasudev, S. C. Jain, Performance Evaluation of an Indigenously Designed Copper (U) tube Coriolis Mass sensors, *Measurement*, 43, 9, 2010, pp. 1165-1172.
- [13]. R. Cheesewright, A. Belhadj and C. Clark, Effect of mechanical vibrations on Coriolis mass flow meters. *Journal of Dynamic Systems, Measurement, and Control*, 125, 2003, pp. 103–113.

2010 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(<http://www.sensorsportal.com>)

IFSA SENSORS WEB PORTAL
Primary Internet Resource for **SENSORS**,
100% Target Audience

**TURN
OUR VISITORS
INTO
YOUR CUSTOMERS
BY THE SHORTEST WAY**

<http://www.sensorsportal.com/HTML/Sensor.htm>
sales@sensorsportal.com

**MEDIA KIT
2010**



The Second International Conference
on Sensor Device Technologies and Applications

SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- 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

<http://www.iaria.org/conferences2011/SENSORDEVICES11.html>



The Fifth International Conference on Sensor
Technologies and Applications

SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- APASN: Architectures, protocols and algorithms of sensor networks
- MECSN: Energy, management and control of sensor networks
- RASQOFT: Resource allocation, services, QoS and fault tolerance in sensor networks
- PESMOSN: Performance, simulation and modelling of sensor networks
- SEMOSN: Security and monitoring of sensor networks
- SECSN: Sensor circuits and sensor devices
- RIWISN: Radio issues in wireless sensor networks
- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
- UNWAT: Under water sensors and systems
- ENOPT: Energy optimization in wireless sensor networks

<http://www.iaria.org/conferences2011/SENSORCOMM11.html>



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

CENICS 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

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/conferences2011/CENICS11.html>

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 it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In addition, 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.

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

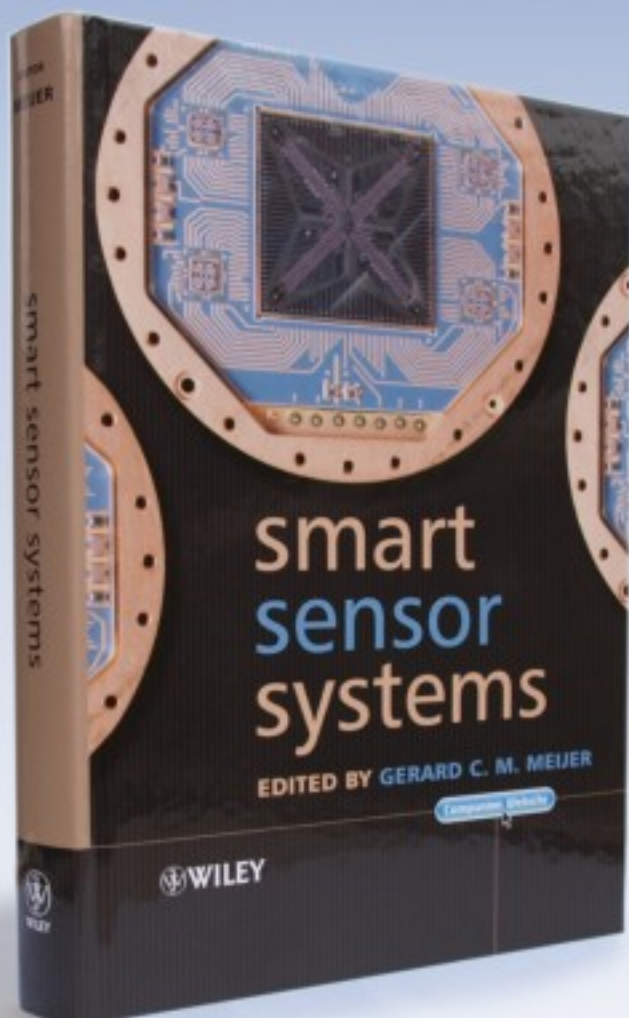
Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submission.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_2009.pdf

 **WILEY**
1807-2007

KNOWLEDGE FOR GENERATIONS



'Written by an internationally-recognized team of experts, this book reviews recent developments in the field of smart sensors systems, providing complete coverage of all important systems aspects. It takes a multidisciplinary approach to the understanding, design and use of smart sensor systems, their building blocks and methods of signal processing.'



Order online:

http://www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensor_Systems.htm

www.sensorsportal.com