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HOW TO TEACH ABOUT MEASUREMENT SYSTEMS - EXPERIENCES FROM THE INTERDISCIPLINARY EDUCATION

Since 1999 the Faculty of Automatic Control, Electronics and Computer Science offers studies in English in: *Automatic Control and Robotics, Electronics and Telecommunication, Computer Science*, with various specializations. Lectures and laboratory classes are in English. The idea of this paper is to present our contribution in this new programme as the Measurement Systems Group, which is a part of the Institute of Automatic Control. We started with our lectures, untitled "Measurement Systems", in the last year (2001), for students which have completed three half-year semesters. After the half-year lecture course, students have begun laboratory classes.

Keywords: metrology, measurement systems, education.

1. INTRODUCTION

The Silesian University of Technology was formally established in May 1945 [1]. The University provides a wide range of 5-year courses in applied science, engineering and technology. All courses available lead to a M.Sc. degree. Each student must submit a thesis and is required to present himself for an oral final examination at the end of his study period. The academic year is divided into two semesters, both lasting for 15 weeks. It starts at the beginning of October and ends at the beginning of June. There are short breaks for Christmas and Easter holidays and an examination period at the end of January, followed by a week's winter holiday. The examinations are also taken in June and September.

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The Faculty of Automatic Control, Electronics and Computer Science was established in 1963 as the Faculty of Automatic Control, being formally part of the Faculty of Electrical Engineering [1]. Since 1999 the Faculty offers studies in English in: *Automatic Control and Robotics, Electronics and Telecommunication, Computer Science* with specialities [2]:

- (1) *Information Processing for Control*
- (2) Databases, Computer Networks and Systems
- (3) Computer Aided Signal Processing;

The studies are run full-time and lead to M.Sc. degree. Their syllabi meet European standards of technical universities. Therefore, students will be able to continue their studies in universities in other countries. Moreover, due to Socrates/Erasmus project a part of the studies may be undertaken at other European Universities.

In the first 3 years of studies students obtain interdisciplinary education in scientific areas and gain additional skills appropriate to specialization. Graduate will be well prepared to compete in fast changing contemporary job market.

2. MEASUREMENT SYSTEMS - LECTURES

2.1. GENERAL FOUNDATIONS

The Institute of Automatic Control is one of the three institutes forming the Faculty. It was formed in 1977 as a result of fusion of several groups. Now there are 5 Groups, in which are conducted research and teaching activities. The research and teaching activities of *the Measurement System Group* are concentrating in the following main topics:

- Theory of Physical and Technical Measurement,
- Modelling of Measurement Signal and Systems,
- Principles of Industrial Measurements for Control Applications,
- Methods of Calibrations of Sensors and Measurement Instruments,
- Electrical Apparatus for Potentially Explosive Atmospheres,
- Sensors,
- Reliability.

The idea of this paper is to present the Measurement Systems Group contribution in this new programme offered by the Faculty. We started with our lectures, untitled "Measurement Systems", in the last year (2001), for students which have completed three half-year semesters. After the half-year lecture course, students have begun laboratory classes. Students begin classis with no prior experience in the field of metrology. In the general 5 years course of 3270 hours the subject of Measurement Systems takes only 30 hours of lectures and 30 hours of laboratory coursework.

2.2. PROGRAMME DISCRPTION

The main idea of the lecture course is to acquaint students with the selected (but basic) problems of measurement systems and that is why the following topics are included in the programme:

Introduction: scope of lectures, literature; integration of intrinsically safe field instrumentation into industrial communication networks; intelligent sensors; institutions: IMEKO, IFAC, EUROSENSORS, PSST – Polish Society of Sensors Technology, COE – Optoelectronic and Electronic Sensors.

Smart sensors: Measurement of fluid flow by means of pressure differential devices - orifice plates and Venturi tubes. Smart interface. The essential sub-systems; list some of the main sensor defects. Zener Barriers (Ex).

The general measurement system: purpose, general structure, elements of system. Definition of sensor; sensor classifications. Example: “Weight measurement system” – elements of system; strain gauges (conventional and silicon).

Vocabulary of basic and general terms in metrology: static characteristics - range, span, zero, zero drift, sensitivity, resolution, response, linearity, hysteresis, calibration, accuracy... ; dynamic characteristics.

Specialized measurement system: gas chromatography – column, carrier gas, solid particles, thin layer of liquid composition, HETP – Height Equivalent to a Theoretical Plate, chromatogram, retention time. Detectors: TCD – Thermal Conductivity Detector (katharometer), FID – Flame Ionisation Detector, ECD – Electron Capture Detector.

Non-Dispersive Infra-Red (NDIR) gas analyser: IR transmission characteristics, one path system, two path system, IR emitters, rotating chopper disc, reference cell, sample cell, radiation detectors (selective or non-selective), transfer equation.

The International Temperature Scale of 1990 (ITS-90): triple points, freezing points, melting points, interpolation instruments – platinum resistance thermometer, gas and vapour thermometers, radiation pyrometer; interpolation equations; thermodynamic (Kelvin) and empirical (Celsius) scales.

Thermal radiation measurement system: high temperatures, moving body, temperature distribution over a surface; “black body”, Planck’s law, emissivity of real body, characteristics of transmission medium; general form of thermal radiation measurement system, optical focusing system without and with lens, transmission characteristics, detectors – thermopiles, bolometers; total detected power, output signal.

Pressure (pneumatic) measurement system: elements of system; metal resistance Strain Gauge - tensile stress, compressive stress, longitudinal strain, transverse strain, elastic modulus, Young’s modulus, Poisson’s ratio, GF – Gage Factor; characteristics of system.

Review of sensors: conventional, thick, thin and semiconductor technologies; Strain Gages, Zirconia Cell (ZrO_2), magnetic (mechanical) sensors, electromagnetic sensors, chemical sensors, gas sensors, resistance and thermocouple sensors.

Reliability of measurement systems: reliability, unreliability, MTBF - Mean Time Between Failures, failure rate, variation of failure rate during lifetime of equipment – “bathtub” curve, reliability of a system of n elements in series or cascade, availability, methods of improving the reliability of measurement systems.

The programme then has an encyclopaedic character and presents the whole range of knowledge, starting with basic metrological terms, sensors, examples of measurement systems and finishing with the reliability of measurement systems.

3. MEASUREMENT SYSTEMS – LABORATORY

3.1. THE AIM AND THE STRUCTURE

The main idea of the laboratory classes is to familiarize students with sensors and measurements of non-electrical quantities. The laboratory illustrates the lecture and also extends it about practical aspects of measuring different non-electrical quantities. The new stands are the acceleration sensors – the piezoelectric and the semiconductor one, the advanced signal processing procedures and the data acquisition systems equipped with DAQ boards and GPIB interface.

The laboratory classes consist of six, three full hours, exercises described in further paragraphs. During each exercise students make a minutes for future preparation of the report. The report from all exercises must be completed to gain the credit for the laboratory classes.

3.2. TEMPERATURE SENSORS CALIBRATION AND TEMPERATURE MEASUREMENTS

The aim of this exercise is to acquaint students with widely used temperature sensors as thermocouples and platinum RTD and also with problems connected with contact temperature measurement and sensors calibration. This exercise is designed to show the whole measuring chain with all typical elements. The acquisition system is equipped with GPIB interface, multi-channel scanner and the digital multimeter. The advanced software enables the configuration of the system.

The main tasks are the fixed-point calibration and the air temperature measurements. The first one enables the students to familiarize themselves with requirements of temperature sensors calibration and detail error analysis. The second task shows the possible error sources due to temperature exchange between a sensor and an environment, during the measurements. These sources are discussed and the possibilities of their decreasing are shown.

3.3. STRAIN GAUGES AND SEMICONDUCTOR PRESSURE SENSORS

This exercise is combined with two parts. First, the typical, made in conventional technology, the wire strain gauges are presented. The main properties are discussed and basic measuring circuits with one and two active strain gauges are investigated.

The second part enables the students to meet the semiconductor pressure sensors. The presentation of modern, semiconductor technology is combined with methods of intrinsic and temperature errors investigation. The use of the vocabulary and general terms in metrology are also preserved.

The laboratory stand, for the second part, is again equipped with computerized measuring and data acquisition system, with GPIB interface, the precision pressure controller, the climatic chamber, the multi-channel scanner and digital multimeter.

3.4. FLOW MEASUREMENT

The exercise „Flow measurement” is the part of Industrial Measurement Laboratory. The measuring installation in the mentioned laboratory consist of three main parts: measuring system for volume or mass flow rate measurement of flowing air, measuring system for water flowmeters calibration, and computerised system for gathering and data processing. The first part of the exercise concerns measuring installation for air flow measurement in the 100 mm diameter pipe with help of orifice plate according to ISO Standard. The first step is the verification of the elements of measuring installation according to the ISO demand. Students calibrate the differential pressure and absolute pressure instruments. Than, for chosen flow-rate of air they measure the differential pressure and absolute pressure and also temperature and relative humidity. In their report they must calculate with normalised procedure (ISO) the value of mass flow-rate and the total error of this value.

The purpose of the second part of the exercise „Flow measurement” is to familiarise with the properties of some of measurements sensors used in water flow measurements. Three types of flowmeters are examined: two electromagnetic flowmeters, turbine flowmeter and two ultrasonic flowmeters. The installation for water flowmeters investigation (test ring) consists of a measuring tank, storage tank, a pump with a set of valves, diverter and a section of a pipeline with primary devices of flowmeters mounted in the pipe wall. The test measuring tank fulfil the demands of the ISO. The test ring is provided with a computerised data acquisition system. The system consists of a PC, BITBUS system and current to voltage converters. On the base of the metrological properties of calibrated flowmeters students must chose some parameters of data acquisition system. The program in the PC calculates the time of filling the measuring tank and minimum water level to ensure the demanded calibration uncertainty. The BITBUS system starts and stops with signals from diverter. The lowest and the highest level of the water in the measuring tank read by students are put to the computer and

program calculates the conventional true value of flow-rate. In the report students compare real errors of these five flowmeters with intrinsic errors.

3.5. HUMIDITY MEASUREMENT

The purpose of the exercise is to familiarise with design, operating principle, the calibration techniques and the typical of gas humidity sensors. In the exercise students use two standards for calibration of humidity sensors: a set of salt solutions and humidity air generator. The set of salt solutions enables calibration of sensor in the so-called fixed points. The second possibility is to use humidity air generator. In the generator a blower forces the air into a Dreschel washer placed in a thermostat. In this washer the air gets humidified to 100% H₂O at temperature T₁ (measured in the water thermostat with accurate mercurial thermometer). This saturated air passes to an air thermostat, where it is warmed up to the temperature T₂ controlled automatically. Temperature T₂ is calculated by students according to demanded value of relative humidity in which we want to calibrate the sensor or humidity meter. The measurement data can be collected directly by students or by means of a PC with DAS16 data acquisition board. Two sensors are tested in the laboratory: 1) APRX capacitive humidity sensor and HD8901 thermohygrometer with digital display, capable of measuring the relative humidity, absolute humidity, dew point and temperature. A special attention is turned on dynamic properties of the sensor. It is important to know how long we must wait for stabilisation of measuring value. The students should estimate the dynamic model of the sensor. Very frequently we assume the dynamic model of the sensor as the first order inertia, that means, that the time needed for output signal stabilisation is not longer than four time constants. Student measure the output signal from the humidity sensor put to the bottle with known salt solution. Students observe, that the signal cannot be estimated with first order inertia model.

3.6. ACCELERATION SENSORS AND MEASUREMENTS

During the exercise students are familiarised with vibration transducers of different types and with methods of determining their characteristics and parameters. There are shown three generations of vibration transducers - from an electromechanical seismometer to a fully integrated single chip accelerometer. Firstly the accelerometer calibration with use of the secondary calibration method (back-to-back comparison) according to the ISO Standard is performed. The laboratory stand is equipped with a vibration exciter, a power amplifier and a sine wave generator. The reference sensor is a piezoelectric accelerometer coupled with a measuring amplifier. The sensor under test is a micromachined integrated capacitive accelerometer. The output voltage is measured using a digital voltmeter. The following characteristics and parameters are

determined: the nominal sensitivity, the sensitivity characteristic, the frequency response and the cross-axis sensitivity. Next, students obtain the dynamic parameters of the electromechanical seismometer usually used in mining. The step responses for different damping resistances are acquired and processed by a digital oscilloscope. The nominal sensitivity, the natural frequency, the internal damping ratio and the critical resistance of the seismometer are determined. Eventually the step responses for different damping ratios are investigated.

3.7. GAS CHROMATOGRAPHY

Gas chromatography is nowadays one of the most important analytical techniques. The main idea of the exercise is to discuss the main problems of chromatography composition measurements. First the main components of the gas chromatograph are demonstrated such as a column (packed and capillary), an oven, a sample port, a FID detector, temperature controllers, gas flow controllers and a data acquisition and processing system. There is also discussed the influence of the column temperature and the carrier gas flow on the speed of elution and the separation of sample components. The chromatograph is shown as a complicated measurement system which operator should be skilled in chemistry, metrology and automatics.

The practise part of the class begins with several calibration experiments with use of standards (C1–C4 alcohols). A chromatographic syringe is used for injecting samples into the sample port. For each standard a retention time is determined and a calibration graph of peak area versus sample volume is drawn. Afterwards students analyse a few mixtures containing from two up to four alcohols in different concentrations. There is performed a qualitative and a quantitative analysis of mixtures. The results are discussed and compared with known chemical constitutions of samples. Finally there is shown a temperature programming for analysing complex mixtures. A sample containing light and heavy alcohols (C1–C10) is used.

4. RECOMMENDED LITERATURE

There is not possible to recommend any book as covering all topics included in the course of Measurement Systems. Thus the literature is selected according to needs of an each topic. Examples of the chosen books and supporting materials are as follow:

- 1) BENTLEY J. P., *Principles of measurement systems*, Longman, London and New York 1985.
- 2) FRADEN J., *AIP handbook of modern sensors, physics, design and applications*. American Institute of Physics Press, 3rd Ed., Woodbury, NY, 1995.
- 3) GÖPEL W., HESSE J., ZEMEL J. N. (editors), *Sensors – A comprehensive survey*. Eight volumes, VCH Weinheim, New York, Basel, Cambridge, 1989 – 1994.
- 4) MICHALSKI L., ECKERSDORF K., Mc GHEE J., *Temperature measurement*. J. Willey & Sons, 1991.

- 5) Sydenham P. H. (ed.), *Handbook of measurement science*; Vol. 1 (Polish translation 1988), Vol. 2 (Polish translation 1990), J. Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore.
- 6) *Laboratory of integrated solid-state sensors*, (Multi-author work), Publishers of the Silesian Technical University, Gliwice 1997.
- 7) *Laboratorium miernictwa przemysłowego*, (ed.), J. FRĄCZEK, S. WALUŚ, skrypt 2041, Wydawnictwo Politechniki Śląskiej, Gliwice 1997.
- 8) *International vocabulary of basic and general terms in metrology*, ISO 1993.
- 9) *Guide to the expression of uncertainty in measurement*, ISO 1993.
- 10) ISO 5347-3:1993, *Methods for the calibration of vibration and shock pick-ups – Part 3, Secondary vibration calibration*.
- 11) ISO 5167-1:1991(E) *Measurement of fluid flow by means of pressure differential devices – Part 1: Orifice plates, nozzles and Ventury tubes inserted in circular cross-section conduits running full*.
- 12) ISO 5167-1:1991/Amd. 1: 1998(E) *Measurement of fluid flow by means of pressure differential devices – Part 1, Orifice plates, nozzles and Ventury tubes inserted in circular cross-section conduits running full, AMENDMENT 1*.
- 13) ISO 8316, 1987 *Measurement of liquid flow in closed conduits - Method by collection of the liquid in a volumetric tank*.

5. CONCLUSION

The Measurement Systems Group can continue further studies if during semesters 7, 8 or 9 will be chosen, as the optional subjects included in the speciality of *Information Processing for Control*, following courses:

- (1) Sensors and Actuators (lectures 30h, laboratory coursework 45h)
- (2) Industrial Measurements (lectures 20h)
- (3) Reliability and Intrinsic Safety (lectures 15h, laboratory coursework 15h).

Not all of them will be chosen. As usual it depends on the individual students. For majority of them the training will finish with the subject of Measurement Systems (lectures 30h, laboratory coursework 30h).

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- [1] *The Silesian Technical University of Gliwice, Historical Background*, Gliwice, Politechnika Śląska.
- [2] *Curriculum and Subject Syllabi*, Vol. II, Full-time studies in English: Automatic Control and Robotics, Electronics and Telecommunication, Computer Science, Editor: Faculty of Automatic Control, Electronics and Computer Science, Gliwice 2001.
- [3] *Activity Report 1999-2000*, Institute of Automatic Control, Gliwice 2001.