Measurement Science

Lecturer: dr hab. inż. Wojciech Toczek (WETI PG); 15 h

Course contents:

1. Cross disciplinary concepts and terms in measurement. Thelecture is elaborated on the basis of International vocabulary of metrology (VIM), which is intended to promote global harmonization of terminology used in metrology. A set of definitions and associated terms is given for a system of basic and general concepts used in metrology. Additional information is given in the form of examples under many definitions. The VIM is meant to be a common reference for scientists and engineers – including physicists, chemists, medical scientists – as well as for practitioners involved in planning or performing measurements, irrespective of the field of application. It is also meant to be a reference for governmental and intergovernmental bodies, trade associations, accreditation bodies, and professional societies.

2. Guide for the use of the International System of Units (SI). The lecture has been prepared to help students in the use of the SI in their work, including the reporting of results of measurements. It provides the rules and style conventions for expressing the values of quantities, using units, specially unit symbols, SI prefix symbols, and clarifying comments on some often troublesome quantities and their units. Lecture elaborates on printing and using symbols and numbers in scientific and technical documents, gives the rules and style conventions for spelling unit names.

3. Measurement methods. Measurement method is a generic description of a logical organization of operations used in a measurement. This lecture discusses the following measurement methods: direct comparison with the reference scale, methods based on a calibrated measuring system, substitution, differential, and null measurement methods with many illustrative examples.

4. Developing a measurement models. The measurement model is formed on theoretical or empirical grounds, and generally depends on the metrology discipline, electrical, chemical, dimensional, thermal, mass, etc. The model is then augmented by terms constituting further input quantities, describing effects that influence the measurement, which may be categorized into random and systematic. In some fields of measurement, this task can be very difficult. The lecture considers a few classes of measurement model categorizing them according to whether the quantities involved are real or complex, the measurement model takes the general form or can be expressed as a measurement function, and there is a single output quantity or more then one output quantity. Multistage measurement models, where the output quantities from previous stages become the input quantities to subsequent stages, are also treated.

5. Estimating measurement uncertainty. There are two approaches: type A uncertainty estimates involve data sampling and analysis, type B uncertainty estimates use engineering knowledge or recollected experience of measurement processes. This lecture discusses sample statistics used to make type A uncertainty estimates and heuristic methods used to make type B uncertainty estimates. The framework proposed in the “Guide to the expression of uncertainty in measurement (GUM)” is used.

6. Interpreting and applying measuring equipment specifications. Manufacturer specifications are used for equipment selection or establishing equipment substitutions for a given measurement application – testing, calibration and other measurement processes. In addition, manufacturer specified tolerances are used to compute test uncertainty ratios and estimate bias uncertainties. Therefore, it is important that manufacturer specifications are properly interpreted and applied. This lecture discusses how manufacturer specifications are obtained, interpreted and used to assess instrument performance and reliability. Recommended practices and illustrative examples are given for the application to uncertainty estimation.

7. Analytic methods of deriving a probability distribution for the result of a measurement. In analytic methods, mathematical analysis is used to derive an algebraic form for the probability distribution for the output quantity. They do not introduce any approximation, but can be applied only in relatively simple cases. An advantage of an algebraic solution is that it provides insight through displaying the dependence of the probability distribution for the output quantity on parameters of the probability distributions for the input quantities.

8. The use of a Monte Carlo method for evaluating uncertainty and expanded uncertainty. The use of the GUM uncertainty framework becomes more difficult when forming partial derivatives for a measurement model that is complicated. A valid and sometimes more readily applicable treatment is obtained by applying a suitable Monte Carlo method (MCM). In a MCM an approximation to the output distribution function is established numerically by making random draws from the probability distributions for the input quantities, and evaluating the model at the resulting values. The lecture provides detailed information on MCM as an implementation of the propagation of distributions.

9. The role of measurement uncertainty in conformity assessment. Conformity assessment is an area of importance in manufacturing quality control, legal metrology and in the maintenance of health and safety. In the industrial inspection of manufactured parts, decisions are made concerning the compatibility of the parts with the design specification. Similar issues arise in the context of regulation (relating to emissions, radiation, drugs, doping control, etc.) concerning whether stipulated limits for true quantity values have been surpassed. Measurement is intrinsic to conformity assessment in deciding whether a measurand conforms to a specified requirement. Because of measurement uncertainty there is a risk of a mistaken decision in deciding conformity to specification. Negative consequences from measurement results can range from wasted resources to loss of mission life.

10. Estimation and evaluation of measurement decision risk. The lecture provides tools for estimating and evaluating the measurement decision risk. The risk takes two forms: False Accept Risk, in which non-compliant attributes of an item are accepted as compliant, and False Reject Risk, in which compliant attributes are rejected as non-compliant. In commercial context, false accept risk has traditionally been called consumer's risk, and false reject risk is called producer's risk. Measurement decision risk is defined in terms of probabilities of the occurrence of events relating to testing. To develop the necessary probability expressions, Bayesian analysis will be employed based on a priori knowledge of a measurand and on the results of measuring the attribute of the item under test

11. New data converters. In the lecture a new class of analog/digital converters (ADC) is considered with an architecture known as "pipeline". Now offered by several manufacturers, pipelined ADCs are among the most efficient and powerful data converters available. They offer high speed, high resolution, and excellent dynamic performance, along with modest levels of power dissipation and small die size, which equates to low cost. They cover a wide range of applications, including CCD imaging, ultrasonic medical imaging, digital video (for example HDTV), and fast Ethernet. Under considerations are: principles of operation, detailed examples, simulation results, digital error correction, the algorithmic (or cyclic) conversion method.

12. Noise-shaping data converters. The sigma-delta analog/digital converters (ADC) offers several advantages over the other architectures. They are now used in many low-bandwidth applications where a low-cost, low-power, high-resolution ADC is required. The lecture introduces to the fundamental concepts of sigma-delta converters: oversampling, noise-shaping, digital filtering, decimation and dithering.