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HOW TO TEACH THE PHYSICAL AND TECHNICAL ASPECTS OF METROLOGY?

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Abstract: According to the recognized elements of General and Applied Metrology, the curriculum of courses covering the field of Electrical Engineering and Computing are presented, for the study programs adapted to the Bologna declaration at the Faculty of Electrical Engineering and Computing in Zagreb, Croatia. The criteria for teaching the metrology are recognized, and the basic approach to the measurement is pointed out. Some aspects from our experience and point of view are presented for the exchange of knowledge and attitudes within the metrologists.

Keywords: metrology, teaching, electrical measurements

1. INTRODUCTION

All of us who are involved in the educational process, especially at the university level, are faced with the same problems: (i) how to teach the metrology; (ii) what would be a curriculum(s) of such course(s); (iii) at which level of study it is appropriate to teach some aspects of metrology, and (iv) what are the reasons and objectives of that? Of course, these are only a few questions among others that could be asked.

In the frame of this paper we would like to share our experience, to express some points of view, as well as to exchange the knowledge and attitudes within the community. At least, we would like to undoubtly emphasize the importance of teaching of the different aspects of metrology, especially at technical faculties.

If we try to find simple answer on the question: What is metrology?, the VIM [1] says that this is "science of measurement", which comprises theoretically and practically all of the phenomenal forms that relate to measurement, with no distinction concerning the level of accuracy, or the field of science and technics. Following this approach we can talk about the General Metrology (GMet), which deals with the problems common to all metrological questions, or about Applied Metrology (AMet), oriented to the measurements for specific applications. Therefore, GMet could contain topics like quantities, units of measurements, basic metrology terms, measurement uncertainty [2], establishment of traceability, metrological infrastructure, industrial or legal metrology, accreditation, calibration, etc. [3]. On the other hand, topics for AMet are more sensitive to the field of application, and can be the following: measuring instruments and their characteristics, methods of measurement, measurement systems, sensors and measuring transducers, programmable devices and interfaces, instruments with A/D converters, or any other field of particular interest [4].

The problem within the teaching process is determination of the knowledge: a) that is necessary to a wider population; b) that is nowadays useful for many applications; c) that fills the basis for the future life-long education [5] and specialization [6] (for instance). Having the mentioned items as the starting points in the deliberation of the possible metrology oriented courses and their curriculum, we are also faced with some limitations, as usually. These limitations could arise due to the finite number of available time, human and material resources, demands of the community or universities, orientation of the particular economy, or from the different opinions about the role and importance of the metrology. Even more, especially for European countries, implementation of the Bologna declaration, i.e. the ongoing process of the implementation of the study programs after which the same degree, obtained in different countries [7], will be widely recognized, makes these requirements even harder.

In Fig. 1 a simple model of measurement is presented, that contains object of measurement, used method of measurement, while the complete analysis of the obtained results (including uncertainty evaluation) is the last part. Therefore, a metrology-oriented course may pay attention to all of these items with the equal portion, or to have more interest into the some part of them. In this very simplified model we can recognize the themes associated to GMet, as well as to AMet, and the course can be more oriented to one of them, or to have a selected chapters from both parties.

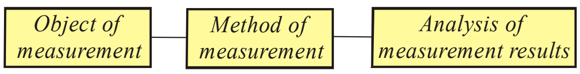

Fig. 1. The basic approach to the measurement

Having the all mentioned in mind, to define a curriculum of a course in "metrology" is not an easy task. However, the opinion of the authors is that course oriented to GMet is essential for the technical education of the students, nevertheless of their primary field or technical discipline, while the courses oriented to AMet could be defined in a more specific way, to cover the requirements and themes of particular field.

2. METROLOGY ORIENTED COURSES

At the Faculty of Electrical Engineering and Computing (FER) of the University of Zagreb, Croatia, the Cathedra for

Electrical measurements at the Department of Electrical Engineering Fundamentals and Measurements (to which belong the authors of this paper) has an eight-decades tradition in teaching of metrology, especially in the field of electrotechnics, on the graduate and postgraduate level. For many years (precisely speaking, decades), a two-semester course "Electrical Measurements" on the second year of the study, obligatory for all students, serves as an open gate and their first contact with the metrology and measurements. The short curriculum of the course is as follows: terms, units and their dissemination; errors and uncertainties; analogue and digital measuring instruments; measuring amplifiers; dc and ac bridges; measurements of electric and nonelectric quantities; instrument transformers; high-voltage and magnetic measurements. Under the leadership of Prof. V. Bego, through the mentioned course the practical needs and knowledge from industry, as well as the experience and art of experimental work from the field of precise measurements, were served to the students. However, due to the ongoing changes of the study programs at FER, the mentioned course in that form and curriculum will not be part of the further educational process.

2.1. Courses for the bachelor degree

In the new study program, that started in the academic year 2005/06 and is prepared according to the Bologna process, to obtain a bachelor degree (after 3 years of study) there are two branches: "Electrical Engineering and Information Technology" (EEIT), and "Computing" (C). The first year of study is the same for both disciplines, as well as a main part of the second year. In the third year specializations for the EEIT branch are: Wireless Communications, Electronics, Electronic and Computer Engineering, Control Engineering and Robotics, and Electrical Power Engineering. For the C branch, the specializations are as follows: Software Engineering, Computer Engineering, Telecommunication and Informatics, Computer Science, and Information Processing and Multimedia Technology. The branches are defined by the obligatory courses, but there is a list of elective courses available to all branches. Since there is a tendency to minimize the amount of courses relevant to electrical engineering in the branch C, the problem by which some other faculties are faced, too [8], the elective courses for the 6th semester (3rd year) of a study should have themes of interest for both branches. Therefore, the new-formed course "Metrology Fundamentals" (Table I) is mainly oriented to GMet, to serve as important part of technical education of the students for both branches. On the other hand, the course "Methods of Measurement" (Table II) is prepared mainly for the students in the branch EEIT, and could be assigned as an AMet oriented course. These statements have a fulcrum on the presented curriculum of them.

Besides the mentioned elective courses, some other aspects of GMet, particularly standardization, traceability, calibration and quality systems, were introduced in the new course "Quality Management", which is obligatory course in the 2nd year of a study for all students (Table III). In that way these important technical aspects will be presented to the whole population of students.

Table I. Curriculum of the course "Metrology Fundamentals" with the relative share of themes

Fundamental terms: measurand, true and conventional true value, measurement, principle of measurement, method of measurement, influence quantities, result of the measurement. Repeatability and reproducibility.	(12 %)
Analysis and internationally recognized expression of the results of measurement. Least-mean squares theory. Combined and expanded uncertainty.	(24 %)
International System of Units (SI). Metre convention. Base quantities and units. Derived units. Decimal and binary multiples. Metrology structure and traceability.	(21 %)
Multimeters. Principles and explanation of the technical data. Voltage, current and resistance measurements. Grounding and shielding. Active and passive interference protection. Sampling.	(22 %)
Computer supported measurements. Virtual and distributed measuring systems. Communication protocols connecting computer and instruments. Calibration through Internet. Software for analysis of the result of measurement. Computer controlled instrument's networks.	(21 %)

Table II. Curriculum of the course "Methods of Measurement" with the relative share of themes

Instruments. Technical data, uncertainty, and application. Oscilloscopes. Operation principle. Probes.	(17 %)
Criteria for selections of measuring methods and procedures. Components of measuring circuits.	(10 %)
Voltage and current measurements. Voltmeters and ammeters. Compensators and calibrators. Resistive and inductive dividers. Measurement of high currents. Methods of measurements of resistance, inductance and capacitance. *U-I* method. DC and AC Bridges. Digital impedance instruments.	(30 %)
One and three phase current power measurements. Wattmeter. Semi direct and indirect power measurements. Measurement of reactive and apparent power. Watthour meters; tariff setting, distance reading.	(17 %)
Measuring converters. Technical data, standardized output data, application.	(7 %)
Temperature measurement. Temperature scales. Sensors, termistors, thermocouples. Measurement of pressure, flow, strain, and relative extension. Application of unbalanced bridges.	(19 %)

Table III. Curriculum of the course "Quality Management" with the relative share of themes

Quality, globalization and harmonization.	(13 %)
Principles of Total Quality Management. Leadership and customer focus. Continuous improvements.	(18 %)
Tools for planning and process control.	(15 %)
Standards and standardization. Standard series ISO 9000, 10000 and 14000.	(10 %)
Quality systems according to the ISO 9001:2000.	(15 %)
Accreditation of a laboratory according to the standard ISO/IEC 17025:2005.	(12 %)
Software quality assurance.	(10 %)
Quality management at the university-level education.	(7 %)

2.2. Courses for the master degree

On the fourth and fifth year of the study at FER (i.e. the second-cycle study) three programs are planned: a) Electrical Engineering and Information Technology; b) Information and Communication Technology; c) Computing. For the first program the following profiles will be established: i) Control Engineering; ii) Electrical Engineering Systems and Technology; iii) Electronic and Computer Engineering; iv) Electronics. At this moment, the mentioned programs and profiles have been mostly defined, and the following courses are planned, mainly for the program a) and profile ii), as obligatory or elective courses:

- "Measurement Theory" (data measurement system, error analysis, weighted regression functions, uncertainty of measurements, analysis of variance)
- "Measurement Technique" (analogue and digital instruments, calibration, instruments with A/D converters, programmable devices and interfaces, PC as measurement platform, virtual laboratory and Internet)
- "Measurement in Technology Processes" (sensors and measuring transducers; measurement of displacement, deflection, angle, vibration, force, torque, RPM, speed, acceleration and temperature; MEMS and NEMS transducers, precision measuring amplifiers, PID regulators, distributed measurement systems)
- "Electrotechnical Measurements" (test and measurement of electrotechnical components, instruments, and systems; methods of generating and measuring high voltages and currents; measurement of noise, vibration and electromagnetic fields; measurement and testing of isolation, capacitive currents and partial discharges).

Important part of all of these courses are laboratory exercises, which makes deeper knowledge and confirms the theoretical basis, nevertheless if the students make experiments directly in the laboratory (for instance [9]), or remotely through Internet.

3. DIFFERENT ASPECTS OF METROLOGY

From the presented curriculum of different courses, as well as their position in the study structure, we could emphasize some opinions and attitudes. However, we will no deal with the details of some themes or subthemes, having in mind that a possible reader is familiar with the subject, but staying focused on the general principles.

3.1. Physical aspect

This is often seen as matter of courses on physics, which could be mostly true from the historical point of view, especially concerning the themes such as the system of units, or their realization and dissemination. On the other hand, the physical aspect could be the interaction of an influence quantity to the object of measurement, or to the measuring instrument, because this follows from the laws of nature and our observations are only a macroscopic view of the processes at the microscopic level. Therefore, we can talk about the following:

- Units of measurement. As it is stated in VIM [1], *measurement* is "set of operations having the object of determining a value of a quantity", by comparing it to a chosen unit and determining the numerical value as their ratio; i.e. for the electrical current it is $\{I\} = I/[I]$. Closely related to the units of measurement are measurement standards, and the implementation of the physical laws for their realizations.

- Principles of measurement. We can also find in VIM [1] that *principle of measurement* is "scientific basis of a measurement" and a consequence of the physical laws. It is important to introduce this concept at the beginning of any metrology-oriented teaching process (or courses), even if the opinion (or "feeling") is that it is well-known or rather understandable.

- Uncertainty of measurement. Although the calculation of uncertainty of measurement according to the widely recognized and adopted GUM [2] can be seen as rather mathematical discipline, the modelling of measurement is undoubtly the crucial element of that process, and follows from the knowledge about the measurement and measurand. Even an interference, which needs to be recognized, is physical phenomena and not our decision or applied rule.

The mentioned items, amongst others, should be introduced in the teaching process as soon as possible because they are common to different branches of science and technics. Mostly these themes will be covered by a course oriented to GMet. However, the concept of the physical nature of a measurand and measurement should be retained and stressed throughout the educational process.

3.2. Technical aspect

Within this aspect we can make the accentuation on the following themes:

- Measuring instruments. Use and application of an instrument (analogue, digital, virtual, recording, etc.) depends of the field of interest, and certainly it could be many of them. However, since the nonelectric quantities can be converted to the electromagnetic quantities by the suitable sensors, the measurement of such quantities by the appropriate instruments has a great influence, specially at nowadays level of industrialization. From the wider point of view, a measurement system can be recognized as the some kind of instrument.

- Methods of measurement. The same words can be used as for the previous item, because the methods depend on the field of interest, and can be direct, indirect, null, etc. Due to the changes in techniques, the spectrum of methods could vary in time, as well as the objects of measurement (for instance, if there is no method for length measurement at nanometre level, it will be no possible to do it, and accordingly there will be no object to measure at that level).

- Calibration, standardization and quality assurance. These are typical technical disciplines, and can be clearly recognized. As well as for other mentioned items (but also as for non mentioned), there could be different approaches and weights for them.

It should be emphasized that the themes that represent the technical aspect are more sensitive to the changes of technics, which means that they can change faster than the themes associated to the physical aspects. Certainly, this technical aspect should be covered by the courses oriented to AMet, and therefore more specialized. It is common that in that case it would be appropriate to present these themes to the students when they are almost introduced with the GMet themes.

4. CONCLUSIONS

Metrology courses could be oriented mainly to GMet or AMet, and therefore their curriculum should be different and relevant to the wider population, or to the some specialization. They should get acquainted students with the both physical and technical aspects of metrology. As expected, on the question how to teach the physical and technical aspects of metrology, there is no one proper (or accurate) answer because they are many of them.

Here we presented the metrology-oriented courses within the new study program at FER in Zagreb that will be taught within our Department. For that reason they are relevant to the electrical engineering and computing, on the basis of (3+2) years to obtain bachelor or master degree, respectively, according to the ongoing Bologna process. They were introduced with: (i) long-term experience in the teaching of metrology; (ii) some limitations, of course, in the given structure and opportunities; (iii) the aim to present and teach students of the technical faculty the important and interesting themes of general and applied metrology.

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