

METROLOGY EDUCATION AT MACHINERY ENGINEERING FACULTY

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Abstract: The curricula at Faculty of Automobiles and Heavy Machinery Engineering at Warsaw University of Technology went a significant evolution since 1990 as a result of the emergence of new technologies and engineering methods as well as in response to labour market and state educational policy. General view on the latest curricula is given with the indication in which courses elements of metrology are also thought. Next special attention is paid to the metrology course (15h lecture + 15h tutorials + 30h laboratory). The course gives fundamental information on classical metrology topics such as uncertainty evaluation, error source analysis, etc. and then focuses on metrology of geometrical quantities. Students in the laboratory acquire indispensable know-how of typical measuring jobs, process their results as well as validate them and the whole measurement process. The organisation of the laboratory and the basic problems of its computerisation are discussed. Paper gives some hints how to teach efficiently metrology at machinery engineering faculty. Finally the work towards implementation of quality assurance system based on ISO 9000 standard in all stages of teaching metrology are mentioned.

Keywords: education, metrology, geometrical tolerancing

1 INTRODUCTION

The fast rise of the requirements relative to dimensional-geometrical accuracy of machine parts and the need of modern approach towards the problem of quality assurance stimulate the development of tolerancing/measuring techniques as well as measuring tools and systems. One of the directions of this development is the use of bigger and bigger possibilities of microprocessors and microcomputers in measuring systems and recent improvements in tolerancing techniques compatible with CAD, CAM, CAQ and CMM systems. As a result of such impact there is a necessity of constant modifying of content, tasks and methods of educating metrology at the university level.

Another factor that stimulates remodelling of Metrology course curriculum is intensive activity of ISO Technical Committee TC 213 *Dimensional and geometrical product specifications and verification* [1]. Authors participate in TC 213 works, they submitted a few elaboration that were accepted as ISO documents. S. Bialas is nominated expert of Polish Standard Committee to Working Groups WG6, WG12 and WG14. Z. Humienny is nominated expert to Advisory Group AG11. Such activity gives us possibility to transfer the latest ISO TC 213 results to the lecture.

In 1995 ISO with cooperation between BIPM, IEC and OIML issued latest version of *Guide of Expression of Uncertainty in Measurement*. New practice of expression of uncertainty is slowly becoming more and more popular through the world. Elements of the new attitude are introduced in our course.

The program of modernising and computerisation of metrology education at Faculty of Automobiles and Heavy Machinery (FAHME) started a few years ago. It is focused on size, form/orientation/location and angle measurements as well as interchangeability of machine parts. The program covers:

- implementation of computer aided education techniques – developed software supports acquisition of metrology knowledge during tutorials and students self learning,
- application of computer aided measuring techniques in laboratory practice.

Student enrolment to the Faculty is approximately 260 annually and the total number of about 1000 students pursuing five year MSc degree programme. The Faculty employs approximately 110 professors and assistants supported by about 80 technical and administrative staff.

The problem where metrology of geometrical quantities is/should be touch as well as curriculums of the courses are discussed in many countries [2,3]. For curriculum composition and upgrading a few lately issued books can be used [4,5,6,7,8].

2 METROLOGY COURSE

The subject named Technical Metrology at FAHME at Warsaw University of Technology belongs to set of fundamental technical subjects. The Metrology education is managed by scientific workers from Production Engineering and Machinery Metrology Group – one of research-teaching groups working at Institute of Machine Design Fundamentals. The curriculum of Technical Metrology contains three teaching forms: lecture, tutorials and laboratory practice. It is oriented mainly towards linear/angular measurements, limit gauges, comparison measurements, gear and thread measurements, measurements of surface profile and determination of form/orientation/location deviations as well as presents fundamentals of the theory of measurements. The Laboratory of Metrology covers 30 hours and gives credit for students of IV semester. This laboratory ought to complement the knowledge acquired earlier from lecture (III semester – 15h) as well as tutorials (III sem. – 15h). Supplementary metrology knowledge students obtain completing other subjects: Technical Drawing Fundamentals (II sem. – lecture 30h), Machine Design Fundamentals (V sem. 30h – lecture, VI sem. – 30h design practice), Fundamentals of Dynamic Measurements (V sem. – 15h lecture, 30h laboratory), Quality in Machine Design (VII sem. – 30h lecture) and during graduate course studies – Theory of Stereometrical Accuracy of Machine Parts (IX sem. – 30h lecture, 15h tutorials). Full time MSc studies in engineering at FAHME covers 2800h.

During the preparation and implementation of curriculum and content of metrology education the following criteria have been taken into consideration:

- presentation of fundamental information on classical metrology topics (uncertainty evaluation, error source analysis, geometrical quantities and their measurements, etc.),
- introduction to the industrial applications of dimensional measurements,
- getting acquainted with elements of modern inspection and process control, with a basic understanding of the different types of instrumentation and equipment,
- individualisation of the metrological tasks given students to perform,
- development of skills for use of fundamental material measures and measuring instruments,
- facilitation to understand how to read and avail oneself of manufacturer catalogues or manual service sheets for instruments and measuring systems,
- development of skills of optimal choice of measuring instruments according to measuring task,
- demonstration of selected measuring systems taking advantage of microprocessors and microcomputers PC class,
- strengthen of the methodology results correct presentation and critical analysis of obtained results.

3 CURRICULUM OF LECTURE AND TUTORIALS

A general curriculum of Technical Metrology at our Faculty was worked out by S. Bialas. The typical engineering design character of FAHME determined content of Technical Metrology. The faculty profile assumes education of mechanical design or operating engineers (not metrology engineers) equipped with basic knowledge of metrology and been able to apply it in practice. Table 1 reviews the subject area of lecture and tutorials of the Technical Metrology.

Due to the size of faculty enrolment the lecture is conducted for two lecture groups, each about 120 students. The dedicated script for lecture [8] is issued by Warsaw University of Technology Printing House. Tutorials are performed with group of 25÷30 students. Students solve calculation examples and presents geometrical interpretation of geometrical product specifications (GPS) under supervision of university teacher.

It seems that 15 hours of lectures is too short time for presentation of metrology fundamentals and GPS. Authors are convinced that to give rough general overview of rapidly developing metrology areas (methods, measurements, instruments, quality systems, new GPS concepts, computer aided tolerancing, etc.) at least 30 hours of study curriculum should be allocated for metrology lecture.

4 CURRICULUM OF LABORATORY

The essential aim of Laboratory of Metrology is the strengthening of the theoretical knowledge and the acquirement of necessary practical skills for taking typical measuring tasks as well as the elaboration and evaluation of possessed results of measurements. The details of curriculum are given in table 2. The table presents the list of exercise subjects and respectively utilised measuring

instruments and equipment. The laboratory covers 12 exercises which are oriented towards familiarising student with selected measuring task or group of measuring devices.

The students get laboratory manuals at the beginning of semester to facilitate their preparation at home. Unified measuring form is given to students when they start each laboratory practice.

Table 1. Lecture and tutorial content of Technical Metrology at Faculty of Automobiles and Heavy Machinery Engineering at Warsaw University of Technology.

CURICULUM OF LECTURE	h	CURICULUM OF TUTORIALS	h
1. ISO system of limits and fits. The aim of tolerancing. Tolerance grades. Standard tolerance factor. Steps of nominal sizes. Tolerances without individual specifications. Fit symbols.	1	1. Dimensional tolerances. Nominal and limit sizes. Deviations, tolerance zone. ISO system of limits and fits. Fit parameters: clearance, interference. Fit character and tolerance. Size distribution in tolerance zone.	3
2. Measurement errors. Definition of measurement – principles and methods. Measurement errors (systematic, random) – identification and estimation. Errors of measurement method and device. Reference conditions (standard temperature).	2	2. Systematic errors and corrections. Uncorrected result. Error source analysis. Determination of systematic errors in length measurements. Systematic error as an effect of thermal expansion and measurement pressure.	1
3. Measuring instruments – general information. Material measure, measuring transducer/system. Metrological parameters of measuring instruments. Verification/certification of measuring instruments.	2	3. Random errors. Statistical analysis. Calculation of measurement result from set of measurements. Analysis of small/large set of results. Uncertainty of measurement.	2
4. Dimensional chains in machine design. Types and structure of dimensional chains. Equations of limit deviations and tolerance. Synthesis and analysis of simple dimensional chains. Interchangeability of parts – types and advantages (worst case, statistical, constructional, manufacturing, selective). Costs.	3	4. Errors in indirect measurement method. Effect of systematic and random errors in direct measurements to indirect measurement result – examples in geometrical measurements.	1
5. Geometrical tolerances. Form tolerances (straightness, flatness, circularity, cylindricity). Substitute elements, location/orientation (parallelism, perpendicularity, coaxiality, symmetry, position) and run-out tolerances. Tolerances with MMC and envelope requirement. Tolerances in Polish and ISO Standards.	3	5. Calculation of dimensional chains. Interchangeability of parts. Analysis of simple dimensional chains – worst case and statistical methods. Computer simulation of deviations of dependent dimension. Synthesis of dimensional chains (minimum cost method - computer aided optimisation). Interchangeability in machine design. Calculation of partition to selection groups.	4
6. Selected examples of geometrical quantity measurements. Material measures (gauge blocks, angle gauges) – applications. Measurements with calliper, micrometer and indicator instruments. Measuring microscopes. Geometrical deviation measurements. CMM. Roughness measurement with surface analyser. Criteria for optimal selection of measuring instrument.	4	6. Makro- and mikrogeometry of surface. Geometrical tolerances in technical documentation – specifications and interpretation of form, location, orientation and run-out tolerances. Roughness and waviness of profile – basic parameters. Roughness tolerancing with respect to dimension tolerances.	4

Two university teachers (assistants or assistant professors) conduct laboratory practice. In the first half of semester exercises from nests A and B are executed, in the second – after reconfiguration of laboratory stands – exercises from nests C and D. Each laboratory task is solved by team of 4-5 students which is usually divided to two sub-teams with individual measuring task and/or workpieces.

About half of the laboratory exercises is performed with computer support – measuring devices/stands with microprocessor and/or dedicated software. We are not going to computerise laboratory more because we are convinced that it will cause decreasing in students familiarisation with basic measuring instruments and measuring data analysis which is still necessary for factory practice.

5. GEOMETRICAL TOLERANCING IN METROLOGY EDUCATION – TYPES OF EXERCISES FOR TUTORIALS

Dimensional and geometrical tolerancing joins the intellectual design process of workpiece generation with its manufacturing process. So it is important to clearly explain and introduce the future engineers for systematic and proper approach to design/manufacturing/inspection procedures.

Teaching geometrical tolerancing/inspection rules we observed that students should solve by themselves much more theoretical/practical examples than during study of other metrology topics.

Form, location, orientation and run-out tolerances are specified in drawings. They are applied to workpieces, which real (actual) surfaces may be presented in drawings. So a number of types of exercises for tutorials can be developed and systematised (table 3). Precise definition and variety of educational targets at given exercises efficiently verifies and consolidates understanding of GPS.

Table 2. The subject area of Laboratory of Metrology.

Ex. No	EXCERCISE SUBJECT	MEASURING INSTRUMENTS AND EQUIPMENT
A1	Material measure of length and angle	Gauge blocks and angle gauges, accessories for gauge blocks, vernier calliper, triangular knife straight-edges, universal bevel protractor, curve gauges, measuring plate
A2	Measurements with vernier and micrometer instruments	Vernier calliper, vernier depth/height gauges, micrometers (external, internal, dial, for wires, etc.), transameter, rod type internal micrometer, digital callipers, digital micrometers in SPC
A3	Cylindrical gears measurements	Vernier calliper, gear tooth vernier calliper, micrometer for gear measurement, general-purpose bevel protractor, gear measuring device TA 450-S1 with computer PC data processing
B1	Indicator instruments measurements. Sampling inspection plans by attributes	Dial bore gauge, dial bore gauge with micrometer head, dial/incremental/spring/inductive indicators, measuring plate, gauge blocks, vernier calliper, general-purpose column/magnetic measuring stands, accessories for gauge blocks
B2	Measurements of form, orientation and location deviations	System PIK-2 for roundness and straightness measurements
B3	Roughness measurements	Roughness reference standards, Schmaltz microscope, surface analyser - Surfrest 402
C1	Measurements of external cone angles	Toolmaker's microscope, external micrometer, sine bar/table, dial indicator, general-purpose bevel protractor, gauge blocks, measuring wires and rolls, magnetic measuring stand measuring plate
C2	Measurements of screw threads (straight, metric)	Screw thread gauges, vernier calliper, external micrometers, measuring wires and rolls, external micrometers for screw threads, general-purpose measuring microscope
C3	Analysis and synthesis of dimensional chains	Computer PC with software developed at Production Engineering and Machinery Metrology Group
D1	Analysis of machine capability	Inductive indicator, gauge blocks, computer PC with dedicated software
D2	Multidimensional inspection. Control chart \bar{x}-R	Multidimensional measuring bench, setting master, computer PC,
D3	Dimensional and perpendicularity measurements in vertical axis	Dial indicator, measuring plate, digital vertical measuring instrument – Trimos vertical TVD 800

6 EDUCATION QUALITY SYSTEM

From 1996 at Warsaw University of Technology has started an implementation of university quality system based on ISO 9000 series standards. The adopted concept of quality system structure has got process character and to all essential processes (research, educational, experimental or service tasks) are referred defined aims as result of university quality politics. At the first stage selected university laboratories were prepared for accreditation. In a second stage implementation of quality system to all teaching activity is anticipated. It assumes preparing of documentation and technical-organising solutions compatible with ISO standard for all laboratories that have not contested for accreditation at first stage.

The quality plan of Technical Metrology course is presented in figure 1. The placement of the lecture, tutorials and laboratory in the metrology course is indicated in the quality plan as well as three procedures that were developed for the laboratory. The implementation of quality plans into metrology education facilities systematising and arrangement of constant improvement of curriculum and methods of exercises organisation.

Table 3. Types of exercises for teaching geometrical tolerancing.

Ex. Type	INPUT DATA	TASK	EDUCATIONAL TARGET
1	Drawing of workpiece with specified tolerance	Explain verbally requirement specified in drawing	Checks understanding of fundamental terms (given in lectures)
2	Drawing of workpiece without dimensions	Specify in drawing 4 form tolerances (4 location/orientation tolerances)	Checks knowledge of symbols and ability of distinction between tolerances
3a	Drawing of workpiece and verbal requirement specification	Specify tolerance in drawing	Reverse to task 1. Checks knowledge of symbols and ability of their interpretation
3b		Tolerance different geometrical features	
4a	Drawing of workpiece and tolerance symbols	Specify tolerance in drawing	Develops ability of tolerance usage and interpretation
4b		Tolerance different geometrical features	
5a	Verbal specification of requirement	Draw workpiece, specify tolerance	Develops ability of tolerancing in design activity
5b		Draw workpiece and tolerance different geometrical features	
6a	Tolerance indication symbol	Draw workpiece, specify tolerance	Develops ability of usage and interpretation of tolerance symbols in design activity
6b		Draw workpiece and tolerance different geometrical features	
7	Two drawings with location/orientation tolerance. The same toleranced element, various datums	Compare specifications in drawings	Shows importance for proper selection of datums for workpiece performance and verification
8	Workpiece drawing with tolerance, actual workpiece	Indicate deviation on actual workpiece	Shows interpretation of geometrical specification
9	Workpiece drawing with tolerance, deviation value	Draw workpiece and mark deviation	Develops understanding of geometrical specification meaning
10	Workpiece drawings with: a) location/orientation tol., b) run-out tol., c) form tol.	Compare specifications in drawings	Shows similarity and differences between location/orientation, run-out and form tolerances
11	Workpiece drawings: a) with MMC, b) without MMC	Compare specifications in drawings	Shows influence of MMC for manufacturing costs and functionality
12	Workpiece drawing (like two steps shaft) with tolerances. Options at roundness measuring system	Analyse available options. Verify specified requirements (performed in the laboratory)	Develops understanding of expression functional requirements by geometrical specifications Shows exact and simplified methods of measurements.
13	Assembly drawing with given dimensions	Define geometrical tolerances ensuring proper assembly performance	Shows full design activity (performed at graduate course)

7 CONCLUSIONS

The paramount objective of teaching metrology at machinery engineering faculty should be to acquaint students with: ♦basic measurement terminology; ♦methods of measurement error analysis; ♦concept of interchangeability; ♦geometrical product specifications and verifications methods.

The computerisation of metrology education means application of multimedia techniques in lectures and tutorials as well as introduction of computer aided measurement in laboratory. The Laboratory of Metrology computerisation seems to be fully justified by development of instrumentation during recent years however there is a lack of basic measurement skills among the students. It defines limits of computerisation. About half of the laboratory time should be devoted to the more traditional measurement techniques, manual operation and set up of basic instruments such as callipers, micrometers, dial indicators, gauge blocks etc.

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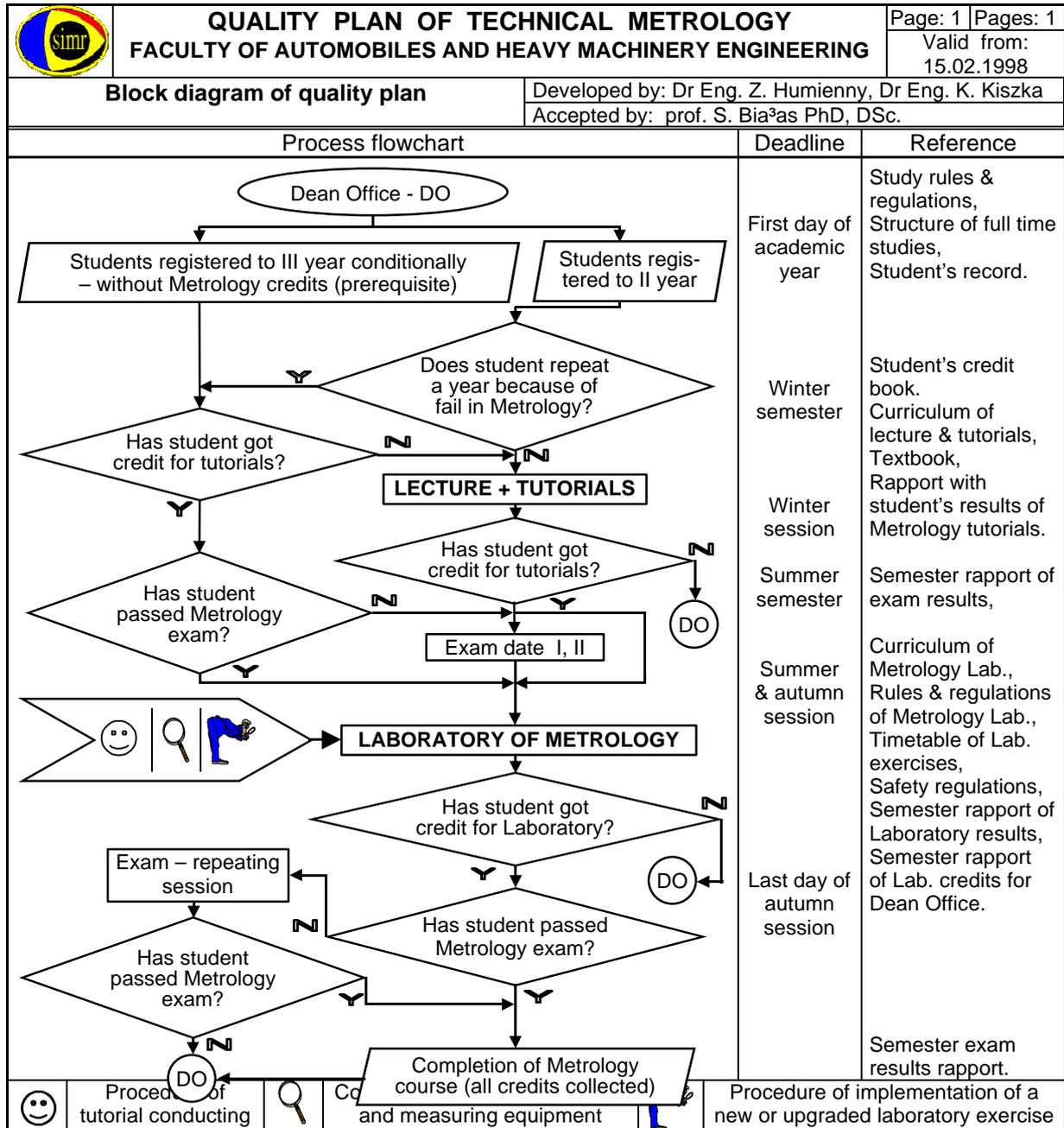


Figure 1. Quality plan of metrology at Faculty of Automobiles and Heavy Machinery Engineering.

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