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ASPECTS OF FORCE, TORQUE AND HARDNESS MEASUREMENT IN ROMANIA

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Abstract. Force measurement holds an important share within the electrical measurement of mechanical quantities in Romania. The paper presents examples that outline the progress in this field, especially in matter of measurement standards and calibration equipment.

Keywords: force, torque, hardness, measurement standard, calibration

1 INTRODUCTION

Measurement of force, torque and hardness is presently performed to a large extent with the involvement of electrical methods and means. Most of the instruments used to this end are automated, intrinsically or computer-assisted, representing a new generation of techniques. The combination of mechanical and electrical principles, as well as of electronic and computer-aided instrumentation, gave birth to a new direction of interdisciplinary development, sometimes called *mechatronics*; a pertinent illustration of these intersecting domains is given in figure 1 (reproduced from Mechanical Engineering, May 1997, p. 61).

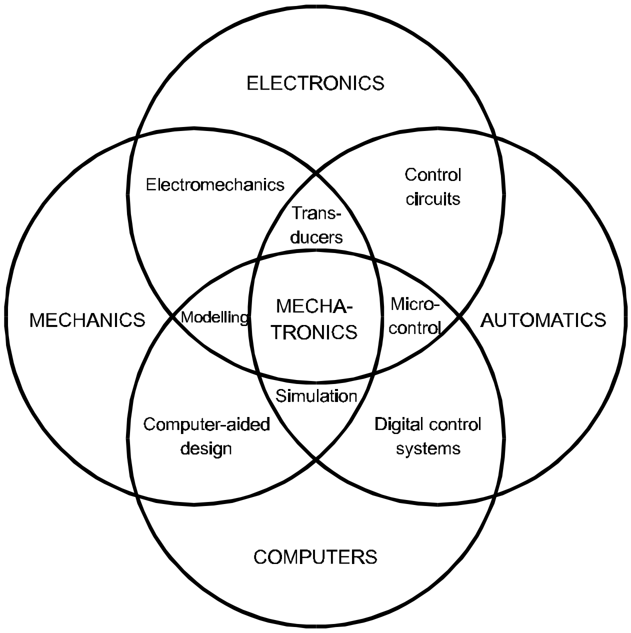

Figure 1. Interfering disciplines defining Mechatronics

Therefore, reviewing the progress of measurement principles and techniques in the field of mechanical quantities should go far beyond the borders of mechanics. The main emphasis lays on sensors and transducers, which are specific to each measurand (quantity to be measured), while the instrumentation used for processing the output signal of the transducers is similar for a large variety of input quantities. A spectacular achievement in this respect is the creation of smart sensors, which have radically changed the architecture of the measurement systems for mechanical quantities.

2 HISTORICAL OVERVIEW

Measurement techniques in general, and measurement of mechanical quantities in particular have a long tradition in Romania. Among the engineers educated in the early years of the Romanian technical universities, many well known personalities have contributed to achievements like the first bridge over the Romanian part of Danube, the first railroad of 60 km length or the first street lighting system in this part of Europe; all of these projects needed highly qualified specialists in mechanical measurements and testing. In 1835, a draft of a law concerning the introduction of the Decimal Metric System of Units was forwarded to the National Assembly in Bucharest; even rejected, it had a strong influence on the country's community, and also a historical significance, being one of the first official attempts in the world to legalize the Metric Units.

Later, during the first half of the 20th century, Romanian professors C. Statescu, St. Hepites and C. Budeanu were promoters of the scientific foundation and development of the future International System of Units. After the 2nd World War, professor R. Radulet - who acted in the 70ies also as president of the IEC - brought significant contributions to the theory of measurement.

On a more practical level, Romanian engineers have proposed several interesting technical solutions, some of them patented, in the field of mechanical measurements (e.g mechanical stress indicators). An extensive fine mechanics industry began to develop in Romania, involving various instrumentation and equipment for mechanical measurements. At the same time, the foundations of a modern force and hardness calibration laboratory were laid by M. Ratiu, in Timisoara, where an entire series of standard force machines have gradually been constructed (presently belonging to the Romanian National Institute of Metrology).

3 NATIONAL STANDARDS

The National Institute of Metrology maintains the national standards of Romania for almost all physical quantities, including dimensional, kinematic, mechanical, electrical, thermal, optical, physical-chemical, ionizing radiations and others.

The national standards for force consist of a group of dead-weight machines of nominal forces of 10 kN, 50 kN and 100 kN, and a hydraulic-amplification machine up to 1 MN. For calibrations at higher value forces standard load cells are used, which allow to extend the range of force values up to 5 MN. The basic uncertainties of these standards are of the order of 1×10^{-5} at force values up to 10 kN augmenting progressively to 1×10^{-3} at 1 MN.

The main parts of the dead-weight machines are the standard weights, the loading frames, and the mechanical set-up for moving and placing on the frame the weights. The force steps at which the calibration is performed are programmed successively, according to the specific norms for such calibrations. For example, for the 100 kN machine the steps - expressed in kilonewtons - are as follows:

1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100.

Special control equipment is used for programming the entire calibration process and displaying the values of interest. The program, including data processing and calibration report editing and printing, is run on personal computers.

For torque, two primary standards are used as reference, of nominal values of 6 kN·m and 200 N·m respectively. The basic uncertainties of these torque machines are 5×10^{-4} and 2×10^{-3} respectively.

Standard equipment of special design is used for reproducing the Rockwell, Vickers and Brinell hardness scales. The uncertainties attained are $0{,}5\times10^{-3}$ for the Brinell scale, 0,3 HR for the Rockwell scale, and $0{,}5\times10^{-2}$ for the Vickers scale.

All these reference standards are regularly compared to national standards of other countries, by participation in international comparisons or by calibration in European national institutes (mainly in P.T.B., Germany) of travelling (transfer) standards. In this way, traceability to internationally recognized force, torque and hardness standards is achieved.

The laboratories which keep the Romanian national force, torque and hardness standards are organized in accordance with a thoroughly elaborated Quality Assurance System. Their evaluation and accreditation by a specialized accreditation body is foreseen for the near future.

Table 1 shows the measuring ranges and best uncertainties that can be provided with these standards for force, torque and hardness calibrations.

Table 1.

Quantity	Measuring Range	Uncertainty
Force	300 N...10 kN (E: C) (10...50) kN (E: C) (30...100) kN (E: C) (40...200) kN (C) (0,2...1) MN (C) (1...3) MN (C) (25...300) kN (E) (0,3...1) MN (E)	5×10^{-5} 1×10^{-4} 5×10^{-5} 7×10^{-4} $1{,}2 \times 10^{-3}$ 7×10^{-5} $1{,}6 \times 10^{-3}$ $0{,}9 \times 10^{-3}$
Torque (static)	(0...6) kN·m (0...6) daN·m	$0{,}5 \times 10^{-3}$ 2×10^{-3}
Brinell hardness, scales: B 10/3000 B 15/750 B 2,5/187,5	≤ 450 HB	$0{,}5 \times 10^{-3}$
Rockwell hardness Scales A, C	(20...93) HR A (20...70) HR C	0,3 HR 0,3 HR
Scales B, F, G	(20...100) HR B 960...113) HR F (10...90) HR G	0,3 HR 0,3 HR 0,3 HR
Scales 15 N, 30 N, 45 N	(70...94) HR 15 N (42...86) HR 30 N (20...77) HR 45 N	0,3 HR 0,3 HR 0,3 HR
Vickers hardness Scales V 02; V 0,5; V 1; V 2; V 3; V 5; V 10; V 20: V 50; V 100	≤ 1200 HV	$0{,}5 \times 10^{-2}$
Scales K 02; K 05; K 1	≤ 1200 HV	$0{,}5 \times 10^{-2}$

C = compression; E = extension

4 NEW DEVELOPMENTS

An outstanding achievement in the field of force standards and calibration is the 32 MN force machine [1], built at ICMET-Craiova, Romania, in cooperation with PTB, Germany. This is one of the world's largest calibration facilities for high value force transducers, the only similar equipment in Europe belonging to NPL, Teddington, UK.

The 32 MN force machine is based on the "build-up" principle. Its main parts are three identical dynamometers, with axes placed along the corners of an equal-arm triangle. The dynamometers are individually calibrated. A dedicated software has been prepared for controlling the whole process, in order to minimize hysteresis and other disturbing effects. The overall uncertainty of the equipment is presently of the order of 0,1 %, a figure of 0,05 % being foreseen for the near future.

Table 2 shows the main force standards for high value forces, existing in the world.

Table 2.

Principle	Maximum force value	Laboratory
Dead weight machines	2 MN 4,4 MN	PTB, Berlin NIST, Washington
Lever amplification	2,4 MN	EAMG, Wobern, Swiss
Hydraulic amplification	5 MN 5 MN 5,5 MN 6 MN 10 MN 16,5 MN 32 MN	BEV, Vienna NPL, Teddington NRLM, Tokyo PTB, Braunschweig PTB, Berlin PTB, Braunschweig NPL, Teddington
"Build-up" techniques	6 MN 6 MN 32 MN	SPM, Boras, Sweden NMI, Delft, Netherlands ICMET, Craiova, Romania

5 COMPARATIVE STUDIES

The Timisoara branch of the Romanian National Metrology Institute (INM) has recently performed [2] an interesting comparative analysis of a number of samples of load cells, manufactured by seven well-known European companies (such as Hottinger, Flintab, Mettler-Toledo, Philips, Pfister, a.o.) and a Romanian one, having accuracy classes between 0,01 and 0,25. As the principal quality index of the tested load cells their "accuracy reserve" was chosen, expressed in terms of the maximum measured error of the cell under test and the permissible error limit according to its accuracy class, with the formula:

$$\text{accuracy reserve} = (\text{error limit} - \text{max. error}) / (\text{error limit}) \times 100\ \%$$

For example, if a load cell has the accuracy class 0,2 and the maximum error measured was 0,14 %, the accuracy reserve is $(0{,}2 - 0{,}14) / (0{,}2) \times 100 = 30\ \%$.

The study was extended by taking separately into account the non-linearity, repeatability and hysteresis effects, calculating finally the average values of the errors as well.

The study undertaken has revealed some unexpected aspects, and also led to valuable suggestions for the future pattern test procedures of force transducers.

6 SERVICES PROVIDED

The National Metrology Institute of Romania (INM), as well as a number among the fourteen regional calibration laboratories of the Romanian Bureau of Metrology, offer calibration services in the area of force, torque and hardness measuring instruments. Traceability of these calibrations is assured by relating them to the Romanian national standards, which in turn are regularly compared to the standards of other countries, mainly those of Germany.

Calibrations have been carried out not only for industrial and other enterprises from Romania, but also for several foreign companies, mostly from Turkey, Bulgaria, Yugoslavia, Moldova.

The Romanian INM also offers training courses and workshops in the field of force and hardness measurements and standards.

Concerning the hardness standards, the Timisoara laboratory of INM - in cooperation with a local metallurgical factory - has developed a complete technology of the manufacturing of reference hardness plates, presently being in the position of offering a full range of Rockwell, Vickers and Brinell hardness plates, with warranty and calibration certificates.

Table 3 shows examples of reference hardness plates that are manufactured by the Timisoara branch of the Romanian INM. Other scales and hardness ranges are possible as well, upon request.

Table 3.

Method	Scale	Hardness range
VICKERS	V_1	250±50; 500±50; 750±50
VICKERS	V_5	250±50; 500±50; 750±50
VICKERS	V_{10}	250±50; 500±50; 750±50
VICKERS	V_{30}	250±50; 500±50; 750±50
VICKERS	V_{50}	250±50; 500±50; 750±50
BRINELL	10/3000	150±30; 250±30; 350±30; 450±30
BRINELL	5/750	150±30; 250±30; 350±30; 450±30
BRINELL	2,5/187,5	150±30; 250±30; 350±30; 450±30
ROCKWELL	A	40±5; 60±5; 80±5
ROCKWELL	B	60±5; 75±5; 90±5
ROCKWELL	C	25±5; 35±5; 45±5; 55±5; 65±5
ROCKWELL	15N	70±3; 80±3; 90±3
ROCKWELL	30N	40±3; 60±3; 80±3
ROCKWELL	45N	20±3; 40±3; 70±3
ROCKWELL	15T	80±3; 85±3; 90±3
ROCKWELL	30T	60±3; 70±3; 80±3
ROCKWELL	45T	35±3; 50±3; 70±3

7 OTHER ACTIVITIES

The Romanian Association of Tensometry (ARTENS) is particularly active in the area of force, mass and torque measurement, having committees and territorial branches throughout the country (see figure 2). ARTENS organizes national symposia with international participation, the papers presented within the "Transducers" Section having a good percentage. The next meeting will be held in May 2000, in Bucharest (all of you are kindly invited to participate !).

Table 4 shows a list of the national symposia on strain gauge techniques organized by ARTENS.

Table 4.

Edition	Place	Period	Papers in Transducers Session
I	Iasi	April 25-28, 1977	30
II	Cluj-Napoca	June 11-14, 1980	53
III	Timisoara	Sept. 28-Oct .1, 1983	30
IV	Brasov	Sept. 24-27, 1986	40
V	Galati	Sept. 20-23, 1989	37
VI	Craiova	Sept. 24-25, 1992	39
VII	Suceava	Oct. 17-19, 1996	40
VIII	Bucuresti	May, 2000	40

One of the authors is for over 10 years a member of the Technical Committee No 3 of IMEKO as well as member of SEM and VDE. In 1986 he sent his first paper to an IMEKO Conference on force measurement [3] and in 1988 he represented Romania at the Golden Jubilee of Strain Gauges in Texas [4]. Other theoretical and practical issues in the force measurement field, illustrated by a selective reference list [5-10], include the optimization of axisymmetrical elastic elements shape for force transducers, and establishment of the optimum strain gauges positions on four of the analysed sections.

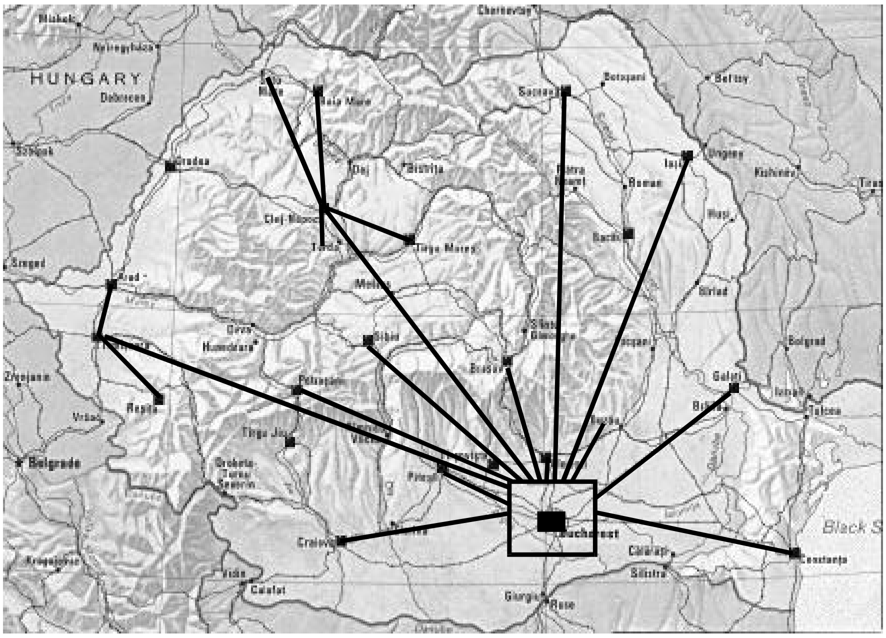

Figure 2. Territorial organization of the Romanian Tensometry Association (ARTENS)

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