TRACEABILITY AND CAPABILITY CONTROL OF MASS MEASUREMENT EQUIPMENT AND DRIFT STATISTICAL ANALYSIS OF NATIONAL MASS STANDARDS IN LATVIA

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Abstract. LNMC is highest metrological institute of Latvia. The paper describes national mass standards currently in use, their traceability, stability, mass measurement equipment and related techniques.

1. INTRODUCTION

Latvian National Metrology Centre (State Agency) is a public organization with legal liability. Its main task is to ensure uniformity of measurement throughout the country and provide metrological services to persons and organizations. LNMC is highest metrological institute of Latvia. Main tasks of State Agency are to maintain uniformity and traceability of physical units, verification and calibration of measuring instruments and standards (weights etc.). Department of mass measurement of State Agency is a holder of national mass standards. These are 1 kg mass standard in stainless steel and two sets of mass standards (from 1 mg to 500 g). Laboratory performs periodic calibration and statistical analysis of mass standards. The Department of mass measurement ensures traceability between national mass standards (with values derived from the International Prototype of the kilogram) and weights of class E_1 and lower. Once in two years national mass standards are carried to DFM (Dansk Fundamental Metrologi, Denmark) or other laboratory for calibration. Department of mass measurement of State Agency has probably the best mass measurement equipment in Latvia, such as “Sartorius” comparator (high-precision mass measurement instrument). ScalesNet32 is the software used for data acquisition and analysis. Computer running ScalesNet32 is connected to both comparator and climate control system of the lab. This equipment allows LNMC to perform calibration of E1 class weights (most accurate ones).

Department of mass measurement of State Agency does participate in various international interlaboratory comparisons schemes: “839 EUROMET”, “EUROMET 786”, “LNMC (Latvia) -METROSERT (Estonia) - MIKES (Finland)”, “832 EUROMET” and others.

Tab. 1. Interlaboratory comparisons of LNMC

Project Id	**Year**	**Description**	**Standard, range**	**Framework reference number**
510 EUROMET. M.M-K4	15.04.2002.- 02.05.2002.	Comparison of mass standards	Standard (Stainless steel) **1 kg**	European metrology programme EUROMET 510
445 EUROMET. M.M-K2	27.03.2003.- 21.05.2003.	Comparison of mass standards	A set of standarts (Stainless steel) **10 kg,500 g, 20 g, 2 g, 100 mg**	European metrology programme EUROMET 445
832 EUROMET	14.12.2004.- 17.01.2005.	Comparison of mass standards	Standard (Stainless steel) **50 kg**	EUROMET 832
V/a LNMC (LATVIA) – METROSERT (ESTONIA) –	05.09.2006.	Calibration of non-automatic weighing instruments	1) Mettler-Toledo, AX504, *Max* 510 g, *d*= 0,1 mg 2) Mettler-Toledo, KB50-2, *Max 60* kg, *d*= 0,01 g	VM1-2006
V/a LNMC (LATVIA) – METROSERT (ESTONIA) – MIKES (FINLAND)	09.÷23.11. 2006.	Comparison of mass standards	Standard 500 kg	-
EUROMET 786 (M.M-K2.1)	04.01.2007.- 02.02.2007.	Comparison of mass standards	A set of standards (Stainless steel) **10 kg, 500 g, 20 g, 2 g, 100 mg**	European metrology programme EUROMET 786

At present, the laboratory is planning interlaboratory comparison of mass measurement capability between various Latvian laboratories. Department of mass measurement will be the pilot laboratory of the comparison. Comparisons like this have never been carried out before. This comparison will be first such project in Latvia. We have to adapt existing methods and procedures for our needs or develop new ones. Major complication is that there is strong competition between some of participants. However, small size of Latvia makes transfer of standards less complex and expensive task. Interlaboratory comparisons allow laboratories to validate measurement capability, identify and correct measurement errors, assess technical proficiency and calibration procedures, verify adequacy of laboratory environment, provide evidence of measurement traceability and demonstrate measurement comparability between laboratories.

2. TRACEABILITY OF MEASUREMENTS

The international definition of 'traceability' is: *property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.* As said above, mass is unique amongst the base quantities of the SI because its unit definition, the kilogram, is based on a physical artifact; a cylinder of platinum iridium alloy, held at the Bureau International des Poids et Measures BIPM near Paris, is defined as being exactly one kilogram in mass. All mass measurements undertaken in the World should be traceable to this single artefact – the international prototype of the kilogram (known as K – see history of the kilogram) – and this is achieved by regularly comparing its mass with the official 'copies' of the Kilogram held in national measurement institutes, such as NPL.

2.1. Elements of traceability

Traceability is characterized by a number of essential elements: an unbroken chain of comparisons going back to a standard acceptable to the parties, usually a national or international standard; measurement uncertainty; the measurement uncertainty for each step in the traceability chain must be calculated according to defined methods and must be stated so that an overall uncertainty for the whole chain may be calculated; documentation; each step in the chain must be performed according to documented and generally acknowledged procedures; the results must equally be documented; competence; the laboratories or bodies performing one or more steps in the chain must supply evidence for their technical competence (e.g. by demonstrating that they are accredited); reference to SI units; the "appropriate" standards must be primary standards for the realization of the SI units; recalibrations; calibrations must be repeated at appropriate intervals; the length of these intervals depends on a number of variables, (e.g. uncertainty required, frequency of use, way of use, stability of the equipment).

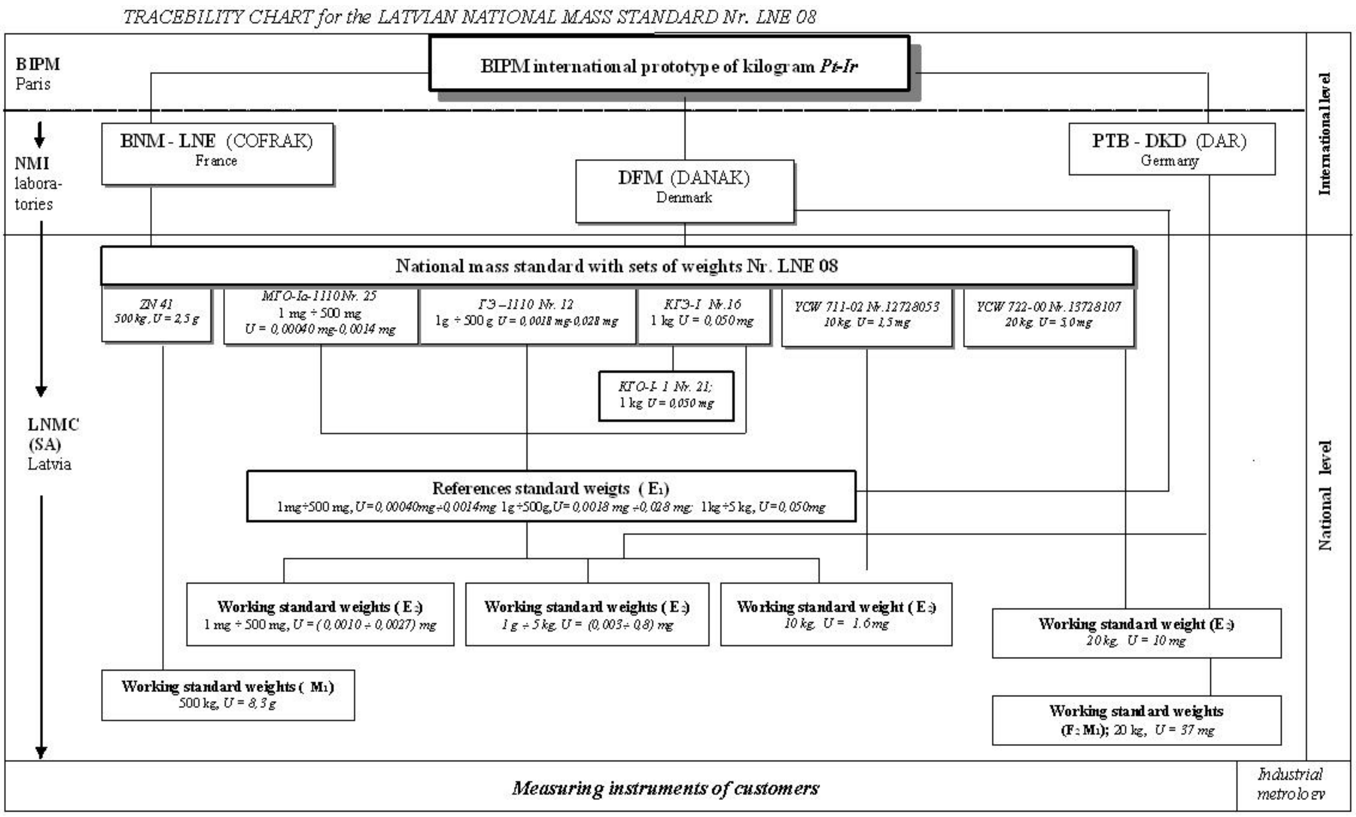

Fig. 1. Standard calibration procedure

At the international level, decisions concerning the International System of Units (SI) and the realization of the primary standards are taken by the Conférence Générale des Poids et Mesures (CGPM). The Bureau International des Poids et Mesures (BIPM) is in charge with coordinating the development and maintenance of primary standards and organizes intercomparisons on the highest level.

The National Metrology Institutes are the highest authorities in metrology in almost all countries. In most cases they maintain the "national standards" of the country which are the sources of traceability for the associated physical quantity in that country. If the National Metrology Institute has facilities to realize the corresponding SI unit of measurement (the term SI units includes all derived units), the national standard is identical to or directly traceable to the primary standard realizing the unit. If the Institute does not have this facility, it has to ensure that the measurements are traceable to a primary standard maintained in another country. The National Metrology Institutes ensure that the primary standards themselves are internationally comparable. They are responsible for disseminating the units of measurement to users. They are the top level of the calibration hierarchy in a country.

Department of mass measurement of LNMC (SA) is a holder of national mass standards. These are 1 kg mass standard in stainless steel and two sets of mass standards (from 1 mg to 500 g). Laboratory performs periodic calibration and statistical analysis of mass standards. This ensures traceability between Latvian national mass standards (with values derived from the International Prototype of the kilogram) and weights of class E1 and lower. Once in two years national mass standards are carried to DFM (Dansk Fundamental Metrology, Denmark) or other laboratory for calibration.

2.2. Weighing cycles

In the weighing cycles, *"A'* represents weighing the reference weight and *"B"* represents weighing the reference weighing the test weight. The cycles *ABBA* and *ABA* are normally used when calibrating E and F class weights. The cycle $AB_1 \ldots B_nA$ is often used when calibrating M class weights, but generally not recommended for E and F class weights. If, however, a mass comparator with an automatic weight exchange mechanism is used and if the system is installed in a protecting housing, this cycle can also be accepted for class E and F weights calibrations. Only cycles ABBA and ABA are useful in subdivision weighing. More than one reference weight can be used; in this case the weighing cycles can be applied for each reference weight separately; the reference weights may then be compared against one another.

Tab. 2. Minimum number of weighing cycles

Class	E_1	E_2	F_1	F_2	M_1, M_2, M_3
Minimum number of *ABBA*	3	2	1	1	1
Minimum number of *ABA*	5	3	2	1	1
Minimum number of $AB_1 \ldots B_nA$	5	3	2	1	1

2.3. Data analysis

Average difference of conventional mass – One test weight. For cycles *ABBA* and *ABA*, the conventional mass difference, Δm_c, between the test weight and the reference weight of a cycle, I, is:

$$\Delta m_c = m_{ct} - m_{cr} \tag{1}$$

$$\Delta m_{ci} = \Delta I_i + m_{cr} \cdot C_i \tag{2}$$

where

$$C_i = (\rho_{ai} - \rho_0) \cdot (\frac{1}{\rho_t} - \frac{1}{\rho_r})$$

The average difference of conventional mass for n cycles is:

$$\overline{\Delta m_c} = \frac{1}{n} \sum_{i=1}^{n} \Delta m_{ci} \tag{3}$$

If the density ρ_t or ρ_r of a weight is not known, but the material is known, the appropriate assumed density from mean value of hand-book should be used. If it is only known that the density of a weight is within the allowed limits then the value 8000 $kg \cdot m^{-3}$ should be used. In cases where air buoyancy correction is estimated to be negligible, i.e., if the term $m_0 \cdot C_i$ can be omitted.

$$|C_i| \le \frac{1}{3} \cdot \frac{U}{m_0} \tag{4}$$

If only one or an averaged value of the air density is available, the buoyancy correction $m_{cr} \cdot C$ can be applied after averaging.

Average difference of conventional mass – Several test weights. If several test weights are calibrated according to weighing cycle $AB_1 \ldots B_nA$, the average mass difference for weight *k* is obtained from equation (3) by replacing ΔI_i with $\Delta I_{i(k)}$ in equation (2).

Average difference of conventional mass – Several series of measurements. If there are several (J) identical series of measurements with average values $\overline{\Delta m_j}$ and with approximately equal standard deviations the average value of all measurements is:

$$\overline{\Delta m_c} = \frac{1}{J} \cdot \sum_{j=1}^{J} \overline{\Delta m_{cj}} \tag{5}$$

Several series of measurements are usually performed only in calibration of class E weights, when the reproducibility of weighing has to be investigated.

Conventional mass of the test weight. The conventional mass of the test weight can be calculated from the formula:

$$m_{ct} = m_{cr} + \overline{\Delta m_c} \tag{6}$$

In verification, the conventional mass of the reference weight is not always known. In these case, its nominal value should be used.

The standard uncertainty $u(m_{cr})$, of the mass of the reference weight should be calculated from the calibration certificate by deviling the quoted expanded uncertainty, U, by the coverage factor k (usually k=2) and should be combined with the uncertainty due to the instability of the mass of the reference weight, $u(m_{cr})$.

$$u(m_{cr}) = \sqrt{(\frac{U}{2})^2 + u_s^2(m_{cr})} \quad (7)$$

The uncertainty due to instability of the reference weight, $u_s(m_{cr})$, can be estimated from observed mass changes after the reference weight has been calibrated several times.

The uncertainty of air buoyancy correction can be calculated from

$$u_b^2 = \left[m_{cr} \cdot \frac{(\rho_r - \rho_t)}{\rho_r \cdot \rho_t} \cdot u_{\rho_a} \right] \quad (8)$$

Where ρ_a is the air density during the (previous) calibration of the reference weight by use of a higher order reference weight. When using equation (8) be sure to use the same value for the uncertainty of the density of the reference weight $u(\rho_\gamma)$, that was used in the uncertainty calculation of the previous calibration. If the air density is not measured and the average air density for the site is used, than the uncertainty for the air density is to be estimated as:

$$u(\rho_a) = \frac{0,12}{\sqrt{3}} \left[kg \cdot m^{-3} \right] \quad (9)$$

At sea level the density of air should be assumed to be 1,2 $kg \cdot m^{-3}$.

Uncertainty of the balance u_{ba}**.** The recommended approach to determine this component is to test the balance and mass comparators at reasonable time intervals and use the results from the test in the uncertainty calculations. If the balance is calibrated with a sensitivity weight (or weights) of mass m_s, and of standard uncertainty $u(m_s)$, the uncertainty contribution due to sensitivity is

$$u_S^2 = (\overline{\Delta m_c})^2 \cdot (\frac{u^2(m_S)}{m_S^2} + \frac{u^2(\Delta I_S)}{\Delta I_S^2}) \quad (10)$$

Where ΔI_S is the change in the indication of the balance due to the sensitivity weight; $u(\Delta I_S)$ is the uncertainty of ΔI_S; and, $\overline{\Delta m_c}$ is the average mass difference between the test weight and the reference weight. If the sensitivity is not constant with time, temperature, and load, its variation must be included in the uncertainty. If the weight does not have the form of a perfect cylinder, then additional corrections or an expanded uncertainty may be required. For a digital balance with the scale interval d, the uncertainty due to resolution is

$$u_d = (\frac{d/2}{\sqrt{3}}) \cdot \sqrt{2} \quad (11)$$

The factor $\sqrt{2}$ comes from the two readings, one with the reference weight and one with the test weight.

Uncertainty due to eccentric loading u_E**.** If this contribution is known to be significant, the magnitude must be estimated and if necessary the contribution must be included in the uncertainty budget.

$$u_E = \frac{(d_1 / d_2) \cdot D}{2 \cdot \sqrt{3}} \quad (12)$$

Where D is the difference between maximum and minimum values from the eccentricity test performed according to OIML R 72-6; d_1 is the estimated distance between the centres of the weights, and d_2 is the distance from the centre of the load receptor to one of the corners. In most cases, the uncertainty contribution u_E is already covered by the uncertainty u_w of the weighing process and may be neglected. When using balances with automatic weight exchange mechanism, the indication difference ΔI, between two weights may be different when the positions are interchanged: $\Delta I_1 \neq \Delta I_2$. This may be interpreted as an eccentric loading error and the corresponding uncertainty should be estimated using equation (13). This uncertainty contribution is applicable, if it is known from previous interchanging measurements with weights of the same nominal value. In case that the interchange is performed during a calibration procedure, the average of the two indication differences shall be taken as the weighing results and u_E can be neglected.

$$u_E = \frac{\left| \Delta I_1 - \Delta I_2 \right|}{\sqrt{3}} \quad (13)$$

Combined standard uncertainty of the balance u_{ba}**.** The uncertainty components are added quadratic ally as follows:

$$u_{ba} = \sqrt{u_S^2 + u_d^2 + u_E^2 + u_{ma}^2} \quad (14)$$

Expanded uncertainty $U(m_t)$**.** The combined standard uncertainty of the conventional mass of the test weight is given by:

$$u_c(m_t) = \sqrt{u_w^2(\overline{\Delta m_c}) + u^2(m_{cr}) + u_b^2 + u_{ba}^2} \quad (15)$$

The expanded uncertainty U, of the conventional mass of the test weight is as follows:

$$U(m_t) = k \cdot u_c(m_t) \quad (16)$$

Where the coverage factor k = 2, should be used.

Tab. 3 - 6. Instability analysis of national mass standards

Type of weights ***МГО – I a – 1110*** No ***25*** *(1 mg-500 mg)* *1989 -2006 years*

No.	**Nominal value of the weights,** m_N ***mg***	$\overline{\Delta m_D}$ ***mg***	**E_1** ***mpe*** ***(OIML R 111)*** ***mg***	**Drift** $u_S(\overline{\Delta m_D})$ ***mg***
1.	**1**	**-0,00003**	0,003	0,000017
2.	**2**	**0,00003**	0,003	0,000017
3.	**2***	**0,00008**	0,003	0,000046
4.	**5**	**0,00003**	0,003	0,000017
5.	**10**	**0,00006**	0,003	0,000035
6.	**20**	**-0,00002**	0,003	0,000012
7.	**20***	**0,00008**	0,003	0,000046
8.	**50**	**0,00010**	0,004	0,000058
9.	**100**	**0,00005**	0,005	0,000029
10.	**200**	**0,00015**	0,006	0,000087
11.	**200***	**0,00008**	0,006	0,000046
12.	**500**	**0,00033**	0,008	0,000191

Type of weights ***ГЭ - 1110*** No ***12*** *(1 g-500 g)* *1989 -2006 years*

		mg	***mg***	***mg***
1	**1**	**-0,00031**	0,010	0,000179
2	**2**	**-0,00038**	0,012	0,000219
3	**2***	**-0,00027**	0,012	0,000156
4	**5**	**-0,00027**	0,016	0,000156
5	**10**	**-0,00029**	0,020	0,000167
6	**20**	**-0,00031**	0,025	0,000179
7	**20***	**-0,00062**	0,025	0,000358
8	**50**	**-0,00107**	0,030	0,000618
9.	**100**	**-0,00280**	0,05	0,001617
10.	**200**	**-0,00495**	0,10	0,002858
11.	**200***	**-0,00359**	0,10	0,002073
12.	**500**	**-0,00793**	0,25	0,004578

Type of weights ***КГЭ - 1*** No ***16*** *(1 kg)* *1985 -2006 years*

No	**Nominal value of the weights,** m_N ***кg***	$\overline{\Delta m_D}$ ***mg***	**E_1** *mpe* *(OIML R 111)* ***mg***	**Drift** $u_S(\overline{\Delta m_D})$ ***mg***
1.	**1**	0,00677	0,5	0,003909

Type of weights ***КГО – I -1*** No ***21*** *(1 kg)* *1984 -2006 years*

No	**Nominal value of the weights,** m_N ***кg***	$\overline{\Delta m_D}$ ***mg***	**E_1** *mpe* *(OIML R 111)* ***mg***	**Drift** $u_S(\overline{\Delta m_D})$ ***mg***
1.	**1**	0,01707	0,5	0,009855

Remark: Where m_N is nominal value of the weights, m_c – conventional mass of the weights, $U(m_c)$ – expanded uncertainty of the conventional mass of the test weigh, $u_s(\overline{\Delta m_D})$ – drift (instability of the test weight)

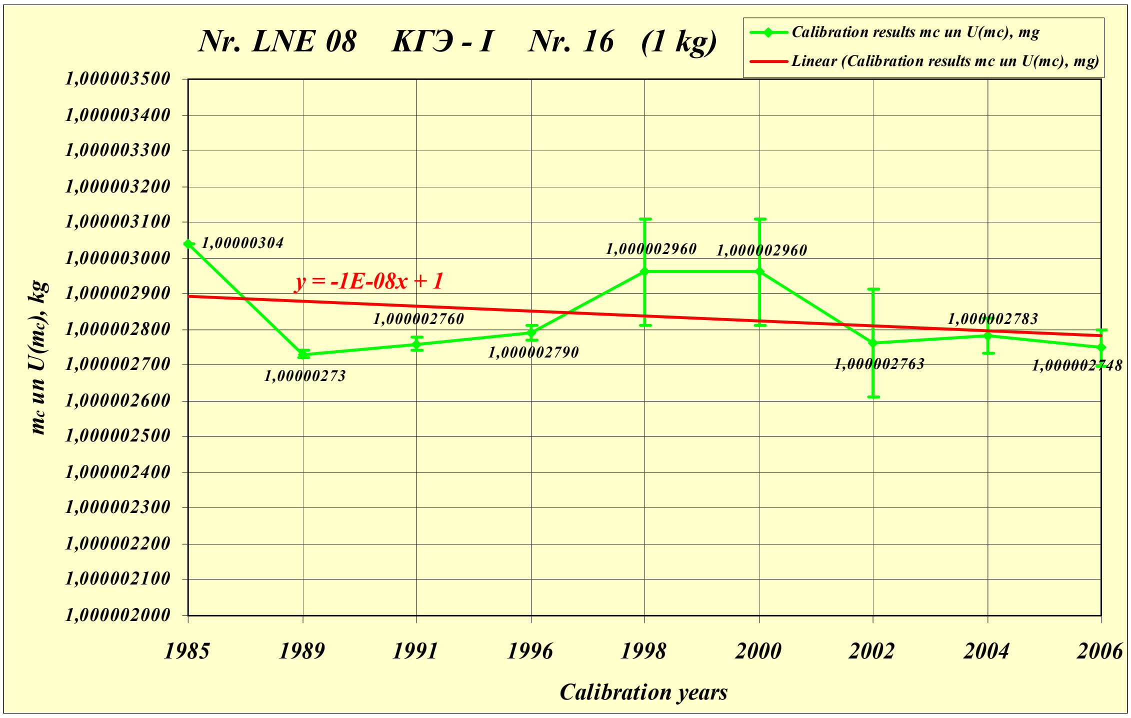

Fig. 2. Calibration results of national standards and approximation

Measurement equipment of Department of mass measurement of State Agency. Department of mass measurement of State Agency has probably the best mass measurement equipment in Latvia (Table 7), such as “Sartorius” comparator (high-precision mass measurement instrument). ScalesNet32 (Figure 3) is the software used for data acquisition and analysis. Computer running ScalesNet32 is connected to both comparator and climate control system of the lab. This equipment allows LNMC to perform calibration of E1 class weights (most accurate ones).

Tab. 7. Mass comparators and balances in Department of mass measurement of State Agency

Mass comparators				
No.	Type	Manufacturer / Productions year	Calibrations weights	
1.	**CC 6**	“Sartorius” Germany, 2003	**E1 ;E2 ;F1 ;F2**	*1 mg ÷ 5 g*
2.	**CC 50**		**E1**	*500 mg ÷ 50 g*
			E2 ;F1 ;F2	*1 mg ÷ 50 g*
3.	**CC 1 000 S-L**		**E1 ;E2 ;F1**	*100 g ÷ 1 kg*
4.	**CC 10 000 U-L**		**E1 ;E2 ;F1**	*1 kg ÷ 10 kg*
5.	**CC 50 002**		**E2**	*20 kg ÷ 50 kg*
			F1	*10 kg ÷ 50 kg*
			F2	*5 kg ÷ 50 kg*
			M1	*1 kg ÷ 50 kg*
6.	**KC 600 sHR**	Mettler-Toledo”, Sweden - MSE Systems, Germany, 2003	**M1**	*100 kg, 200 kg ÷ 500 kg*
7.	**CCS 3 000 K**	“Sartorius” Germany, 2006	**M1**	*2 t ÷ 3 t*
Balances				
No.	Type	Manufacturer / Productions year	Calibrations weights	
8.	**ВЛО-200g-Ia**	«Госметр», Russia, 1968		*50 g ÷ 200 g*
9.	**ВЛО-200g-I**	«Госметр», Russia, 1978		*50 g ÷ 200 g*
10.	**ВЛО-1kg-I**	«Прибор», Ukraine, 1988		*200 g ÷ 1 kg*
11.	**ВЛО-5kg-I**	«Госметр», Russia, 1975		*500 g ÷ 5 kg*
12.	**ВЛО-20kg-II**	“Etalon”, Latvia, 1955		*5 kg ÷ 20 kg*

ScalesNet32 fulfils the requirement of a quality management system, regulated by national standards. Calibration of weights always relates to a project or a customer, serial number and type of the weights, and others essential parameters, creating a unique description of the test object. The weight date is saved in a database, assuring the availability of the weights history at all times. The balances used for testing user supplied weights are calibrated in predefined intervals. These calibration data is recorded in the database. ScalesNet32 controls the used reference weights and climate stations with a set of connected sensors. The software will inform the user of *necessary routine* calibrations of the reference weights used for testing. The calibration intervals for the balances and reference weights are entered into the system by the user. The following modules are available: calibration of customer weights; external calibration of customer weights; calibration of reference weights; calibration of weights with dissemination of mass scale; quick calibration of weights; calibration of weights with row data output; manual input of weighing data; calibration of Balance; Collection of environment data.

Most important features of Scales Net

- Centralized SQL Database to record all measurements and data;
- Auto-read of process data via a Balance-port. Port parameter can be configured according to the specifications of the scales manufacturer;
- Automatic measurement of the labs environmental parameters during weighing cycles;
- Adjustment of weighing cycles and measurement profiles (ABBA or ABA) in classes;
- Selection of classes according to OIML R111, ASTIM 617, or other national standards;
- Simultaneous testing of weights, belonging to one set of weights, using different Comparators in a Laboratory environment;
- Plausibility test for reference weights and balance (testing if selection of weights and balance matches pre-defined classes);
- Each tested weight is provided with a test certificate, recording all test results (reference weights and balance used, temperature, humidity, air pressure, etc.);
- Optional history report for each tested weight;
- User definable Word templates to create calibration and/or test protocols, or DKD protocols. Data to be represented will be positioned via text markers within the word document. During printing the text markers will be replaced by the actual measurement data. DKD protocols can be generated in 2 languages;
- Automatic inventory generation, listing all used balances reference weights.

External System Hardware

- **Scales-Controller**
  Microprocessor controlled terminal to perform all necessary steps of the calibration procedures for weights and test equipment. Connectivity to the ScalesNet32 database is provided via CAN bus.
- **Climate Station**
  Collects all environment data of the laboratory. During a measurement cycle the environment data will be delivered and combined with the actual weighing data. A data logger-converter is needed to convert the environment data into a ScalesNet32 readable format. If a third party system is used instead.

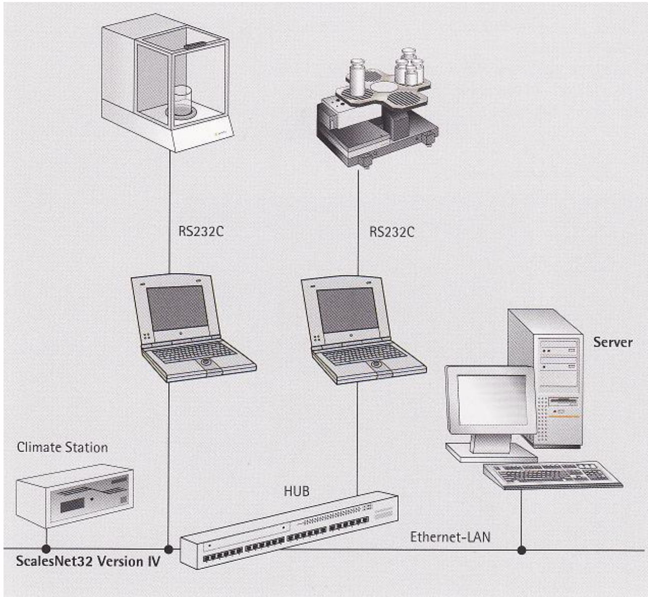

Fig. 3. ScalesNet32

2.4. Mass comparators

Mass determinations of the highest accuracy are carried out with mass comparators. These are used in laboratories high up in the hierarchy of the dissemination of the unit of mass, starting with the international prototype of the kilogram. In particular, the International Bureau of Weights and Measures (BIPM) in Sevres near Paris and the national metrological institutes (NMI) which generally have the national prototypes at their disposal belong to this hierarchy. Mass comparators are based on the compensation principle. This means that the weight force is largely balanced by force acting in the opposite direction. The range of the balance's display is therefore limited, and corresponds to the remaining difference of the weight forces. Only mass standards of the highest quality are used on such balances. Most comparators are based on the principle of the beam balance, where the weight force of a mass standard is compensated by the weight force of a counter weight via a lever. A comparator that works on the hydrostatic weighing principle has been realised, the compensation being effected by the buoyancy in a liquid. In the older beam ba-lances, the knife-edges and bearing blocks form pivots, and in more recent models it is the flexure-strip. Some of these mass comparators were developed in the laboratories of national metrological institutes, and others in workshops with many years experience in the construction of balances. Today, comparators are industrially manufactured that have a standard deviation of up to 10^{-9}. The best comparators in NMI reach up to 5×10^{-12}.

Fig. 4 shows the characteristic quantities of a beam balance in a general two dimensional representation. The axes of rotation are reduced to pivots i.e. assumed to be parallel. The beam's bearing is at point S'; the weight force of its mass m_S acts at its centre of gravity S. The masses m_L and m_G hang at points L and G. The broken line represents the gravitational horizon; the line connecting L and G forms an angle α with the horizon and is divided by the perpendicularly through S' with the length a into the sections l_L, l_G; the lever arm of the balance's centre of gravity with a length l_S forms an angle γ with α. In equilibrium, the torqueses are neutralised. With the gravitational accelerations g_L, g_G and g_S, in the three gravitational centres of the masses, the following is valid:

$$0 = g_L m_L \left[l_L \cos\alpha - a \sin\alpha \right] + g_G m_G \left[l_G \cos(\pi+\alpha) + a \sin(\pi+\alpha) \right] + g_S m_S l_S \sin(\gamma-\alpha) \tag{17}$$

In the following it is assumed that $g = g_L = g_G = g_S$. A change in the mass m_L by dm_L causes an inclination of the beam by $d\alpha$; the *sensitivity* of the balance is therefore defined according to E_q. (17) as follows:

$$d\alpha / dm_L = (l_L \cos\alpha - a \sin\alpha) / (m_L \left[l_L \sin\alpha + a \cos\alpha \right] + m_G \left[l_G \sin(\pi+\alpha) - a \cos(\pi+\alpha) \right] + m_S l_S \cos(\gamma-\alpha)) \tag{18}$$

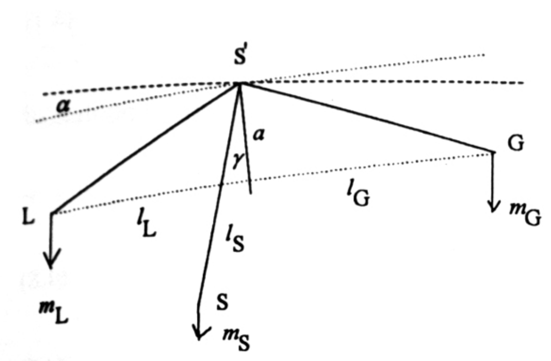

Fig. 4. Beam balance (schematic). S, S' gravitational centre or pivot of the beam; m_S mass of the beam; L, G pivots of the suspensions for the load with a mass m_L and the weights with the mass m_G; a distance between S' and the connecting line LG: l_L, l_G lever lengths of the load and weight arms projected on to LG; l_S lever length of the balance's centre of gravity; α angle of beam's inclination; γ angle between l_S and α.

According to Eq. (18) the balance's sensitivity depends generally on all the parameters.

Case I: $\alpha = 0$ (horizontal position)

$$0 = m_L l_L - m_G l_G + m_S l_S \sin\gamma \tag{19}$$

or:

$$0 = \frac{m_L}{m_G}\frac{l_L}{l_G} - 1 + \frac{m_S}{m_G}\frac{l_S}{l_G}\sin\gamma \tag{20}$$

and

$$\frac{d\alpha}{dm_L} = \frac{l_L}{(m_L + m_G)a + m_S l_S \cos\gamma} \tag{21}$$

From Eq. (20) it is apparent that a change in the arm length ratios l_L/l_G is inversely proportional to the mass ratios m_L/ m_G.

Case II: $a = 0$ and $l = l_L = l_G$ (equal arm lengths):

$$0 = (m_L - m_G)/l + m_S l_S \sin\gamma \tag{22}$$

$$\frac{d\alpha}{dm_L} = \frac{1}{(m_L + m_G)a + m_S l_S \cos\gamma} \tag{23}$$

The sensitivity now depends only on the load $m_L + m_G$ and one the angle γ of the position of the level arm's centre of gravity.

Case III: $\alpha = 0$, $l_L = l_G - l$; and $\gamma = 0$ (symmetrical balance)

$$m_L = m_G = m \tag{24}$$

$$\frac{d\alpha}{dm_L} = \frac{1}{2ma + m_S l_S} \tag{25}$$

The beam of a symmetrical balance is horizontal only if masses m_L and m_G are equal. If the shape of the beam is also symmetrical the centre knife-edge and the two suspensions mounted on the side knife-edges are the same in form and mass, the balance is not sensitive to changes in air pressure and the relative air moisture. However, the sensitivity still depends on the mass m of the load body (see Eq. (25)). This means that if the side knife-edges are lower than the centre one ($a > 0$), the sensitivity decreases with increasing load; if they are higher ($a > 0$), and then the sensitivity increases with the load up to an a where the balance becomes unstable, that is when $2ma + m_S l_S \leq 0$.

Case IV: $\alpha = 0$, $l = l_L = l_G$, $\gamma = 0$ and $a = 0$ (pivots on one level);

$$\frac{d\alpha}{dm_L} = \frac{1}{m_S l_S} \tag{26}$$

In this case the sensitivity is independent of load, depending only on the mass and the position of the centre of gravity.

3. CONCLUSION

The results achieved by National Agency of Metrology are quite acceptable as national standard. Drift and error values are well within requirements for E1 class. The equipment and procedures used by the laboratory allow most accurate and perfectly traceable measurements. Most customers only need F2 or M1. However, some of them require calibration of E1 weights (for example, pharmaceutical industry). The laboratory can satisfy all their needs, at the same time remaining small and effective organisation. This is very important for such a small country like Latvia.

At present, all standards used by the laboratory are being sent for calibration to other laboratories such as DFM (see Fig. 1). In theory, it is possible to have direct traceability to international mass standard. Directly traceable laboratory could provide metrological services to the most demanding customers such as national metrology organizations of other countries and research institutions. However, further improvement is needed to become international laboratory like this. From purely technical point of view, overall design of the building and location of the laboratory must be reconsidered. In urban areas, moving masses (trucks etc.) and ground vibrations may influence results of highly accurate mass measurements. The laboratory should be moved outside the city. The building must be designed with maximum stability in mind.

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