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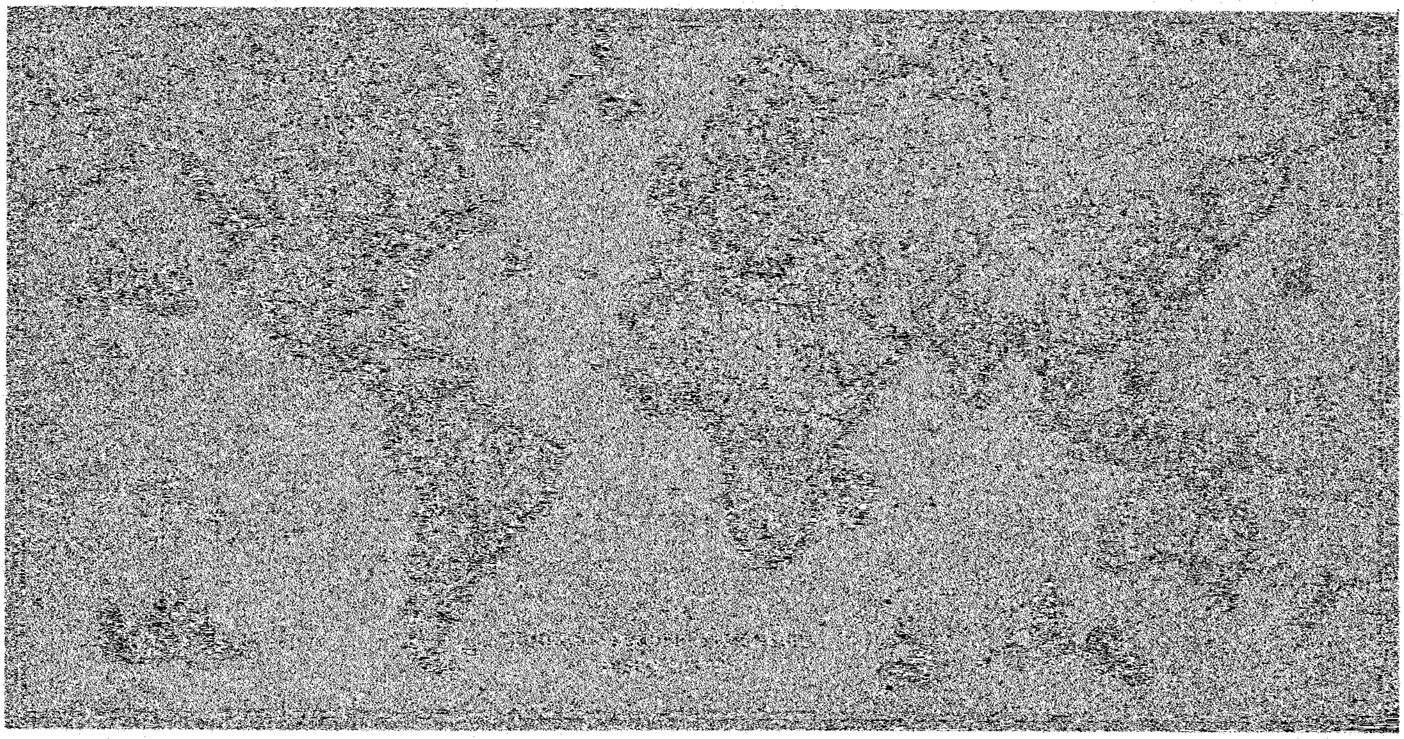

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La MÉTROLOGIE AUJOURD'HUI au PORTUGAL

par **Antónío CRUZ**
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INTRODUCTION — Le Comité International de Métrologie Légale tiendra sa vingt-cinquième session en octobre prochain à Porto. Le choix du lieu de cette réunion, à laquelle assisteront quelque 70 métrologues représentant les 50 Etats Membres de l'OIML, marque la participation toujours croissante du Portugal aux activités internationales et régionales dans le domaine de la métrologie, comme l'ont par exemple déjà montré les réunions EUROMET et WECC tenues dans le courant de 1990. Dans ce contexte, il nous a semblé utile de tenir les lecteurs du Bulletin de l'OIML informés des derniers développements et des projets de développements futurs du système métrologique portugais, étroitement imbriqué au système national de gestion de la qualité.

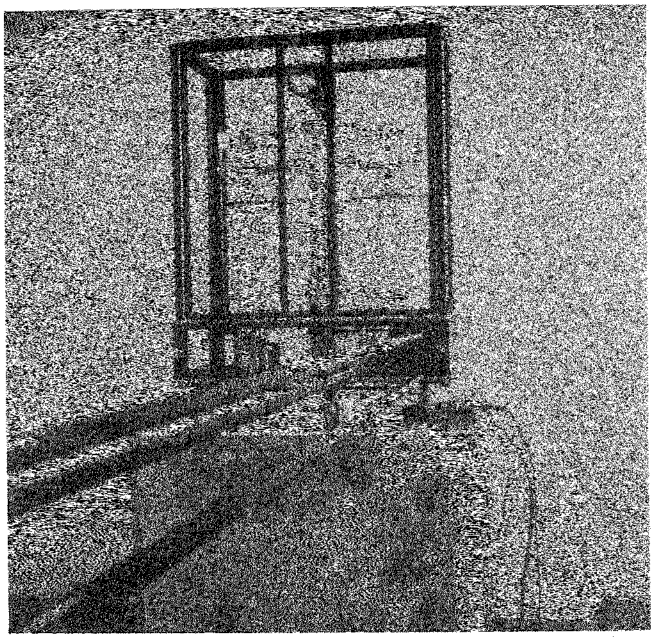
INTRODUCTION — The International Committee of Legal Metrology will meet for the twenty-fifth time in October in Porto. This choice of venue for a meeting to be attended by seventy or so metrologists representing OIML's fifty Member States bears witness to Portugal's ever increasing activity at both regional and international level in the field of metrology, as the meetings of EUROMET and WECC in 1990 have already demonstrated. In such a context it seems appropriate to inform readers of the OIML Bulletin of the latest developments and plans for the future of the Portuguese metrological system, which is closely intermeshed with that of quality control.

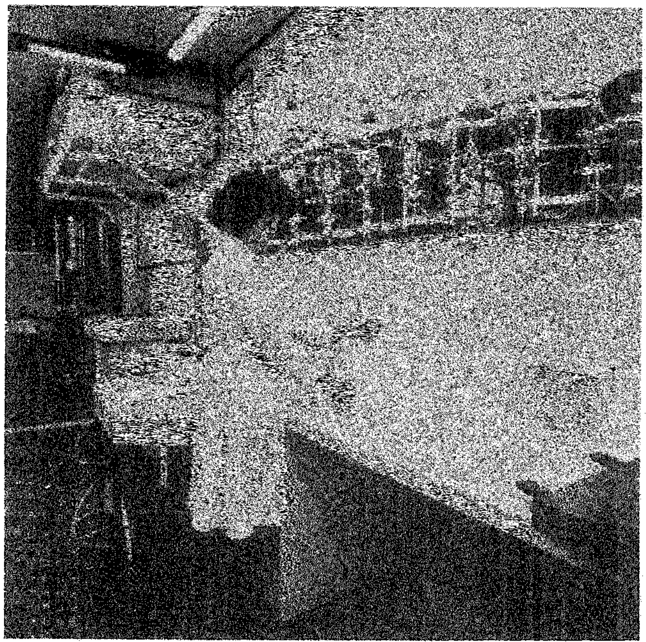
La Qualité

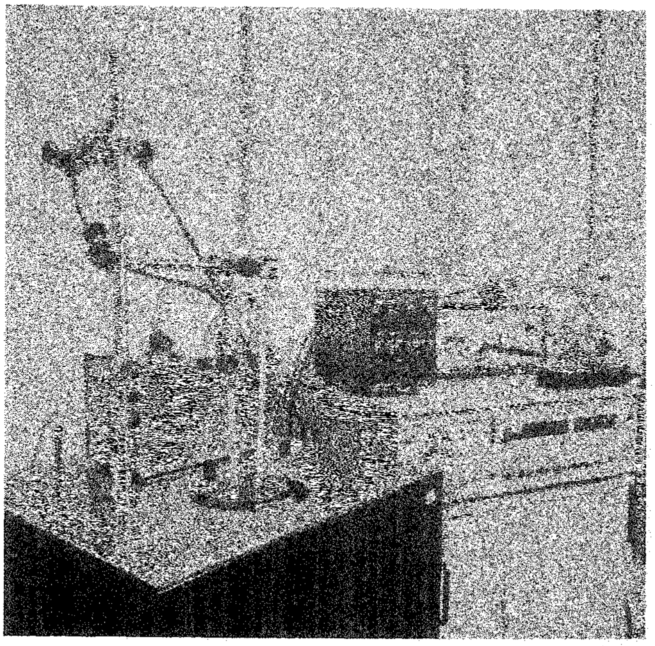
Au Portugal, la métrologie est considérée, depuis 1983, par loi, comme un des moyens fondamentaux de la qualité. En effet, le décret-loi n° 165/83 a créé le Système National de la Gestion de la Qualité (SNGQ) qui institue un système ouvert où toutes les entités intéressées peuvent jouer leur rôle, qu'elles soient publiques ou privées. Le SNGQ est constitué par trois sous-systèmes qui s'occupent respectivement de la métrologie, la normalisation et la qualification. Ce même décret a confié la responsabilité au plus haut niveau, pour tout le système, à un seul organisme du Ministère de l'Industrie et de l'Energie: l'Institut Portugais de la Qualité (IPQ). A chaque sous-système correspond un service opérationnel de l'IPQ.

Faisons d'abord une brève référence aux systèmes de la normalisation et de la qualification. La normalisation, c'est-à-dire l'activité qui concerne l'élaboration des normes nationales, est coordonnée par l'IPQ, bien que la plupart des travaux soient répartis sur plus de trente organismes de normalisation sectoriels. Le sous-système de la qualification s'occupe de l'ensemble des activités relatives à la certification des produits, entreprises et services et aussi l'accréditation des organismes et autres entités. La certification des produits peut aussi être effectuée par des organismes de certification sectoriels par branche d'activité industrielle, mais toujours sous la coordination de l'IPQ au niveau national et après accréditation préalable.

Le SNGQ, en tant que système national qui s'applique à tous les domaines d'activité, dispose d'un Conseil National de la Qualité où tous les ministères participent, mais aussi les syndicats d'industries privées, les confédérations des travailleurs, les associations des consommateurs et autres experts. Ce Conseil a deux réunions par année et dispose de commissions d'appui technique qui s'occupent de chacun des systèmes.







Le Système National de la Métrologie

La métrologie dans son ensemble, c'est-à-dire métrologie scientifique ou fondamentale, métrologie industrielle et métrologie légale, est intégrée dans le SNGQ. A l'IPQ, le Service de la Métrologie s'occupe de la coordination de toute la métrologie portugaise. Le Service possède son propre laboratoire et d'importants développements sont en cours. La création d'un futur Laboratoire Central de Métrologie au sein de l'IPQ va permettre de mieux satisfaire et de répondre aux besoins de l'industrie. Ce laboratoire s'occupera de toutes les activités relatives aux travaux d'étalonnage et d'essais d'approbation de modèle et de l'assurance de la traçabilité des laboratoires industriels d'étalonnage. Ces fonctions, qui sont maintenant remplies par le Service de la Métrologie en utilisant des installations provisoires, seront dans un proche avenir intégrées dans le Laboratoire Central de Métrologie. Ce projet, d'un coût estimé à 35 millions USD, sera terminé en 1993.

Le Contrôle Métrologique

Le Système National de la Métrologie, comme tout le SNGQ, est un système ouvert où toutes les entités publiques ou privées peuvent participer, sauf en ce qui concerne le contrôle métrologique. Cette exception s'achèvera bientôt avec la révision du décret-loi n° 202/83 qui contient les bases générales du système. Ce décret-loi s'applique au contrôle métrologique de tous les instruments de mesure réglementés et est mis en vigueur dans un arrêté général et dans un arrêté spécifique pour chaque catégorie d'instruments. Jusqu'ici ont été publiés des arrêtés spécifiques concernant les taximètres, chronotachygraphes, instruments de pesage, poids, compteurs d'eau, de gaz, de temps et d'électricité, thermomètres médicaux, cinémomètres-radar, pompes à essence et parcmètres. Plusieurs autres instruments sont en train d'être réglementés et il y a encore des dispositions anciennes qui s'appliquent à d'autres instruments comme les manomètres, les mesures de longueur, de volume, etc.

Les entités qui exercent la réparation et l'installation des instruments de mesure doivent être accréditées par le Service suivant une procédure simplifiée semblable à celle appliquée aux laboratoires d'étalonnage.

Les activités de vérification sont exercées par cinq Délégations Régionales du Ministère de l'Industrie et de l'Energie, qui disposent de leurs propres laboratoires avec des installations provisoires et qui reçoivent pour le rééquipement un support financier de l'IPQ. Cinq projets de bâtiments pour des nouveaux laboratoires régionaux sont aussi en développement. Il y a encore 250 vérificateurs qui dépendent des autorités locales et dont les activités sont coordonnées par les laboratoires régionaux. Ces agents s'occupent essentiellement des balances et des poids du commerce. Le Service de la Métrologie de l'IPQ effectue une coordination nationale des travaux des régions par des réunions bimensuelles, chaque fois dans une région différente, et des visites techniques. Un séminaire national pour les régions se tient tous les deux ans ainsi que des cours annuels et des séminaires pour les agents locaux.

La Métrologie Industrielle

L'activité d'accréditation des laboratoires d'étalonnage, comme de tous les autres laboratoires d'essais, est développée par l'IPQ au Service de la Certification. L'ensemble des laboratoires accrédités constitue le Service d'Etalonnage National dont le responsable est le Directeur du Service de la Métrologie de l'IPQ. A présent, le Service d'Etalonnage est un nouveau-né avec six laboratoires accrédités. Plusieurs autres sont en projet. La traçabilité de ces laboratoires est en plusieurs domaines encore réalisée par des liaisons avec des laboratoires nationaux d'autres pays, parce qu'il n'y a pas encore de moyens appropriés dans les laboratoires de l'IPQ ou d'autres institutions nationales. Dans le domaine de la métrologie industrielle, le Laboratoire Central de Métrologie (actuellement en projet) s'occupera surtout des étalonnages aux plus hauts niveaux. Le Service de la Métrologie coopère avec le Service de la Certification dans ses activités d'accréditation.

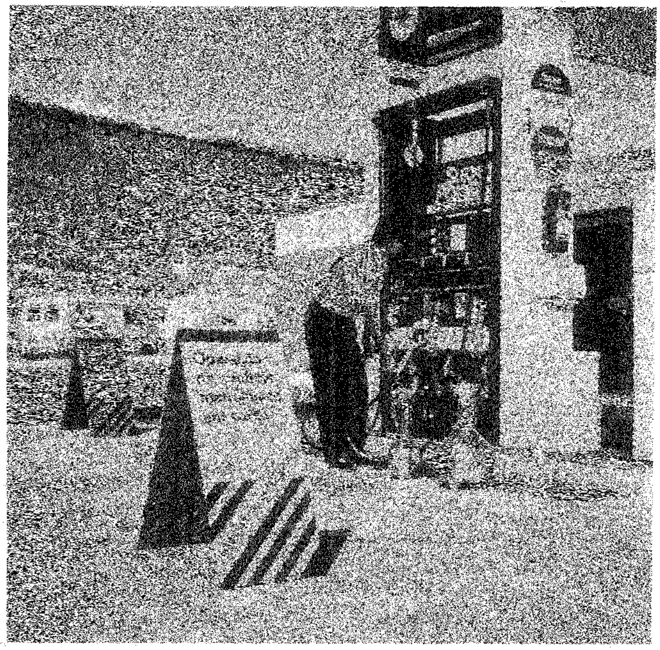
Les Etalons Nationaux

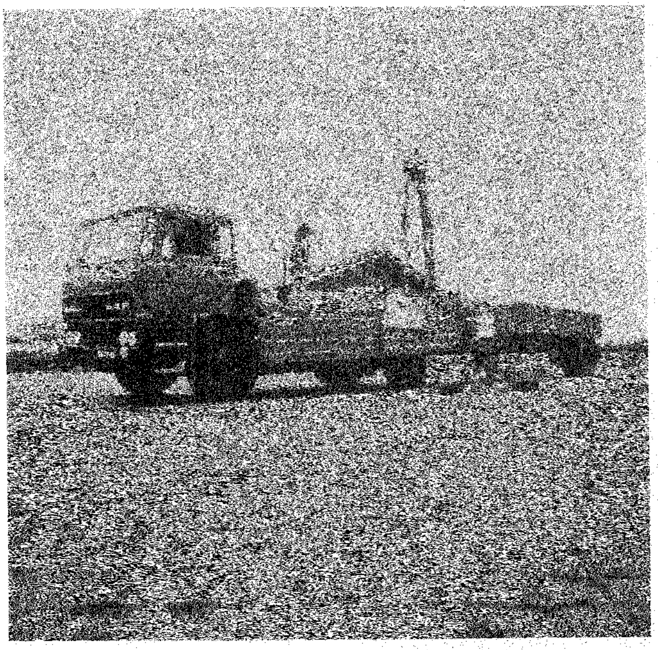
La métrologie scientifique ou fondamentale exercée ou coordonnée par l'IPQ est à présent réalisée par plusieurs laboratoires, y compris ceux de l'IPQ dans le Service de la Métrologie. Celui-ci s'occupe actuellement des grandeurs : longueur, masse, fréquence, température, pression et volume. Il y a des équipements qui, en raison de leurs caractéristiques et dimensions, ne sont pas disponibles dans les installations provisoires de l'IPQ mais dans des installations de l'industrie. Les domaines de l'acoustique, de l'électricité et des radiations ionisantes sont à présent développés dans d'autres laboratoires d'Etat qui ont accepté de collaborer avec l'IPQ dans ces domaines. Des accords spécifiques ont été signés et un très grand support financier est consenti par l'IPQ à ces institutions pour le développement des étalons nationaux exclusivement. Le futur Laboratoire Central de Métrologie développera les moyens actuels de l'IPQ et de son Service de la Métrologie dans les domaines traditionnels et autres, et regroupera des moyens qui sont à présent en d'autres locaux. Toutefois, il n'est pas envisagé de couvrir tous les domaines de la métrologie et certains domaines continueront sans doute d'être décentralisés chez d'autres institutions nationales, avec l'aide de l'IPQ en ce qui concerne les étalons nationaux.

Les Relations Internationales

Le Portugal a repris ses relations internationales dans le domaine de la métrologie dans les années 80, sauf pour le BIPM avec qui les relations ont toujours été maintenues depuis la signature de la Convention du Mètre en 1875.

Le Portugal est ainsi devenu Etat-membre de l'OIML par décret de 1985 et participe depuis 1986 aux travaux de WECC (Western European Calibration Cooperation) dont il assure actuellement la Présidence du Comité. Il participe également, depuis leurs débuts, à EUROMET et à WELMEC (Western European Legal Metrology Cooperation).





REP. FED. D'ALLEMAGNE

PLANNING and EQUIPPING LABORATORIES for ELECTRICAL METROLOGY *

by **H. BACHMAIR**

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SUMMARY — Planning and equipping of an electrical standards laboratory should be guided by the needs of the respective country and the services presumed to be rendered. Precision measurements require stable and reproducible environmental conditions inside the laboratory. These are discussed in the first part of this paper.

The second part deals with the state of the art of some very important electrical quantities. A basic description is given of the measuring methods, standards and other equipment required for measurement of DC voltage and resistance and for AC/DC transfer. The article also indicates the best expected uncertainties of such measurements.

RESUME — La planification et l'équipement d'un laboratoire d'étalons électriques doivent être orientés selon les besoins du pays concerné et les services que ce laboratoire doit rendre. Les mesures de haute précision exigent un environnement très stable et reproductible. Ces conditions sont traitées dans la première partie de l'article.

La deuxième partie expose l'état actuel de la technique des grandeurs électriques les plus importantes et décrit notamment les méthodes de mesure, les étalons et autres équipements nécessaires pour les mesures de tension continue, de résistance et de courant alternatif par conversion en courant continu. Des indications sont également données sur l'incertitude de ces méthodes.

Introduction

Metrology is certainly a "must", not only from the point of view of legal requirements for trade, health and safety but also for practically all fields of industrial activities. Planning and equipping of a laboratory should be guided by the needs of the respective country and the services presumably to be rendered. Briefly, the activities are to be planned so as to allow efficient operation which can follow the progress achieved in technology.

The approach to the task under discussion must take two different aspects into account: the environmental conditions and the equipment. Only little information is available on the environmental and equipment requirements to be met by laboratories working in the field of electrical metrology. It is the objective of this paper to contribute to meet this need.

(*) Presented at the OIML seminar on Planning and Equipping Metrology and Testing Laboratories, Paris, 25-26 September 1989.

1. Structural and environmental conditions for the laboratory

The measured value assigned to a standard or measuring instrument is essentially qualified by the fact that the assigned value strongly depends on the specific conditions of calibration. If these specific conditions do not prevail when the device is used to calibrate other instruments, any variables introduced can give rise to a substantial uncertainty. With this fact in mind, it is obvious that there is a need for stable and reproducible environmental conditions inside a laboratory. In addition to site, surroundings, size etc., certain other factors should be considered [1, 2, 3] in order to meet as many of the technical requirements as possible, thereby avoiding expensive and unnecessary elaborations.

1.1 Room climate

As far as the room climate is concerned temperature, relative humidity, and dust must be considered.

TEMPERATURE: A temperature controlled room should have a minimum of surfaces that are directly influenced by climatic temperature conditions, such as external walls, light-weight non-insulated roofs and windows. If windows cannot be dispensed with, they should be multiple-glazed and should face north (south in the southern hemisphere). Location in the basement or ground floor position, where the temperature-controlled laboratory is surrounded by other rooms or passages of approximately the same temperature offers considerable advantages.

The area of a laboratory should not be too large; an area of 30 m^2 to 50 m^2 seems to be the best choice. Otherwise, temperature stability and conformity will deteriorate. The temperature should be individually adjustable for each room within a temperature range from 20 °C to 25 °C. This can be done best by means of a decentralized system, each room having its own air-conditioning unit while heating and cooling power are generated by a central source. This is also the most economical solution. Up to now, direct current (dc) measurements often have been carried out at a temperature of 20 °C whereas alternating current (ac) and low frequency (lf) measurements are carried out at 23 °C. For dc measurements there is a certain tendency to apply 23 °C, too, as in many countries 20 °C will be too low for human comfort and difficult to maintain without the risk of high relative humidity.

As the most sensitive standards for electrical measurements must be thermostated anyhow, the temperature stability of the laboratory is not too critical an aspect. For the most sensitive measurements, a temperature stability of ± 0.2 K with respect to time and a homogeneity of ± 0.5 K with respect to the area are suitable. For less critical measurements, the figures are ± 1 K in both cases.

The design of the laboratory should exclude protuding features that could interfere with the flow of air in the room and, for the same reason, bulky furniture should not be included in the equipment. It is very important that the effect of local sources causing the gain or loss of heat and moisture be avoided (a person is a source of heat approximating to 100 watts), and that the dissipated power be generated as steadily as possible. Equipment arranged on a cold floor or even a few centimetres above the floor on feet will exhibit temperature gradients which may adversely affect the measurements.

RELATIVE HUMIDITY: For electric measurements the relative humidity does not need to be regulated. It is sufficient to keep it within a range from 40 % to 60 %, thereby bearing the interdependence of humidity and temperature in mind. In order to keep the relative humidity within the limits of ± 5 %, the change of temperature should not be larger than ± 1 K. Direct sunlight must not enter the laboratory, as the temperature in a patch of bright sunlight may be several kelvins higher than elsewhere in the laboratory and the relative humidity may be lower by as much as 10 %. The limits given above will minimize static electricity (in the case of a very low relative humidity) and hygroscopic effects which will reduce insulation resistances (in the case of a very high relative humidity) and ensure optimum permissible comfort of the laboratory staff.

DUST: The air cleanliness required in the fields of computers, guided missiles and artificial satellites is not necessary for laboratories for electrical metrology. It is the larger particles of more than 10 micrometres in size that tend to settle under gravity. Taking all factors into consideration, the filtering of particles of 1 micrometre and above is considered adequate for most metrological work. This level of control can be achieved by using standard dry or viscous-type filters.

The provision of an airlock with a dust-collecting floor covering at the entrance and a slightly positive air pressure inside the laboratory rooms will minimize the ingress of dirt. The effective control of cleanliness depends very much on the "good housekeeping" of the metrology staff and those responsible for cleaning. The floor should be covered with linoleum or plastic material, preferably welded or laid as one piece.

The adverse effect of dust on measuring instruments and other equipment must be mentioned, too. In low-frequency measurements, dust accumulated on insulating or conducting surfaces can influence the measurements. Many standard laboratory instruments utilize exposed contact construction, making repeated cleaning necessary in a dust-laden area. The dust contamination of oil baths required in standards laboratory measurements must be considered.

1.2 Lighting

A "general" specification of 1 000 lux at bench level or reading surface is considered to be sufficient for all types of functions in a metrology laboratory. For convenience, the lamps may be switched in two or three groups with an illumination of two times 500 lux, or two times 250 lux and one time 500 lux, respectively. For even brighter illumination, special supplementary lighting is the best solution. The design and installation of both general and supplementary lighting must provide not only a sufficient amount of light, but also ensure the proper direction of light, diffusion, and eye protection.

The effect of radiation on the sensor of the laboratory air conditioner and the power dissipated by the lamps must also be taken into account. Due to much greater efficiency, fluorescent lighting has permitted much better illumination without an attendant increase in the heat load upon the air conditioning equipment. This may be further reduced if the lamps are directly connected to the outlet of the air conditioning system. Fluorescent lighting increases however the problems of electromagnetic interference, especially inside shielded rooms. In this case, a combination of fluorescent lamps and incandescent lamps will be the best solution.

In addition to the amount of illumination, other factors should be considered, e. g. the proper balance of brightness and brightness ratios, control of direct and reflected glare, the colour and reflectance of room surfaces, and auxiliary lighting for accomplishing special tasks.

1.3 Electrical supply

Much valuable time can be lost in the repeating of measurements which are not satisfactory because of a varying voltage in the power supply. Also, measurements may be made without the observer being aware that his measurements may be erroneous if the power supply voltage is beyond certain operating limits.

The stability of the voltage in the power supply can be improved if individual consumers are supplied via different circuits separated by transformers. Separate distribution transformers should be used for the illumination of rooms and corridors, for powerful units such as air-conditioning equipment, elevators and the machine shop, and for the experimental set-ups. In some cases an auxiliary supply will be necessary for thermostated or other equipment which must be permanently supplied. The power installed for laboratory equipment should be large compared with the mean power needed to diminish the effect of voltage drops on the internal lines which are sometimes troublesome if they are not constant. If several circuits are installed, great care must be taken that the earth lines are properly grounded in order to prevent ground loops being built up which are open to electromagnetic interference.

In the case of a poor stability of the mains supply, voltage regulators will be necessary. There are different types of regulators on the market, e. g. of the motor-generator type (expensive!), the magnetic resonant transformer type (cheap!), the silicon-controlled rectifier (SCR) type, and the newly developed electronic voltage regulators. Their main characteristics should be as follows:

Voltage stabilization:	± 0.02 % for ± 10 % change in line voltage
Load regulation:	± 0.01 % for change from zero to full load
Harmonics:	Total harmonic content 2...3 %
Transients:	Recovery time < 100 µs

In some cases — in particular for highly sensitive dc measurements or where large dc currents are needed — battery supply will be convenient. A battery with a rated voltage of 6 V which can deliver 200 A for at least 8 hours, and a cross bar distributor for voltages up to 400 V and currents up to 1 A is a good choice.

1.4 Vibrations

Even if special precautions are in general not necessary for electrical measurements, there are some guiding principles which should be followed in planning and equipping a laboratory. First of all, the laboratory should be located away from sources of vibration. At the same time, the generation of vibrations within the laboratory must be kept to a minimum. Whenever possible, only equipment that is self-damped should be used. Equipment that generates vibrations such as the machine shop, the elevator, and the air-conditioning plant should be located in a detached part of the building which is separated from the main building by an isolating gap. Vibration dampers for rotating machines and a pneumatic elevator will further decrease the amount of vibration.

The most sensitive laboratories should be located on the ground floor of the building where the level of vibrations is minimum. In addition, sensitive instruments may be deposited on antivibration pads or mats. By means of pneumatic suspensions or seismographic mountings, the resonant frequencies can be detuned. With a heavy foundation a cut-off frequency of the order of 20 Hz to 25 Hz may be obtained while cut-off frequencies from 0.5 Hz to a few Hertz can be realized with pneumatic systems.

1.5 Electromagnetic fields (shielding)

Shielding against electromagnetic fields is increasingly gaining in importance, since the amount of electromagnetic radiation in the environment is increasing. If a laboratory building is made of concrete instead of bricks, the reinforcement may be welded together, forming something like a Faraday cage. Other precautions were already mentioned in the foregoing sections. Separate circuits (cf. section 1.3) are very useful to prevent mutual distortions. In addition, gating control with silicon-controlled rectifiers (SCR) should not be allowed in the laboratory. Wiring must be done so as to form a minimum of loops with areas as small as possible. The same requirement holds for earth connections, the impedance from the ground bus to ground having to be as small as possible for dc and ac. In section 1.2 it has already been mentioned that incandescent lamps are superior to fluorescent lamps as far as electromagnetic interference is concerned.

Shielded rooms or cabins [4] are only necessary for the most sensitive electrical measurements. In that case, the damping factor should be 60 dB at 10 kHz and 100 dB from 100 kHz up to the cut-off frequency (1 GHz, 10 GHz, 35 GHz). All connexions — electrical as well as non electrical — must be made using filters.

2. Metrological requirements standards and measuring equipment

It would be beyond the scope of this paper to describe all the electrical and magnetic quantities. We will restrict ourselves to the most important quantities and discuss in more detail the standards and measuring equipment required for dc voltage, resistance and ac/dc transfer.

2.1 Definitions and terms

Before discussing the different units, a clear delimitation of the terms definition, realization, reproduction, and maintenance and dissemination of a unit is necessary (see Table I) [5].

Table I — Definition, realization, reproduction, maintenance and dissemination of the electrical units ampere, volt, and ohm

	ampere	volt	ohm
definition	1 A	$1\ \mathrm{V} = \frac{1\ \mathrm{W}}{1\ \mathrm{A}} = 1\ \mathrm{m^2 kg\ s^{-3}\ A^{-1}}$	$1\ \Omega = \frac{1\ \mathrm{V}}{1\ \mathrm{A}} = 1\ \mathrm{m^2 kg\ s^{-3}\ A^{-2}}$
realization	current balance	voltage balance	calculable cross capacitor
reproduction	gyromagn. coefficient $\omega = \gamma p \cdot B \quad I = k \cdot f/\gamma p$	Josephson effect $U_I = h/2e \cdot f \cdot n$	quantum Hall effect $R_H = 1/i \cdot h/e^2$
maintenance and dissemination	standard cell or electronic voltage standard standard resistor	electro chemical cell (standard cell) or electronic voltage standard	wire wound precision resistor (standard resistor)

The definitions of the units within the SI are based on ideal assumptions which cannot be directly transferred to practice. In the case of the definition of the ampere, words like "straight parallel", "infinite length", and "negligible cross-section" point to this fact. The definitions must be distinguished from their realizations, that is to say their embodiments in the laboratory. The ampere and the volt are realized using so-called current or voltage balances which are electrodynamic current-to-force or electrostatic voltage-to-force transducers. The ohm is realized by means of a calculable capacitor, the so-called Thompson-Lampard cross capacitor. Common to all these realizations is the great expenditure of time and money which can only be made available by the larger national standards laboratories.

As the realization of a unit is such a sophisticated task, it is normally carrried out only once every few years. In the meantime, the units are reproduced by means of quantum measures. These are experiments, where a unit is related to a fundamental constant which, from our present knowledge, is as such independent of time and location. Examples are the Josephson effect, the quantum Hall effect, and the gyromagnetic ratio of the proton. The reproduction of a unit by means of a macroscopic quantum effect involves a medium expenditure and is done by the majority of the national standards laboratories and with certain restrictions by large metrological laboratories in the industry.

Maintaining and disseminating a unit by means of a standard instrument or a group of standards is the procedure most frequently adopted which involves only low costs. Widely used standards are standard cells or electronic voltage standards for the unit of voltage and wire-wound standard resistors in the case of the unit of resistance. The unit of current is maintained by means of both types of standards.

2.2 Voltage standards

There are two different categories of voltage standards: Josephson standards and standard cells or electronic standards. It depends on the level of accuracy and the laboratory environment which type of standard is best suited for a certain laboratory.

JOSEPHSON VOLTAGE STANDARDS

Until 1972, groups of selected standard cells [6] served for the maintenance and dissemination of the unit of voltage in the national standards laboratories. A considerable improvement was achieved with the introduction of Josephson voltage standards which allowed the unit of voltage to be reproduced with a relative uncertainty of a few parts in 10^8 [7]. Meanwhile, the next generation of cryogenic voltage standards has been developed, based on a series connexion of Josephson tunnel junctions. With these new standards, the measurement uncertainty can be reduced by more than one order of magnitude ($\approx 1 \cdot 10^{-9}$) [8].

The Josephson voltage standards are based on the ac Josephson effect (Fig. 1) for which the energy relation

$$2 \cdot e \cdot U_J = n \cdot h \cdot f \qquad U_J = n \cdot h/2e \cdot f$$

holds, with U_J = voltage across the Josephson junction, e = elementary charge, h = Planck constant, f = frequency of the microwave. n is an ordinal number which indicates the harmonic on which the Josephson oscillator is synchronized by the incoming microwave. The uncertainty of the voltage U_J is only given by the uncertainty of the frequency and the uncertainty with which the fundamental constant h/2e is known in SI units. When another voltage standard is calibrated against a Josephson standard, the uncertainty due to the calibration (measuring set-up) must be added.

As the product of the ordinal number n and the frequency f cannot be increased arbitrarily, the voltage drop across a single Josephson junction is always very small. For tunnel junctions it is in the order of a few millivolts. Connecting junctions in series is the only way to increase the voltage and at the same time decrease the uncertainty of Josephson voltage standards. With the newly developed series arrays, about 1 500 junctions are connected in series thus producing quantized voltages from 0.3 V to 1.5 V. Attemps are being made to connect an even higher number of junctions (up to 15 000) for voltages up to 10 V [9].

When a standard cell or an electronic voltage standard is calibrated against a series array, the quantized voltage across the array must be adapted as close as possible to the emf of the device under test by choosing a suitable step number and adjusting the right frequency. For n = 7 000, f = 70.373 139 26 GHz, and 2e/h = 483 594 GHz/V, a voltage of 1.018 647 822 V is adjusted. A nanovoltmeter (EM Model N1a) is used as a null detector. The thermoelectric emf's and a possibly existing offset of the nanovoltmeter are compensated by setting the array to the n = 0 step and replacing the standard by its equivalent internal resistance ($\approx 500\,\Omega$ in the case of a standard cell).

Beginning on 1st January 1990, a new value for the Josephson constant, that is to say, for the quotient of frequency divided by the potential difference corresponding to the n = 1 step in the Josephson effect, will be used [10]: K_{J-90} = 483 597.9 GHz/V. This new value will replace all other values currently in use, and will lead to internationally uniform maintenance and dissemination of the unit of voltage.

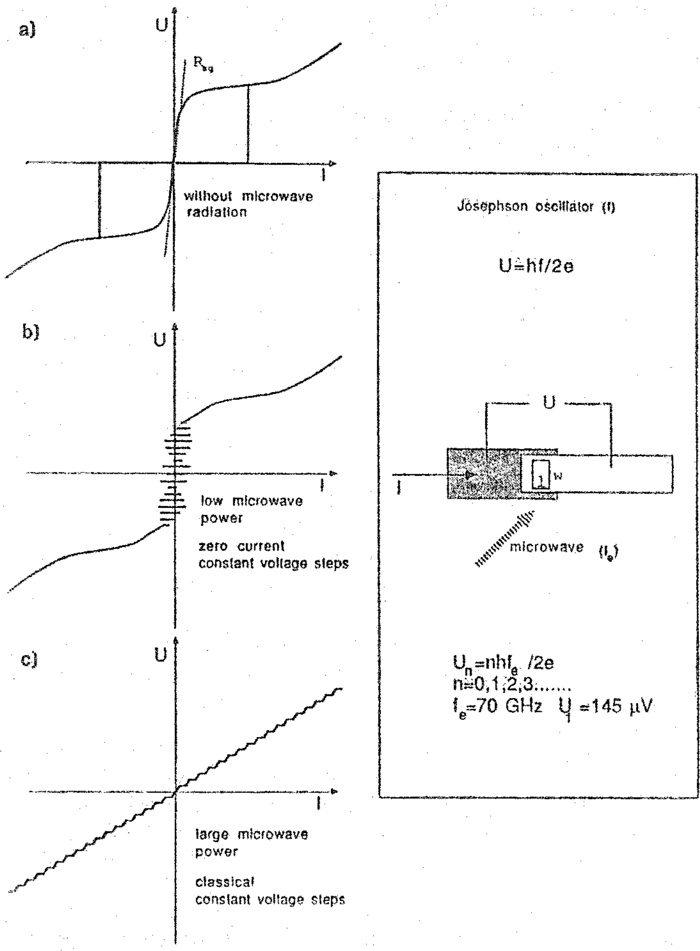

Fig. 1 I-V-Characteristic of a highly hysteretic Josephson tunnel junction [15]
a) without microwave radiation
b) with low-power microwave radiation
c) with high-power microwave radiation

Operating a Josephson voltage standard presupposes a few, but very important points. As a complete standard is not yet on the market, it must be designed and built by the laboratory staff from different components. The procurement of the series arrays is another severe problem. Well-trained personnel is therefore necessary for the construction and operation of a Josephson voltage standard. Due to the high sensitivity and excellent stability with time of such a standard, very small voltages in the nV range must be detected, which makes a shielded room or cabin with a corner frequency of 35 GHz necessary. In addition, the room must be temperature controlled to reduce the influence of thermoelectric emf's. The operation of the standard at very low temperatures requires continuous supply with liquid helium. Only if all these prerequisites are fulfilled, should a laboratory think seriously about equipping itself with such a standard.

STANDARD CELLS AND ELECTRONIC VOLTAGE STANDARDS

As the most accurate reproduction of the volt requires great effort, only a few laboratories run such a Josephson standard while the majority uses secondary standards, first of all standard cells [6] which have been in use for nearly 100 years, and also electronic voltage standards which are increasingly gaining in importance [11].

When an electronic voltage standard is compared with a standard cell, evaluation criteria such as environmental influences, long-term stability, transport characteristics, serviceability, and efficiency must be considered.

Standard cells are very sensitive to environmental influences. First of all, their temperature and load dependence must be mentioned. The temperature coefficient of standard cells amounts to $-40 \cdot 10^{-6}$/K at room temperature. It is given by the difference of the coefficients of the two single poles which have a temperature coefficient of about ten times this value. Temperature gradients must therefore be avoided by all means. Besides, standard cells show a more or less distinct temperature hysteresis. If it exceeds 30 µV for a temperature change of 5 °C for non-thermostated cells, these cells can no longer be used as a voltage standard. In contrast to this, electronic voltage standards have much smaller temperature coefficients which amount to $5 \cdot 10^{-7}$/K for non-thermostated and $5 \cdot 10^{-8}$/K for thermostated instruments. Output voltages which are derived from the 10 V output by means of resistive dividers have a somewhat larger temperature coefficient, amounting to about $1 \cdot 10^{-6}$/K.

Charging or discharging of standard cells must by all means be avoided. If a current is drawn from the cell, the recovery time is proportional to the charge and amounts to 1 d/mC. A current which flows into the cell is much more critical. In this case, the recovery time will take several months, provided that the cell is not damaged permanently. Electronic voltage standards are insensitive to loading. The only effect is a small change in the output voltage due to the internal resistance of the standard. Typical values are a few milliohms for the 10 V output and about 1 kΩ for the divider outputs.

Standard cells are superior to electronic voltage standards as far as their noise voltage is concerned. It is in the order of a few nanovolts and corresponds to the white noise of their internal resistance at room temperature ($R_i = 1$ kΩ; $t = 20$ °C; $B = 1$ Hz). The output noise of electronic voltage standards is ten times larger. It is mainly caused by the noise of the buffer amplifier and the reference element itself.

Regarding their long-term stability, electronic voltage standards are comparable to transportable standard cells. About 60 % of the instruments show a drift rate smaller than $1 \cdot 10^{-6}$/a (Fig. 2). Even smaller drift rates are obtainable, but only with non-transportable standard cells. The best cells show drift rates smaller than $1 \cdot 10^{-7}$/a. The data given for electronic voltage standards are restricted to the 10 V output of those instruments which are operated in a stand-by mode, i. e. the Zener current is not switched off. Due to changes in the ratio of the resistive dividers, the 1 V and 1.018 V outputs are not as stable as the 10 V output. The same holds for instruments where the Zener current is switched on and off.

Measurements over a long time show (Fig. 3) that most of the electronic voltage standards have drift rates smaller than $1 \cdot 10^{-6}$/a. Fig. 3a shows the three output voltages of an electronic voltage standard, Fluke model 732 A, as a function of time for a period of three years. The 1 V and 1.018 V outputs have a somewhat larger drift which is caused by the resistive divider scaling down the 10 V output. Fig. 3b shows a corresponding curve for an electronic voltage standard, Cropico model ESC 1, which was observed over a period of one year. After six months, this instrument showed a slight jump in its output voltages which could not be explained. Spontaneous changes in the output voltage and changing drift rates are not untypical of electronic voltage standards, even if they lie within the manufacturer's specifications. In this respect, standard cells differ from electronic voltage standards. They show some remarkable characteristics before they become useless. An increased voltage hysteresis for a given change in temperature as well as a rise in their internal resistance indicate a possible change of the output emf in the very next future.

Even portable standard cells must be transported with greatest care and need a recovery time of several weeks before they can be calibrated. Changes in the output emf are sometimes unavoidable. As opposed to this, electronic voltage standards can be transported without any problems of the limiting values of temperature, relative

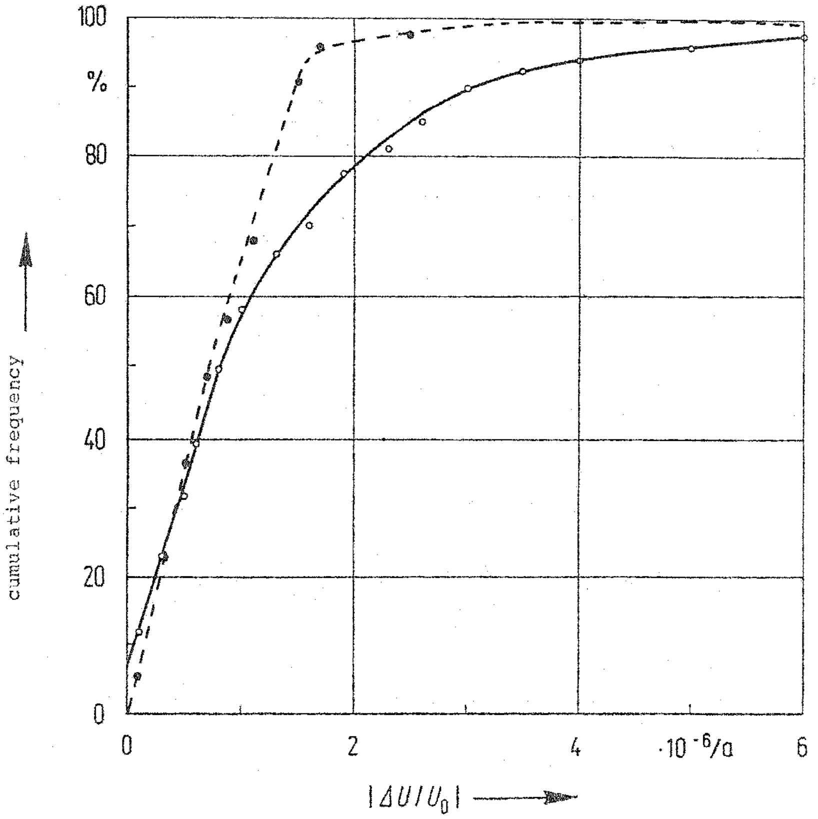

Fig. 2 Annual changes in the output voltage of transportable standard cells and electronic voltage standards
—— for 200 standard cells calibrated at the PTB
- - - for 44 electronic voltage standards (Fluke 732 A, 10-V output)

humidity, shock, and vibration given by the manufacturer are complied with. Non-thermostated instruments need a recovery time of about eight hours in order to adapt themselves to the new environmental conditions. Thermostated instruments are ready for operation immediately after transport.

As inappropriate handling of standard cells may cause a change in their output emf or a damage to the cell, only trained personnel should measure these cells. In this respect, electronic voltage standards are also much less sensitive. Normally, such a standard will not be damaged or its characteristics changed by incorrect operation.

Most of the features discussed so far are directly or indirectly related to the question of economy, even if they can not be expressed in ready money. A non-thermostated single standard cell in a transport enclosure is still the cheapest solution. It costs about 600 US $. Standard cell enclosures such as Guildline standard cell banks, models 9152/12 and 9145 D, are much more expensive. Nowadays, they cost between 7 500 US $ and 12 500 US $, depending whether they are equipped with four or twelve standard cells. In addition, they need a mains supply or a battery supply during transport.

Electronic voltage standards are available on the market with battery and/or mains supply. Dependent on their outfit, they will cost between 2 500 US $ and 7 500 US $ and thus form an alternative to standard cell enclosures. In principle, arbitrary output voltages between 0 V and 10 V could be adjusted; in practice, the fixed values 1 V, 1.018 V, 6.3 V and 10 V are used either as a single output voltage or

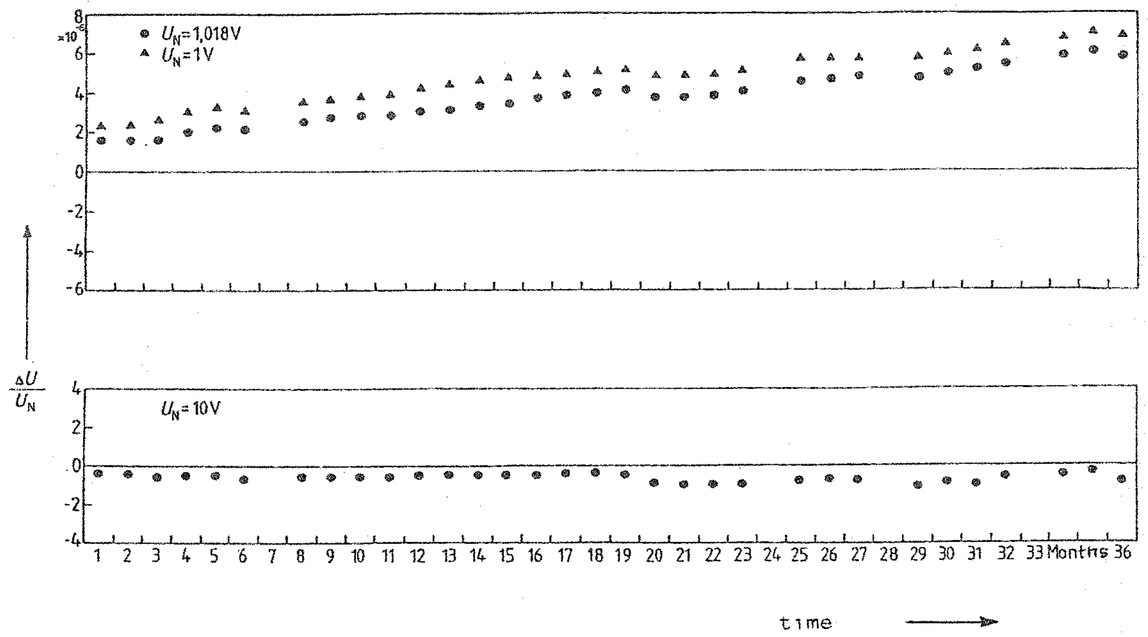

Fig. 3 a Output voltages of an electronic voltage standard, Fluke, model 732 A, as a function of time

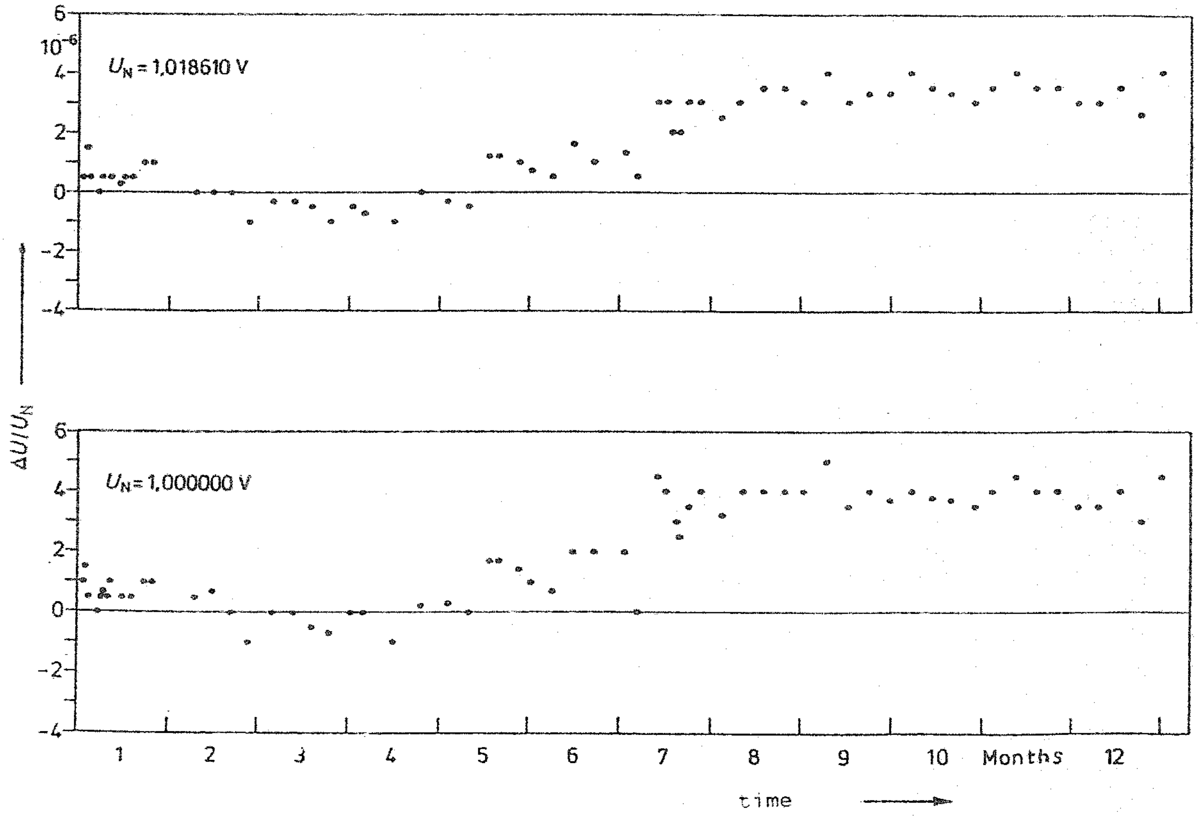

Fig. 3 b Output voltages of an electronic voltage standard, Cropico, model ESC 1, as a function of time a combination of different voltages. While the power supply of the cheaper instruments consists of non-rechargeable batteries which must be switched off after operation, the more expensive instruments are equipped with a battery-buffered mains supply which operates continuously. In addition, some of them are thermostated.

VOLTAGE MEASUREMENT

The most versatile instruments for voltage measurements are digital voltmeters [12] and calibrators [13]. The most accurate 8½ digit voltmeters measure voltages in the range from 0.1 V to 1 000 V with a resolution of 10 nV and a relative uncertainty from $3 \cdot 10^{-6}$ to $6 \cdot 10^{-6}$ (for a time interval of one year). Calibrators having a 7½ digit resolution and a voltage range from 0 V to 1 100 V are commercially available. The uncertainty referred to a reference standard is $2 \dots 3 \cdot 10^{-6}$ (for a period of 30 days) or $4 \dots 6.5 \cdot 10^{-6}$ (for a period of one year). For traceability to a national standard, the uncertainty of the transfer standard must be added. The temperature coefficient of the output voltage is $0.1 \dots 0.2 \cdot 10^{-6}$/K and its linearity $0.5 \dots 2 \cdot 10^{-6}$.

To reach an even smaller uncertainty, potentiometers and a current comparator in conjunction with a potentiometer can be used. The voltage range of the most precise instruments [14] extends from 0.02 V to 2 V with a resolution of 1 nV, a linearity of $5 \cdot 10^{-8}$ (related to the measuring range), and a relative uncertainty from $2 \cdot 10^{-6}$ to $5 \cdot 10^{-7}$ depending on the measuring range. Higher voltages of up to 1 000 V can be measured using a resistive divider (cf. section 2.3) in addition to the potentiometer.

The smallest uncertainty, best linearity, and utmost stability can be achieved with a Josephson potentiometer [15] the application of which is restricted to the national standards laboratories, as such an instrument is not yet available on the market.

2.3 Resistance standards

For resistance standards, the situation is very similar to that of voltage standards: besides different types of standard resistors, the newly developed resistance standards based on the quantum Hall effect have been used for a few years.

QUANTUM RESISTANCE STANDARDS

The quantum Hall effect, discovered by K. v. Klitzing in 1980 [16], provides the national standards laboratories with an extremely useful tool to monitor their as-maintained units of resistance by the accurate reproduction of quantized resistance values.

THE QUANTUM HALL EFFECT

The quantum Hall effect appears at low temperatures ($T < 4.2$ K) and high magnetic fields (up to 15 T) in so-called two dimensional systems, i. e. two dimensional conductive layers as they can be obtained to a good approximation with special semiconductors. The effect was first observed on MOS field effect transistors (MOSFET's, Fig. 4). Applying a gate voltage, a two-dimensional conductive layer is formed at the boundary surface between the semiconductor (p-Si) and the oxide (SiO_2), its electron density being a linear function of the gate voltage. Due to the strong electric field and the low temperature, the possible energy states of the electrons in the boundary layer are quantized with respect to their motion perpendicular to this layer. This condition is what is called a two-dimensional electron gas (2 DEG) which exhibits, especially in attendance of a strong magnetic field, quite another characteristic as the three-dimensional electron gas normally present in semiconductors or metals. Lately, GaAs-GaAlAs-heterostructures have been used instead of the MOSFET's, which show well-developed quantized resistances at lower magnetic fields (7 to 9 T).

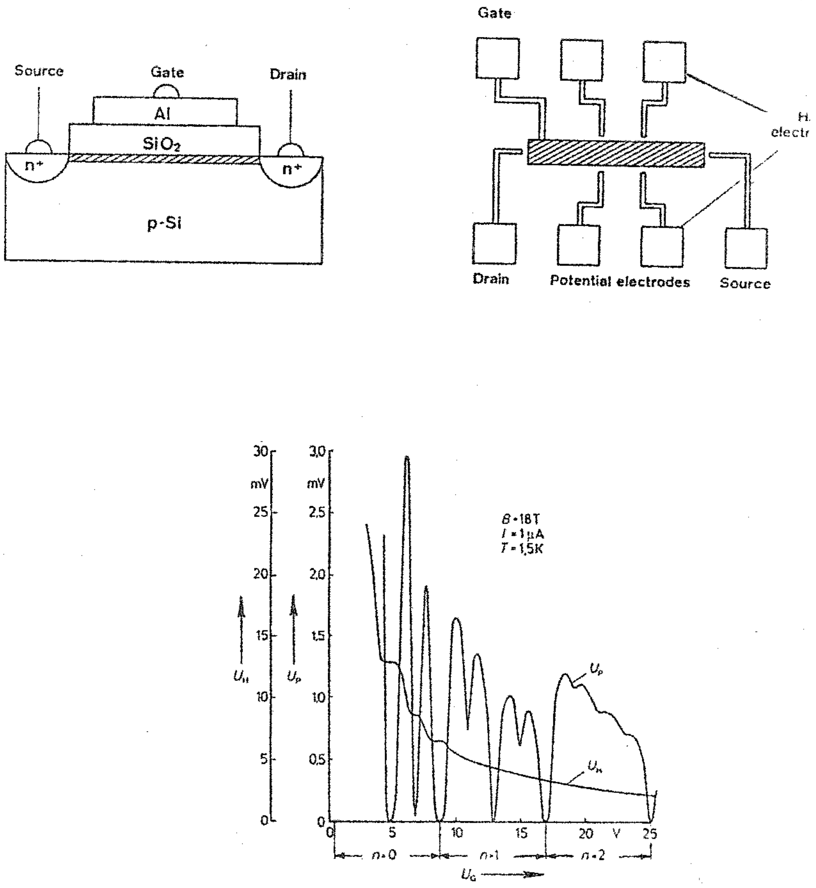

Fig. 4 Schematic structure of a MOS field effect transistor. The diagramme shows Hall voltage U_H and longitudinal voltage U_P of a MOSFET as a function of gate voltage U_G .

When a two-dimensional electron gas is exposed to a strong magnetic field, another quantization of the energy states due to the magnetic field can be observed. The magnetic field constrains the electrons into closed loops, causing each electron to occupy a certain area. As often as one Landau level is filled with electrons, the Hall voltage as a function of gate voltage (in the case of MOSFET's) or magnetic field (in the case of heterostructures) shows plateaus which are characterized by a Hall resistance — that is the quotient of Hall voltage divided by the probe current —

$$R_{H,i} = U_{H,i} / I = 1/i \cdot h/e^2,$$

h = Planck constant, e = elementary charge, i = 1,2,... is an ordinal number.

At the same time, the longitudinal voltage disappears. The uncertainty of the quantized Hall resistance $R_{H,i}$ is only given by the uncertainty with which the fundamental constant h/e^2 is known if the effect is properly established. Unfortunately, uneven values are obtained for the resistances — e. g. 12 906.4 Ω for the i = 2 step — so that the uncertainty of the measuring set-up must be added with which a standard resistor — e. g. a 10 kΩ resistor — is calibrated against the quantized Hall resistance [17].

For precise measurements of quantized Hall resistances, cryogenic methods have been developed, using cryogenic current comparators [18] and Josephson potentiometers [19]. For cryogenic current comparators (CCC), two different methods of almost equal total uncertainty are applied in practice: a balance method which uses a conventional null detector in conjunction with a CCC, and a deflection method which makes use only of a CCC. The relative uncertainty of both methods is about $1 \cdot 10^{-8}$ for a comparison of $R_{H,2}$ with a 10 kΩ standard resistor. With the Josephson potentiometer, the voltage drops across the quantized Hall resistor and the standard resistor are measured if the same current passes through both items. The relative uncertainty is mainly determined by the drift of the current source and the null detector. It amounts to a few part in 10^8. The measurement uncertainty must be combined with the uncertainty of $2 \cdot 10^{-7}$ with which h/e^2 is known in SI units.

Beginning on 1st January 1990, a new value for the von Klitzing constant, that is to say, for the quotient of the Hall potential difference divided by current corresponding to the plateau $i = 1$ in the quantum Hall effect, will be used: $R_{K-90} =$ 25 812.807 Ω. This new value leads to internationally uniform maintenance and dissemination of the unit of resistance [10].

Operating a quantized Hall resistance standard presupposes a few, but very important points. As a complete standard is not yet on the market, it must be designed and built by the laboratory staff from different components. The procurement of Hall samples is another severe problem with respect to both the material and the making of the contacts. Well-trained personnel is therefore necessary for the construction and operation of a quantum resistance standard. As the two-dimensional electron gas is disturbed by large currents, only small currents in the order of 10 to 50 μA can be used, producing voltage drops of 130 to 650 mV. In order to compare these small currents and voltages with the desired accuracy, shielded and temperature-controlled rooms are required. Last but not least, the operation of the standard together with a superconducting magnet needs several hundred litres of liquid helium a week. Only if all these prerequisites are fulfilled should a laboratory think seriously about such a standard.

STANDARD RESISTORS

Resistance standards must exhibit good long-term stability, independence of environmental influences, and low thermoelectric emf against copper. Standard resistors are needed for a wide resistance range extending from 10^{-5} Ω to 10^{12} Ω.

Low ohmic resistances (10^{-5} Ω to 1 kΩ) are made from manganin, a copper-manganese-nickel alloy with a temperature coefficient of a few 10^{-6}/K at room temperature. The most stable standards are 1-Ω resistors of the Thomas type [20] with a long term stability of typically $< 10^{-7}$/a. In order to eliminate the influence of lead resistances, low ohmic resistors are measured in a four-terminal configuration.

While the low-ohmic resistors are best suited for current measurements, the modern electronic instrumentation has a need for higher resistances (10 Ω to 10^8 Ω). The most stable resistors are fabricated from Evanohm, a chromium-nickel alloy with a temperature coefficient below 10^{-6}/K. Best suited are 10-kΩ resistors [21] with a long term stability of a few parts in 10^7 per year.

High-ohmic resistors (10^8 Ω to 10^{14} Ω) are used for the measurement of ultra low currents. They are fabricated from metal oxide (temperature coefficient: $1 \ldots 5 \cdot 10^{-4}$/K; stability: 0.1 %/a) or carbon films (temperature coefficient: $1 \ldots 3 \cdot 10^{-3}$/K; stability: 0.1 %/a ... 1 %/a) melted into a glass tube, whereby their resistance depends on the measuring voltage [22].

Most precise resistance ratios can be established by means of so-called Hamon resistors [23]. This is a configuration of n resistors which can be connected in series or in parallel forming a resistance ratio of n^2:1. Normally, to get decadic resistance ratios, n is equal to 10, and the single elements have decadic resistances, too. The uncertainty of the resistance ratio is smaller than 10^{-7}.

Decade resistance boxes are used for adjustable resistances. If several decades are connected in series, a resistive divider is obtained which is often used to scale down a voltage into a measurable quantity. The most accurate dividers are Kelvin-Varley dividers the input resistance of which is independent of the setting of the switches. For low voltages (10 V), the linearity of such a divider with seven decades may be of the order of 10^{-7}.

RESISTANCE MEASUREMENTS

A resistance is defined by the quotient of the potential difference across the terminals of the resistor and the current passing through it. In general, a resistance ratio is therefore determined by measuring a voltage and a current ratio:

$$R_X = U_X/I_X \; ; \; R_N = U_N/I_N \; ; \; R_X/R_N = (U_X/U_N) \cdot (I_N/I_X)$$

If the same current passes through both resistors, only one voltage ratio must be measured, the measuring method being called a potentiometric method. On the other hand, the potential drop across the resistors may be equal and the current ratio is measured by means of a current comparator.

Current comparators work on the principle of ampere-turns equilibrium [24]. The two currents I_X and I_N flowing through the resistors to be compared, at the same time flow through the two windings N_X and N_N of the comparator. The ampere-turns balance $N_X \cdot I_X = N_N \cdot I_N$ is controlled by means of a second harmonic magnetic modulator. Thereby, the resistance ratio is traced back to a turns ratio: $R_X/R_N = N_X/N_N$. Current comparator bridges are best suited for the measurement of low-ohmic resistances [25]. With an instrument commercially available [26], resistances from 10 mΩ to 10 MΩ can be measured with a basic uncertainty of $2 \cdot 10^{-7}$ and a linearity of $2 \cdot 10^{-8}$ related to the specified measuring range.

With the potentiometric method, the voltage drop across the standard and the device under test is measured and the voltage ratio is calculated. The uncertainty of measurement strongly depends on the stability of two currents: the current which flows through the resistors, and the current from which the compensation voltages are derived. With a careful experimental set-up, a relative uncertainty in the order of $1 \cdot 10^{-8}$ can be obtained for a 1:1 comparison [27]. Besides the potentiometers, resistance bridges are also used: the Wheatstone bridge for two-terminal resistors of the medium and high resistance range, where the lead resistances do not play an important role, and the Thomson (Kelvin) bridge for low-ohmic resistances which must be measured in a four-terminal configuration.

In addition, mention must be made of the electronic measuring instruments. Calibrators [13] supply resistances in a range from 1 Ω to 100 MΩ with a basic uncertainty of $7 \cdot 10^{-6}$ in the medium range and an uncertainty of up to $230 \cdot 10^{-6}$ for the higher resistances. The temperature coefficient lies in a range of $5 \cdot 10^{-6}$/K. Digital multimeters [12] measure resistances in a range from 10 Ω to 1 GΩ, the smallest resolution being 1 μΩ and the relative uncertainty extending from $6 \cdot 10^{-6}$ to $2\,500 \cdot 10^{-6}$.

2.4 AC/DC transfer of voltage and current

As the units are defined for dc and not for ac, ac standards must be referred to the national standards via the corresponding dc quantities. For this purpose, transfer standards are used which work on electrostatic, electrodynamic, or thermoelectric principles, the latter having the greatest importance due to their small transfer uncertainty and the wide frequency range [28]. AC quantities at power frequencies and beyond that in a frequency range from 10 Hz to 1 MHz are of great technical and economic interest. The transfer uncertainty should be as small as possible in order not to loose too much accuracy for ac measurements.

Single junction thermal converters are widely used; they operate in a frequency range extending from power frequencies up to the MHz range with a basic transfer uncertainty of a few parts in 10^6. They consist of a short and very thin resistance wire acting as a heater, and a single thermocouple which is isolated from the heater though in close thermal contact with it. If a current flows through the heater, a rise in temperature corresponding to the rms value of the current occurs, generating a thermoelectric emf of up to 10 mV. The transfer uncertainty is limited by thermoelectric effects in conjunction with the temperature gradient along the heater. This limitation can be overcome if a large number of thermocouples are distributed along the heater thus reducing the temperature gradient drastically and producing higher output voltages of up to 100 mV. At the same time the transfer uncertainty can be reduced to a few parts in 10^7 for a frequency range from 10 Hz to 100 kHz.

The maximum voltage and current of a multijunction thermal converter are limited by the maximum temperature difference, the maximum heater power, and the heater resistance to about 0.6 V and a few milliamps. In order to increase the voltage or current capability series resistors or shunts are connected to the converter. They must be of a special design to keep the frequency dependence as small as possible. Smaller voltages can be obtained by combining an amplifier and an inductive voltage divider (IVD). The amplifier amplifies the voltage to be measured up to the rated input voltage of the converter. At the same time, this voltage is scaled down by the IVD and compared with the original voltage so that the gain of the amplifier does not influence the measurement result.

The relative uncertainties of the transfer differences range from $2 \cdot 10^{-5}$ to $10 \cdot 10^{-5}$ depending on the voltage (0.5 V to 1 000 V) and frequency range (10 Hz to 100 kHz). For ac current, the figures are $5 \cdot 10^{-5}$ to $30 \cdot 10^{-5}$ (1 mA to 10 A; 20 Hz to 100 kHz). Commercially available instruments [29] show a somewhat higher uncertainty (0.01 % to 0.2 %; 0.5 V to 1 000 V; 5 Hz to 1 MHz and 0.02 % to 0.05 %; 10 mA to 20 A; 5 Hz to 100 kHz). Their inputs are overload-protected, thus facilitating an easy handling of these instruments. Even computer-controlled instruments have been on the market for some time. A very cheap solution is a digital multimeter which is capable of measuring ac and dc quantities. If the ac/dc ratio has been calibrated once, it will be very stable with time, even if the characteristics for ac and dc will change.

2.5 Power and energy measurements by AC/DC transfer

Like ac voltage and current, ac power and energy must be referred to the corresponding dc units by means of transfer devices. For the most accurate measurements, two different methods are being applied: one method is based on an electronic multiplier which works on the time-division principle [30], the other method uses a thermoelectric multiplier (thermal wattmeter) [31]. If two voltages proportional to the input voltage and current are multiplied, the time-independent mean value of the product is proportional to the real power. This product is compared with a dc quantity which is derived from a dc reference voltage multiplied by the same multiplier. In this way, the characteristics of the multiplier do not affect the ac/dc transfer to a first order, thus leading to very small transfer uncertainties. Both types of instruments are commercially available [32]. They exhibit a relative transfer uncertainty which is smaller than $1 \cdot 10^{-5}$ for power and $5 \cdot 10^{-6}$ for voltage or current measurements. The latest development are power sources which generate a very stable and accurate ac power for testing precision watt-hour meters [33]. They have an uncertainty smaller than $5 \cdot 10^{-6}$ for a rated voltage of 120 V, a rated current of 5 A, and at unity power factor.

While most of the ac/dc transfer devices and power sources are single-phase instruments, precision three-phase electronic watt-hour meters are available for calibrating electricity meters [34]. All these standards are working on the time division multiplication principle. They deliver a dc voltage or a frequency proportional to the input power. Integration of the frequency output is a measure of the electrical energy. The relative uncertainty of these meters is typically 0.05 % for rated current and voltage and unity power factor and smaller than 0.1 % for the whole measuring range. Together with computer-controlled three-phase voltage and current sources, they are suited for automatic meter testing.

Conclusion

In the past, the requirements for the uncertainty of measurement have been considerably tightened not only in legal metrology but even more so in industrial metrology. For example, with the introduction of static watt-hour meters of class 0.2 (cf. IEC Publication No. 687), the test equipment for the calibration of these meters must comply to an error limit of $\pm 0.04\ \%$ for unity power factor and of $\pm 0.06\ \%$ for $\cos \varphi = 0.5$ (cf. IEC Publication No. 736). The same situation is given for other measurands. Voltage standards must be calibrated with a relative uncertainty of $5 \cdot 10^{-7}$ at 1.018 V and 10 V; for resistance standards, the same uncertainty is given in the range from 1 Ω to 10 kΩ. These figures underline that the requirements for the uncertainty of measurement in calibrations have been considerably tightened in the past, putting the standards laboratories again and again to the proof.

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REP. FED. D'ALLEMAGNE

The NEW VERIFICATION ORDINANCE in the FEDERAL REPUBLIC of GERMANY — OBLIGATIONS of the MANUFACTURERS and USERS of MEDICAL MEASURING INSTRUMENTS

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SUMMARY — In this paper the contents of the new Verification Ordinance (Eichordnung, EO) as relevant for medical measuring instruments are described in a condensed form. The connections to respective OIML work are explained.

On November 1, 1988, the new Verification Ordinance (EO) [1] and the relevant Appendices 15.1 to 15.12, Medical Measuring Instruments [2], entered into force in the Federal Republic of Germany. In the following, a description will be given of the legal obligations which have now been more strongly differentiated and which follow from the EO, sections 1 and 4, for the manufacturers and users of medical measuring instruments (cf. also [3]). The EO has dispensed with the definition of new technical requirements to be complied with by the instruments when this objective could be reached by reference to accepted rules of technique (e.g. standards of DIN). The rules of technique relevant to the accuracy of measurement and to stability have been compiled for most of the measuring instrument categories in the so-called PTB-Requirements (PTB-Anforderungen).

1. Section 1 of EO

Section 1 specifies the measuring instrument categories subject to the different surveillance measures; they are listed in the following (with a * pointing to respective OIML International Recommendations or drafts as described in part 3). The method applied to ensure the accuracy of measurement is indicated by a symbol which will be explained below.

— Volume measuring instruments,
tubes for the measurement of the
erythrocyte sedimentation rate*,
syringes*: A, DC, T: 1991;

— Haemocytometer dilution pipettes*,
blood cell counting chambers*: A, V(M);

— Clinical thermometers made of glass*:
A or PA(EEC), V(M), T (thermometers for the determination
of the basal temperature): 1991;

- Clinical electronic thermometers*: PA, V(M), SV, T (thermometers for the determination of the basal temperature): 1991;
- Non-invasive sphygmomanometers*, tonometers*, ophthalmodynamometers: PA, V(M), SV;
- Person weighing machines used in hospitals: PA, V, SV (every 4 years);
- Other person weighing machines used in the practice of medicine: PA, V;
- High accuracy and special-accuracy weighing machines*: PA, V, SV;
- Absorption photometers: A, DC, MS, T: 1990;
- Electrocardiographs with automated interpretation*: PA, DC, T: 1991;
- Audiometers*: PA, DC, M (annually), T: 1990;
- Thermal imaging instruments: PA, DC, M (every 2 years);
- Foot crank ergometers*: PA, DC, M (every 2 years), T: 1990;
- Therapy level dosemeters*: PA, V, SV (with exceptions).

These regulations do not apply to non-interacting auxiliary devices for medical measuring instruments (e.g. printers, personal computers). They also are not applicable during the clinical trial of newly developed measuring instruments, provided the instrument manufacturer or importer has informed the PTB of the trial and the instrument is accompanied by a copy of that information. The PTB may limit the number of instruments and the duration of the trial.

Explanation of symbols

A = ACCEPTANCE

The measuring instrument categories are accepted for verification or for the issue of a declaration of conformity if they comply with the requirements of the Verification Ordinance (Appendix 15) and the accepted rules of technique (DIN standards, PTB Requirements). Therefore, a pattern approval is not required.

PA = PATTERN APPROVAL

A measuring instrument, which does not appertain to A will be tested by the PTB in a technical pattern approval examination and will then be approved by the PTB for verification or for the issue of a declaration of conformity if they comply with the conditions stated under A or if the accuracy of measurement is ensured in another way. A distinction is then made between national and EEC pattern approval. At present, EEC pattern approval is possible only for clinical thermometers made of glass and for weighing machines.

V = VERIFICATION BEFORE USING OR KEEPING AN INSTRUMENT READY

The verification comprises the technical verification test and the affixing of the verification mark by the competent verification authority, of a measuring instrument acceptable for verification.

Keeping ready means that the instrument may be put into use without special preparation.

V(M) = VERIFICATION PRIOR TO MARKETING

Marketing comprises any delivery, free or against payment, of measuring instruments by the manufacturer, importer or dealer to commercial enterprises or private persons.

SV = SUBSEQUENT VERIFICATION

The period of subsequent verification is usually two years.

DC = DECLARATION OF CONFORMITY

The conformity of measuring instruments with the pattern approval is certified by the manufacturer or by a competent authority by application of the mark of conformity (issue of the declaration of conformity).

Whoever issues the declaration of conformity according to section 5 of EO has to check whether the measuring instruments comply with the pattern approval or with the conditions stated under A. For the conformity test, only standards may be used which are traceable to the national standard and which keep within sufficiently narrow error limits.

Verifiable records regarding the above test are to be retained for a period of five years. Whoever markets imported measuring instruments has to keep available for a period of five years from the date of import all records regarding tests carried out abroad.

M = MAINTENANCE

Whoever is obliged to maintain measuring instruments or to have them maintained by a maintenance service has to keep clear records from which the date of the maintenance, the maintenance work carried out and the name of the person or firm having carried out the work can be taken. These records are to be retained for a period of five years. A maintenance service for medical measuring instruments may be operated only by a person who has been authorized to do so in writing by the competent authority (supervising verification authority of the respective federal state). The authority is granted for particular measuring instruments if the applicant has the technical competence required and has at his disposal the necessary equipment and if he guarantees that the maintenance work will be carried out properly. The competent authority may require information and documents to prove these prerequisites.

MS = METROLOGICAL SPECIFICATIONS

According to the EO, Appendix 15, section 2, each absorption photometer must be accompanied by a description of the metrological specifications. It is to be certified by the declaration of conformity that the absorption photometer complies with said specifications.

T = TRANSITIONAL REGULATIONS

Pursuant to section 77 of the EO, transitional regulations have been stipulated for particular categories of measuring instruments. They are valid until January 1 of the year stated.

2. Section 4 of EO

This section covers new legal regulations for the field of laboratory medicine valid from July 1, 1989:

"Whoever carries out quantitative medical laboratory examinations with medical measuring instruments has to supervise the measurement results by internal laboratory quality control and by participation in two intercomparisons per year pursuant to part I, section 2 of the guidelines of the Federal Medical Association for the quality assurance in medical laboratories [4]. He has to retain the records regarding the tests carried out and the certificates of participation in intercomparisons for a period of five years and submit them to the competent authority upon request."

This does not apply at present, and until the guidelines of the Federal Medical Association have been supplemented, to quantitative medical laboratory examinations with carrier-bonded reagents (dry chemical procedures). The respective part of the guidelines is at present being drawn up by the Federal Medical Association.

3. Relations between the Verification Ordinance and OIML International Recommendations and drafts

There are many relations between EO (and the complementary PTB-Requirements [3]) on one side and corresponding OIML Recommendations or drafts on the other.

TUBES FOR THE MEASUREMENT OF THE ERYTHROCYTE SEDIMENTATION RATE

Conformity between EO and OIML R 78.

SYRINGES

Conformity between EO and OIML R 26 for syringes with glass cylinders. Both EO and the OIML 3rd predraft for plastic syringes (SP 5S-Sr 4; 1987) rely on ISO standards.

HAEMOCYTOMETER DILUTION PIPETTES

The OIML 2nd predraft (SP 26-Sr 2; 1987) has been withdrawn because of the infection danger by possible mouth pipetting.

BLOOD CELL COUNTING CHAMBERS

Conformity between EO and OIML 1st predraft (SP 26-Sr 1; 1988).

CLINICAL THERMOMETERS MADE OF GLASS

Conformity between EO and OIML R 7 (and with the European Commission Directive No. 84/414/EC).

CLINICAL ELECTRONIC THERMOMETERS

General conformity between EO with 2 OIML first drafts (SP 12-Sr 7; 1988) with a difference in the maximum permissible inaccuracy for compact fever thermometers.

NON-INVASIVE SPHYGMOMANOMETERS

Conformity between EO and OIML R 16 (1973) concerning only non-electrical and non-automatical sphygmomanometers with slight difference concerning the maximum permissible error. Conformity between EO with OIML 1st predraft (SP 11-Sr 5; 1987).

TONOMETERS

It was proposed by BIML (1981) to adopt an ISO standard after its completion as an OIML Recommendation. This work shall be done by SP 26.

HIGH ACCURACY AND SPECIAL-ACCURACY WEIGHING MACHINES

Conformity between EO and OIML R 76-1 concerning the general requirements, not the maximum permissible inaccuracy.

ELECTROCARDIOGRAPHS WITH AUTOMATED INTERPRETATION

Electrocardiographs without interpretation as described in OIML R 90 are not being object of the EO.

AUDIOMETERS

Conformity between EO and OIML 2nd predraft (SP 14-Sr 2; 1989) on pure tone audiometers.

FOOT CRANK ERGOMETERS

It has been proposed by SP 26 to elaborate an OIML Recommendation on the base of the EO.

THERAPY LEVEL DOSEMETERS

OIML 2nd predraft (SP 16-Sr 1; 1975), no further OIML work since then.

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Bundesgesetzblatt, Teil I, Nr. 43, S. 1657-1684.

[2] Anlagenband zum Bundesgesetzblatt, Teil I, Nr. 43, S. 67-79.

[3] Eichordnung (EO) vom 12. August 1988, published by the Physikalisch-Technische Bundesanstalt, Deutscher Eichverlag, D-3300 Braunschweig, Postfach 29 03
EO, Allgemeine Vorschriften (order number 9560)
EO, Volumenmeßgeräte für Laboratoriumszwecke, Appendix 12 of EO, (order number 9572)
EO, Medizinische Meßgeräte
1. Appendix 15 of EO
2. EEC directives
3. PTB-Requirements
(order number 9575).

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LABORATORIES for FORCE-METROLOGY *

by **F. PETIK**
Bureau International de Métrologie Légale

A force measurement laboratory represents "heavy metrology"; usually large and heavy equipment and spacious rooms, often with special auxiliary equipment.

Reasons for installing a force-metrology laboratory

A practical need, a demand from industry or other branches of the national economy, or the long-term development trends of the economy may justify the construction of such a laboratory. The extent of the facilities, installations, and measurement ranges is also dependent on national needs. Some of the possible fields of application are:

— Material testing machines, used in industries producing metals, machinery, textiles, rubber, plastics, in laboratories destined to ensure the quality of such goods imported from abroad, and in the building industry. Most material testing machines, in tensile and compression testing, supply the measurement result as a force value; accordingly, the essential part of the testing machine is the force measuring device. This may be of the pendulum type (Fig. 1) (with lever transmission or hydraulic transmission) or of the spring type. Modern testing machines, the so-called electronic machines, have also a spring-type force measuring device. The built-in load cell is a very rigid spring, small deformations of which are measured by strain gauges or similar devices connected to electronic equipment for display, recording, and processing of measured data (Fig. 2).

Testing machines, especially the force-measuring device, need constant supervision by the user, and — as prescribed by the metrological regulation of many states — official verification, both initially and periodically. Force-measuring devices of testing machines are verified by dynamometers, which are transfer standards ensuring the traceability of the measurement by the testing machine to the national or regional force standard.

— Dynamometers, used for various force-measurement tasks in many fields of technology. These dynamometers have of course to measure correctly, i.e. they must be traceable to force standards (Fig. 3).

A few examples of practical application: The correct tensioning of various elements in buildings, e.g. prestressed reinforced concrete elements, or the pretensioning of the cables of a suspension bridge, or of an electricity power line. The traction force of vehicles is a characteristic which should be measured reliably (locomotives, road vehicles, ships, aircraft).

— Safety requirements, which also necessitate force measurements, e.g. checking the maximum load of a crane, or the axle load of vehicles to prevent early deterioration of roads, or the correct loading of aircraft to maintain the centre of gravity within the permitted limits.

(*) Presented at the OIML Seminar on Planning and Equipping Metrology and Testing Laboratories, Paris, 25-26 September 1989.

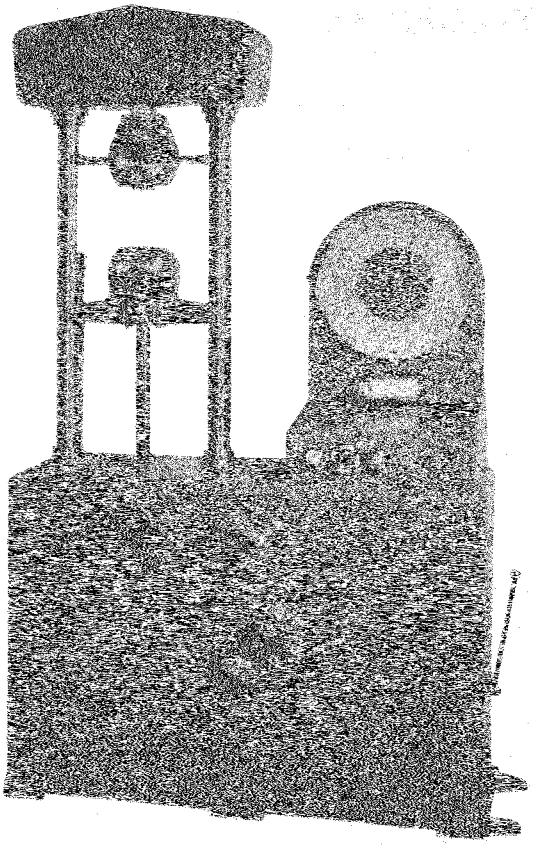

Fig. 1. Mechanical tensile testing machine. Pendulum type force measurement with lever transmission (About 1955, AVK, Budapest, Hungary).

Fig. 2. Modern electronic testing machine with computer (Zwick, Ulm, FRG).

Tasks of the national force-measurement laboratory

A. Standards

One of the primary tasks of the national laboratory is to maintain the national standards of force. In each country there must be a place where the units of measurement, their multiples and submultiples are reproducible with the highest accuracy, sufficient for the requirements of the given country. These standards must be continuously maintained in perfect working order, their accuracy being ensured partly by fundamental measurements, partly by comparisons with other national or international standards.

B. Calibration

The second task is the calibration of portable force-measuring instruments (dynamometers) on the force-standard machine (Fig. 4). This operation is the first link in the hierarchy scheme to be discussed later. The calibration of force-measuring instruments establishes a functional relationship between the conventionally true force values, as represented by the force standard, and the output signal (indication) of the dynamometer. According to national regulations, calibration can be a voluntary act, or compulsory (verification).

Useful information on the calibration of force-measuring instruments, and also of other types of instruments can be found in the BIML Publication "Guide to calibration", 1989.

C. Pattern approval

The metrological regulations of several states prescribe the requirements for pattern approval of force-measuring instruments, of dynamometers and of testing machines. This is an important step to ensure that only reliable types of instruments are used. Pattern evaluation is applied to all characteristics of the instrument which may have an effect on its durable operation and performance.

D. Verification

The verification of material-testing machines used in various laboratories and factories is often a task of the national force-metrology laboratory, if an official verification is prescribed by metrological regulations. The calibration or verification of the force measuring device of material-testing machines establishes the difference between the values indicated by the machine and the conventionally true values, as represented by the transfer-standard dynamometer.

E. Routine force measurements

The force measurement laboratory is equipped with various portable instruments, mechanical dynamometers or load cells. Industrial or other companies, where the need for force measurement arises only from time to time, cannot buy dynamometers for occasional use. In such cases the evident solution is to ask the cooperation of the national force measurement laboratory where the necessary equipment and specialized skill is available. Sometimes the advice of laboratory staff on force measurement is sufficient.

F. Measurement regulation

Force standards and transfer standards (dynamometers) should be used in a manner strictly in accordance with the prescriptions of the metrological laboratory. Of course it is not desirable to develop different prescriptions for each country; it is preferable to adopt international standards (OIML International Recommendations,

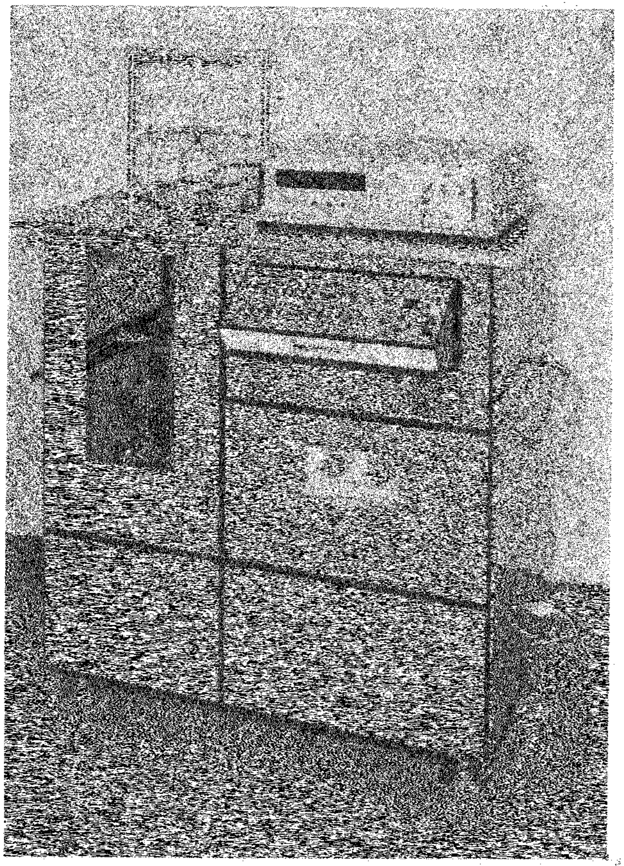

Fig. 3. Calibration of a load cell on a small capacity force standard machine (OMH, Budapest).

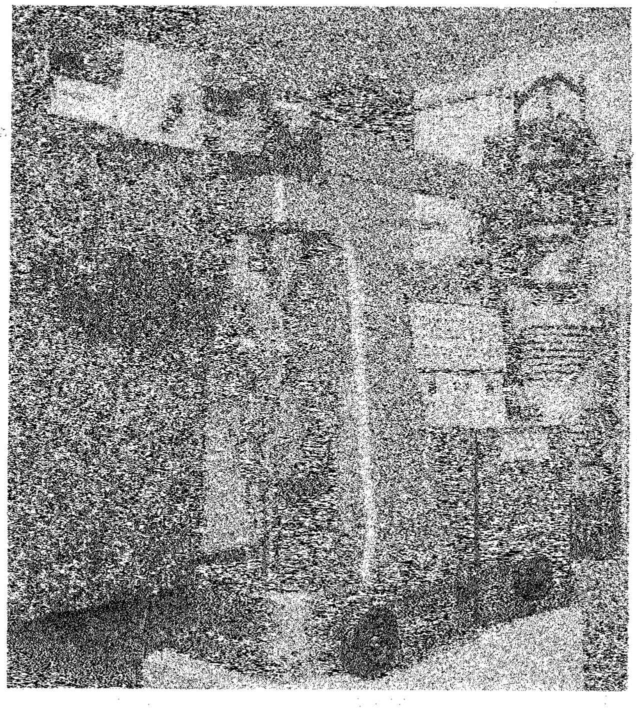

Fig. 4. Calibration of a dynamometer on a 100 kN force standard machine (OMH, Budapest).

ISO Standards, regional Standard Specifications) or to adapt the existing national regulations to them taking into consideration, if necessary, special national requirements.

The following OIML International Recommendations are concerned with the fields being discussed:

Testing machines: R 64, 65
Load cells : R 60
Hardness testing: R 9 to 12, 37 to 39.

Equipment of the force-measurement laboratory

The unit of force is an SI derived unit, the newton, derived as the product of mass and acceleration:

$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2.$$

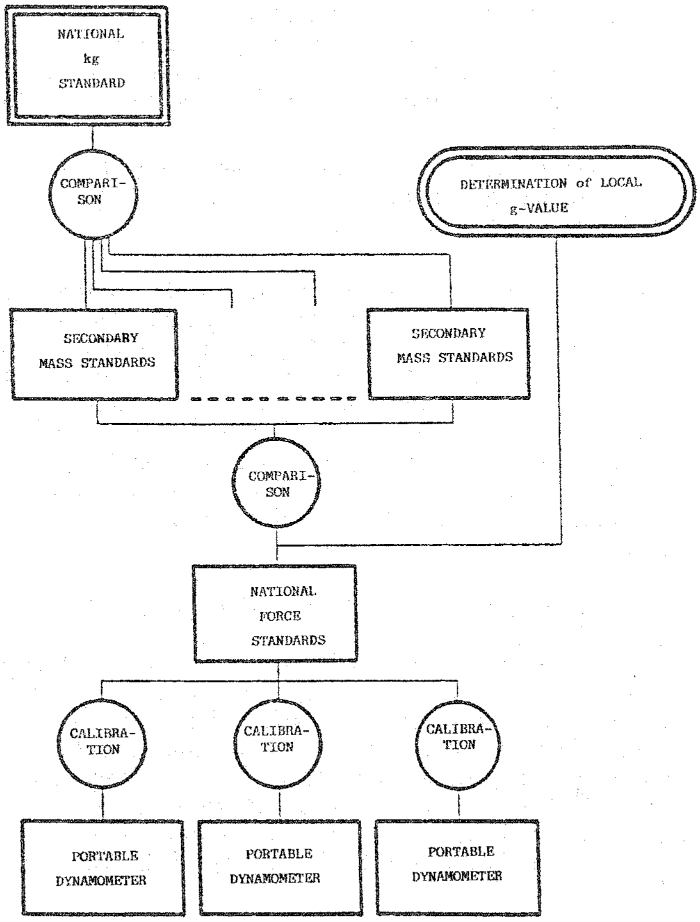

Fig. 5. Hierarchy scheme of force measurements.

Thus three SI base units, namely kg, m, s are included in the expression of this unit.

The practical realisation of the unit of force, of its multiples and submultiples is an experiment in which a precisely defined mass is exposed to the effect of the local acceleration due to gravity. In practice the derivation is made according to the hierarchy scheme shown in Fig. 5.

Force standards are machines capable of producing particular force values with a high accuracy. They can be classified according to the following three groups:

- Deadweight machines
- Machines with deadweights and mechanical or hydraulic multiplication
- Machines with master dynamometers.

A. **Deadweight machines** are the most accurate and the most expensive standard installations. The existing maximum force produced at present by deadweight force standards is 4.5 MN (at NIST, Washington, D.C., U.S.A.). In Europe there is a machine of 2 MN in Berlin, GDR, and of 1 MN in Braunschweig, FRG. The claimed uncertainty of such machines is less than or equal to $\pm 2 \times 10^{-5}$. The error components to be considered here are the determination of the masses of the deadweights, the uncertainty of the measurement of the local value of the acceleration due to gravity and the effect of changing air buoyancy. Deadweights are supposed to hang freely on the instrument to be calibrated, thus normally no friction errors are to be taken into consideration. The effects of some unknown factors are the subject of research.

The need for deadweight force standards arises only in highly developed industrial countries, with the exception of the range of low force values, up to about 2 kN, which can be built at acceptable cost (Fig. 3).

B. Force standard **machines with mechanical or hydraulic transmission** can be built at a cost which is high, though still reasonable. Mechanical transmission levers used to have a transmission ratio of about 1: 20 (Fig. 6), though ratios of 10 or 100 can also be found and, in a special case, even 1: 15 000. The deflection of the lever and possible changes in the position of knife edges (unstable mounting) are sources of error additional to those found in deadweight machines. Hydraulic-transmission machines are pressure balances; forces are generated by weights acting on a rotating piston. The highest measuring ranges have been realised by hydraulic machines (e.g. 20 MN in Japan). Claimed uncertainties of hydraulic and lever-type machines are from 1×10^{-4} to 5×10^{-4}.

The components of uncertainty are determined experimentally or calculated and estimated theoretically. One method is by tracing the force value of the transmission-type force standard to a standard of a higher order, that is to a deadweight machine. This method is not always feasible, for the uncertainty of the portable standard instruments is of the same order as that of the stationary standards to be checked. Transfer standards have recently become available which can be used, with special care, with an uncertainty of about 5×10^{-5}, i.e. better than that claimed for force standard machines with multiplication of deadweight action. By tracing back to higher order standards the laws of error propagation apply: the uncertainties of the primary and transfer standards are to be included in the value specified for the secondary standard.

C. The third group of **force-standard machines** is **based on the use of transfer-standard dynamometers** (Fig. 7). These are machines which can load simultaneously and equally two dynamometers arranged mechanically in series. The indications of the dynamometer to be calibrated are compared with those of the transfer-standard dy-

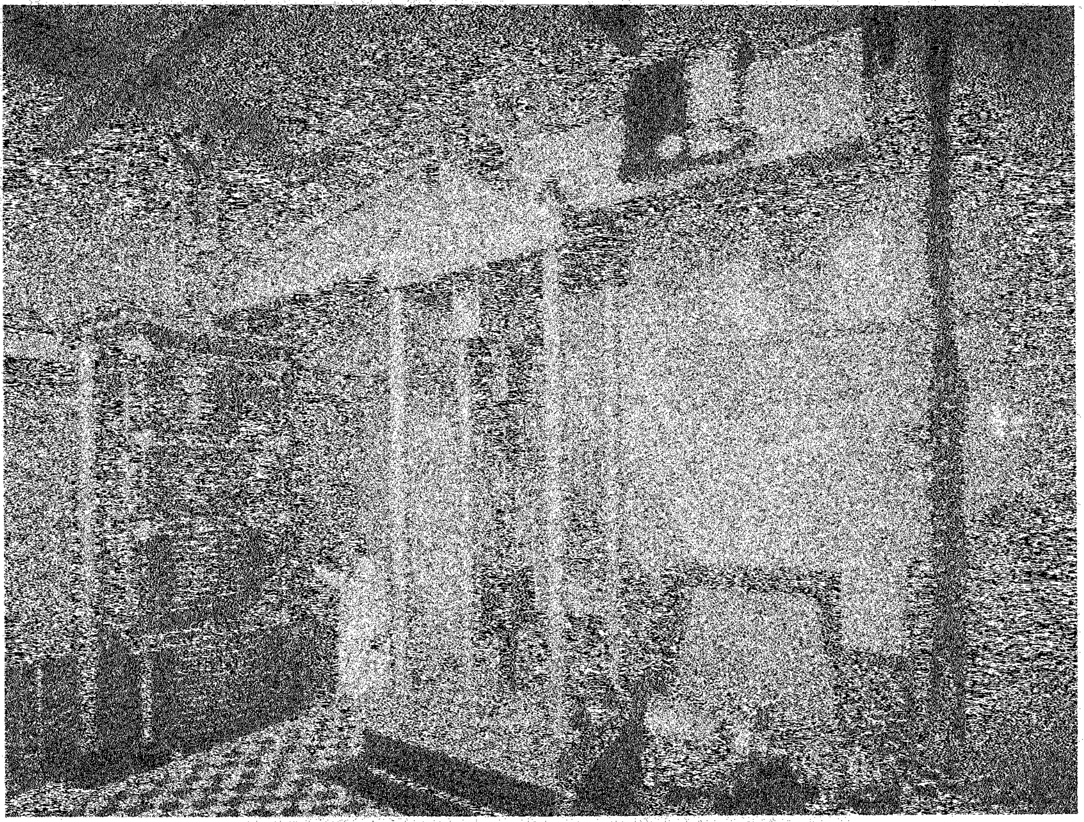

Fig. 6. 1 MN force standard machine with lever transmission (OMH, Budapest).

namometer calibrated previously on a force-standard machine of the types already discussed. For force generation (compression or tensioning of the two dynamometers) a relatively simple hydraulic device can be employed, without indication of the acting force or pressure; nevertheless the possibility of fine control of small displacements, and of ensuring stable positions (absence of hydraulic leak losses) is essential. This type of equipment is recommended for laboratories newly starting in this activity and also for working dynamometers used very frequently under unfavourable conditions of operation or transport, which should be checked periodically by a rapid and simple comparison with a master dynamometer kept under laboratory conditions.

These or similar machines can be used also for the calibration of dynamometers in the so-called pyramidal build-up-procedure. Three dynamometers or load cells of identical design, each previously calibrated on a deadweight standard, are arranged on the plate of the calibrating machine, which may also be a material-testing machine. On a plate above the three load cells, another load cell having a measuring range three times higher is arranged. By compressing the 3 + 1 load cells the calibration is performed as in the previous case.

Force-standard machines are very expensive and are not used continuously; nevertheless they should be available at a reasonable geographical distance. A very good solution is an agreement by several smaller states to install a centrally located regional force standard machine, operated in common.

D. In addition to the force-standard machines, the laboratory for force metrology should be equipped with **portable force measuring instruments.** These can be spring

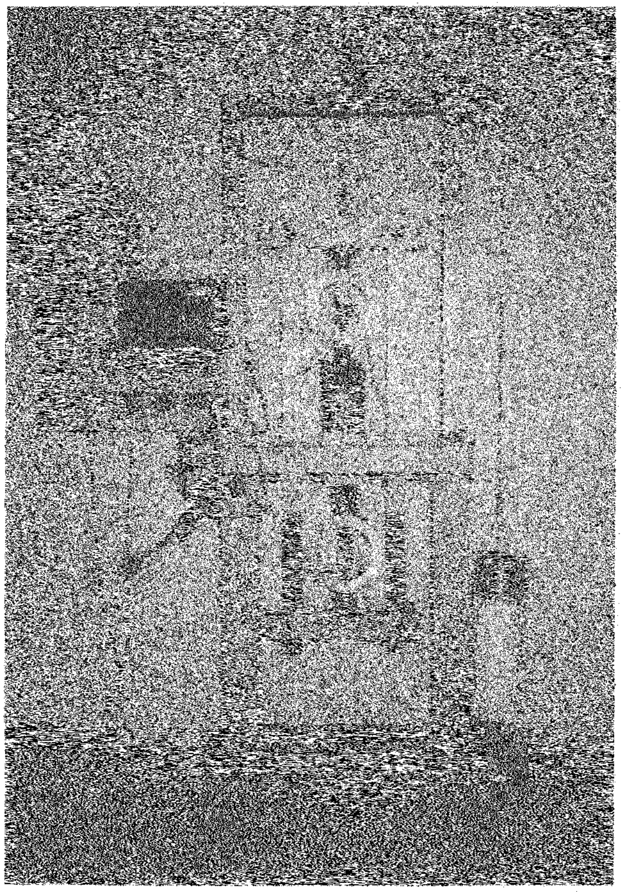

Fig. 7. Calibrating machine with transfer standard dynamometer (CERIB, Epernon, France).

devices with mechanical or electrical indication of deformation, or electrical load cells with various principles of operation, of which the most frequently employed is the strain-gauge type, both for tension and compression. The measuring range of these instruments depends on the needs of the fields where they are to be employed. In the verification of material-testing machines tensile forces higher than 1 MN occur only exceptionally. The verification of concrete testing machines, however, may necessitate compression dynamometers of several meganewton capacity, though the accuracy required of those machines is less than that of those used in testing metals. For the calibration of metal-testing machines (class 0.5 or 1 %) dynamometers having a repeatability error range of 1×10^{-3} to 2×10^{-3} are required; for compression tests on concrete (class 2 or 3 %) a dynamometer with a repeatability error range of 5×10^{-3} is sufficient.

It is advisable to have at the disposal of the force metrology laboratory a **delivery** van in which specialists can travel with the necessary instruments, together with the tools and auxiliary devices required for their work, to the various places of measurement.

In a developing country the laboratory for force metrology may be adjoined to a **material testing laboratory,** with equipment appropriate to local demands.

Some countries have also **standard equipment for** the conventional **hardness scales** (Rockwell, Brinell, Vickers) (Fig. 8).

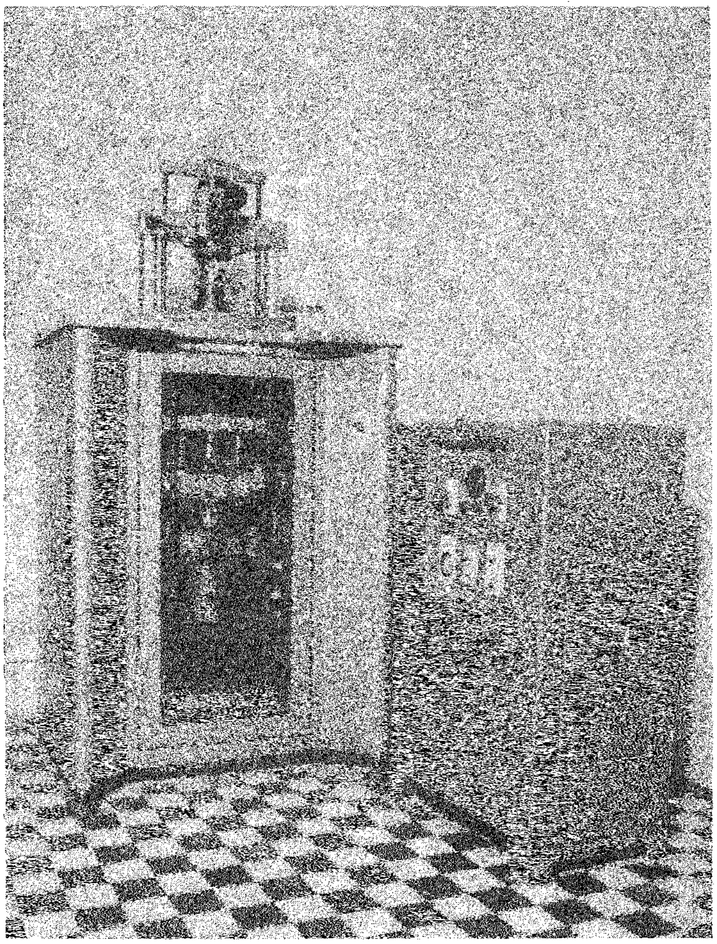

Fig. 8. Rockwell hardness standardizing machine (OMH, Budapest; made in GDR).

Because of the similarity of their tasks and equipment, it is desirable that the force measurement laboratory cooperates closely with the mass-measurement laboratory responsible for the verification of weighing instruments and balances.

Laboratory building

There are well established rules for the construction of metrological laboratories; they are not repeated here (see for instance the BIML Publication "Planning of metrology and testing laboratories" - 1986). But, as mentioned in the introduction, force measurement can be regarded as "heavy metrology", therefore it is useful to mention here some specific features of the building housing the force metrology laboratory.

Force-standard machines are big, their height generally extends to two or three floors of the building. Beyond the height of the actual machine, sufficient space should be available above and around it for the crane if it is necessary for assembling the machine, or for moving the dynamometers to be calibrated. To move heavy dynamometers, often simple transport equipment (lifting devices, trolleys, rails) is installed and a large door leads directly to the exterior, permitting the entry of a small van into the laboratory. Because of the need for heavy base blocks and foundations, the force-metrology laboratory should be installed on the ground floor. The laboratory floor should have a covering very resistant to oil and to wear.

If material testing is also included among the tasks of the laboratory, foundations should be independent of the building, so that vibrations and shocks arising when specimens break are not transmitted to other laboratories. In such circumstances the best solution is separate buildings for the force measurement laboratory and the material testing laboratory.

Air conditioning of a large laboratory is expensive; in moderate climatic conditions it is not an essential requirement, especially at the beginning of the operation of a force measurement laboratory. But it is desirable to design the building so that air conditioning may be installed later.

The laboratory should have a small workshop where mechanical and electrical repair work can be done. The maintenance of measuring equipment requires a small stock of essential spare parts, especially those having long delivery times.

Personnel

It goes without saying that the efficiency of the laboratory depends on the knowledge and personal qualities of its staff. The composition of the staff depends on the tasks and equipment of the laboratory; consequently it is difficult to give general advice.

ROYAUME-UNI

MANUFACTURING LOAD CELLS CONSISTENTLY to MEET OIML R 60 REQUIREMENTS *

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SUMMARY — This paper examines what is necessary for a manufacturer to produce load cells to meet consistently the stringent accuracy requirements recommended by the OIML and now adopted by leading Weights and Measures Authorities around the world.

Ensuring that each and every standard production load cell meets the required accuracy level demands very strict manufacturing procedures and this paper outlines the requirements for this in terms of load cell design, quality control and production techniques as well as describing some of the equipment necessary.

Introduction

With the introduction of the OIML recommendations for the testing of load cells, Weights and Measures Authorities are now well equipped to determine load cell accuracies and hence their suitability for particular weighing applications. However there may still not be sufficient control to ensure that manufacturers supply consistent quality product after the approval has been granted.

Although under an obligation to supply approved quality load cells for stamped applications, companies may not always have the necessary production facilities or discipline to do this. They may be capable of producing a small number of "golden load cells" which are capable of passing the Weights and Measures stringent tests but are they then in a position to continue to supply products to the required standard ?

So how does a load cell company set out to ensure that its load cells do meet the stringent requirements? This paper outlines the salient features of the product and the production processes that are required to achieve this.

Load cell performance

The performance of a load cell is a function of three key factors:

— Design
— Build
— Test.

All three areas must be optimised in terms of control to ensure consistent quality.

Good basic materials and an accurate and well disciplined production process are needed to ensure the repetitive manufacture of high quality load cells. The key constituents of the process may be enumerated as follows:

(*) This paper was presented at the Conference "Weighing, calibration and quality standards in the 1990s" in Sheffield, 13-14 February 1990 and is reproduced with the kind permission of South Yorkshire Trading Standards Unit, organizers of the Conference.

- The best possible load cell elements — embodying high material stability, minimum hysteresis and constant predictable quality.
- Optimum quality strain gauges — very accurately produced and designed, matched and adapted specifically for each individual load cell type and material batch.
- Accurate and controlled bonding — using special, high temperature adhesive, carefully cured under well-defined temperatures and bonding clamp pressures.
- A repeatable and accurate production process — carried out according to precise and well documented procedures and employing highly skilled and qualified personnel.
- High accuracy test equipment — including dead load temperature test machines to full load cell capacity (inaccuracy less than 0.005 %).
- Approved quality control procedures — defining test equipment traceability to recognised external standards.

Load cell design

The design of the load cell element is of paramount importance to ensure not only its discrete performance but to further ensure that the accuracy levels are maintained when the cell is mounted in its application. It is vital that the cell only sees and measures the requisite forces in a repeatable fashion. To this end, close customer liaison is essential to understand and cater for their needs.

The choice of material for the load cell body is usually a compromise between performance, cost, machineability and environmental compatibility. The metal used must be of predictable quality and performance. The only way to guarantee this, is to purchase material in annual lots from one "melt". The raw material will contain unwanted residual stresses and a carefully controlled heat treatment cycle is necessary after machining to ensure an homogenous billet prior to gauging. Each time the material is changed, then a small sample of load cells must be produced to check strain gauge matching and overall performance.

For many harsh-environment applications, stainless steel is the obvious choice for the load cell body material. However the available steels are not ideal for this application. Most exhibit poor hysteresis characteristics and are difficult to machine. As a result therefore, very few stainless steel load cells are capable of meeting the required approval standards. In order to achieve these performance levels considerable experience is necessary together with the ability to understand and correct the inherent hysteresis through strain gauge design.

Apart from temperature effects, the three main load cell parameters are:

- Linearity (or non-linearity)
- Creep
- Hysteresis.

Linearity is usually a function of the metal element, which cannot readily be modified by the design of the gauges. However with experience, both creep and hysteresis can be controlled in the design and manufacture of the gauges. This is one of the reasons why leading load cell companies design and produce their own gauges. They can then modify the parameters on a continual basis to match exactly the behaviour patterns of the load cells, thus ensuring consistently high quality. The temperature characteristics of individual strain gauges will vary depending on the thickness of the foil used even though the material is purchased in quantities for up to 10 years usage. As a result gauges produced from one square of foil will normally be kept together in sets for use in individual load cells.

Thus it can be seen that the performance of a load cell is a complex function of the metal sensing element and the strain gauge. The match of the gauges to the metal has a direct effect on the accuracy of the finished load cell. If this is not optimised then no amount of calibration can change the cells performance.

Strain gauge bonding

The bonding of the gauges to the metal is probably the most important step in the manufacturing process. Accurate gauge position marking and surface cleaning are essential. After this, jigs must be used to provide the required clamp pressure on the bonded gauges. A carefully controlled heat-curing cycle then ensures the required adhesion and glue-line thickness. This glue thickness plays an important part in the overall performance of the load cell in terms of creep and long-term stability. (See Fig. 1). The actual positioning of the gauges has a marked effect on the performance of a load cell especially in terms of load application sensitivity.

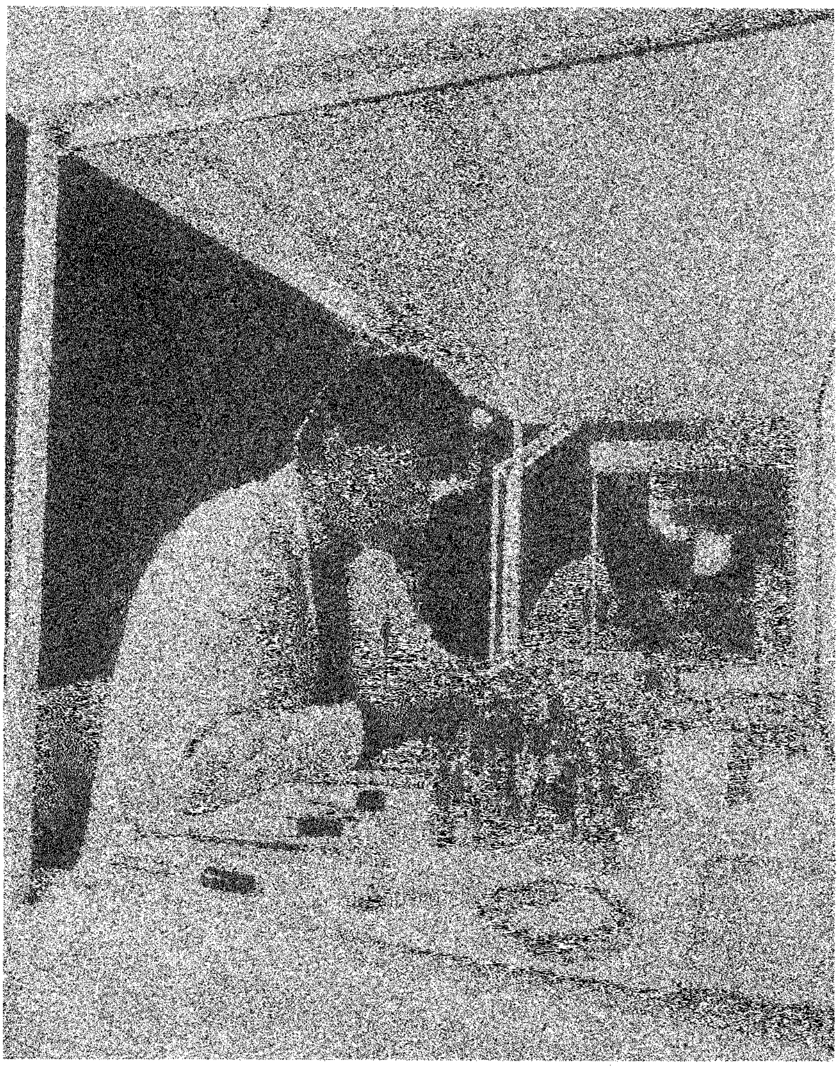

Fig. 1 — Bonding strain gauges to the load cell bodies.

Test procedure

After interwiring, the load cell begins its carefully documented test, compensation and calibration procedures. At this stage, the linearity, creep and hysteresis characteristics have been determined and no further compensation can be carried out for these vital parameters. The test routines collect data for temperature compensation and verify that the load cells meet the required in-house accuracy levels for all parameters.

The load cells at this point will still be temperature dependent. In other words, the no load output and span output will vary with temperature. The procedure to compensate for this is fairly straightforward but requires careful monitoring. It is at this very labour and time intensive stage that it may be tempting to cut corners. In practice, approved load cells are only checked at one temperature by local inspectors when they are built up into a scale. However, manufacturers have both a moral and legislative obligation to supply its customers with the required accuracy level products. In order to ensure this, then each and every load cell must be subjected to temperature testing over the full temperature range as laid down by OIML (usually — 10 °C to + 40 °C). Testing over a narrower range and then extrapolating the corrective measures is not sufficient.

To ensure each load cell meets specification it should be subjected to no load temperature testing at three temperatures. This is normally done at + 20 °C, + 40 °C and — 10 °C. It is virtually important that the load cells are soaked at each temperature for a sufficient time period. The required time for this will depend on a number of factors including the "mass" of the load cell but is normally never less than 4 hours.

Once the results of the outputs at the various temperatures have been logged, then corrective compensation can be carried out. In order to verify this compensation, the load cells must then be temperature cycled once again. The stability of the no-load output is vital to the performance of each load cell and is a fixed percentage error of the rated output. Therefore this error becomes more significant as the utilisation of the cell is lowered.

Load cell manufacturers often publicise the fact that their products are approved for use in "legal for trade" applications, say, to 3 000 divisions. However this statement is limited unless the utilisation or minimum verification interval is specified.

In other words a load cell that can be used to 60 % of its rated output need not be as accurate as one used to 30 %. Some manufacturers show this information in their literature.

Table 1 — MINIMUM VERIFICATION INTERVALS FOR THE REVERE TRANSDUCERS SSB SHEARBEAM.

MINIMUM LOAD CELL VERIFICATION INTERVAL (v_{min})						
Accuracy class			C1	C2	C3	C3/M
SSB	500 kg	g	100	50	50	30
SSB	1 000 kg	g	200	100	100	60
SSB	2 000 kg	g	400	200	200	120
SSB	5 000 kg	g	1 000	500	500	300

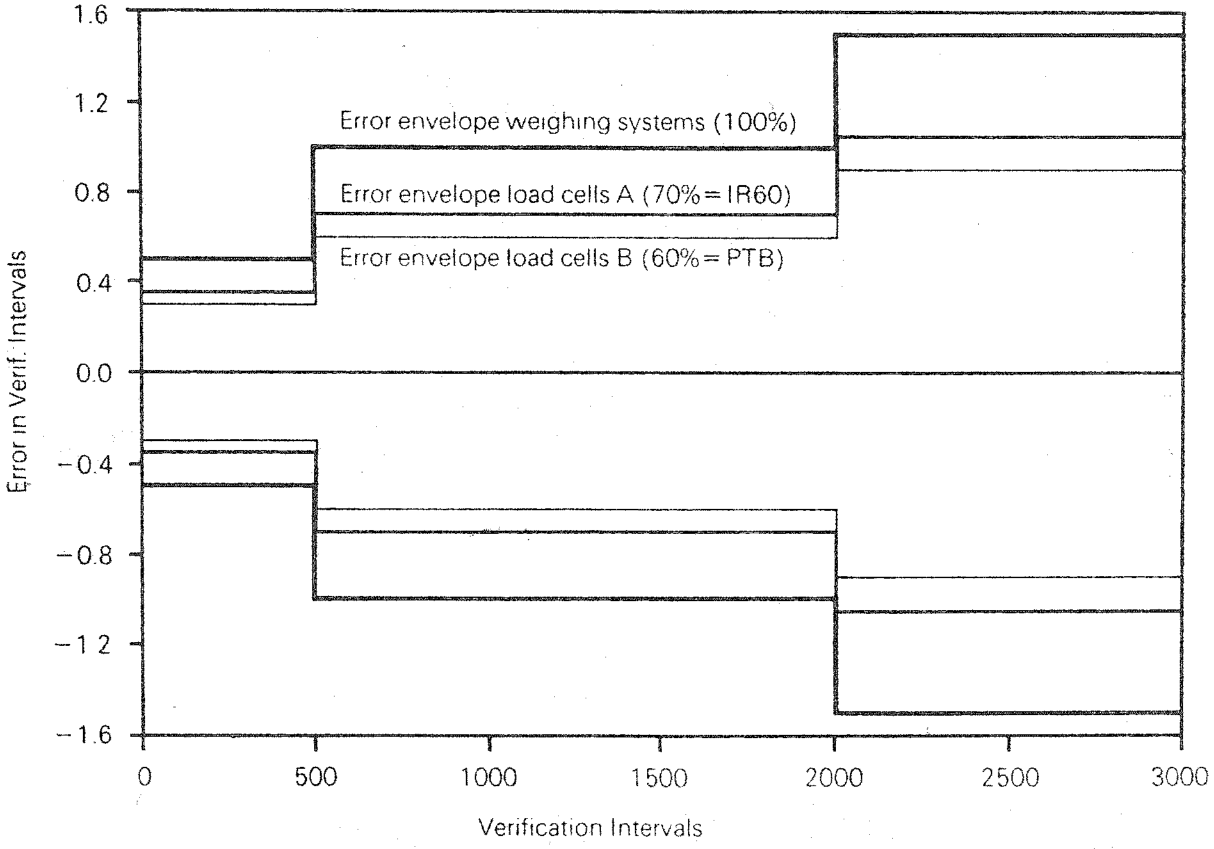

Fig. 2 — Error envelopes for load cells class c/3000.

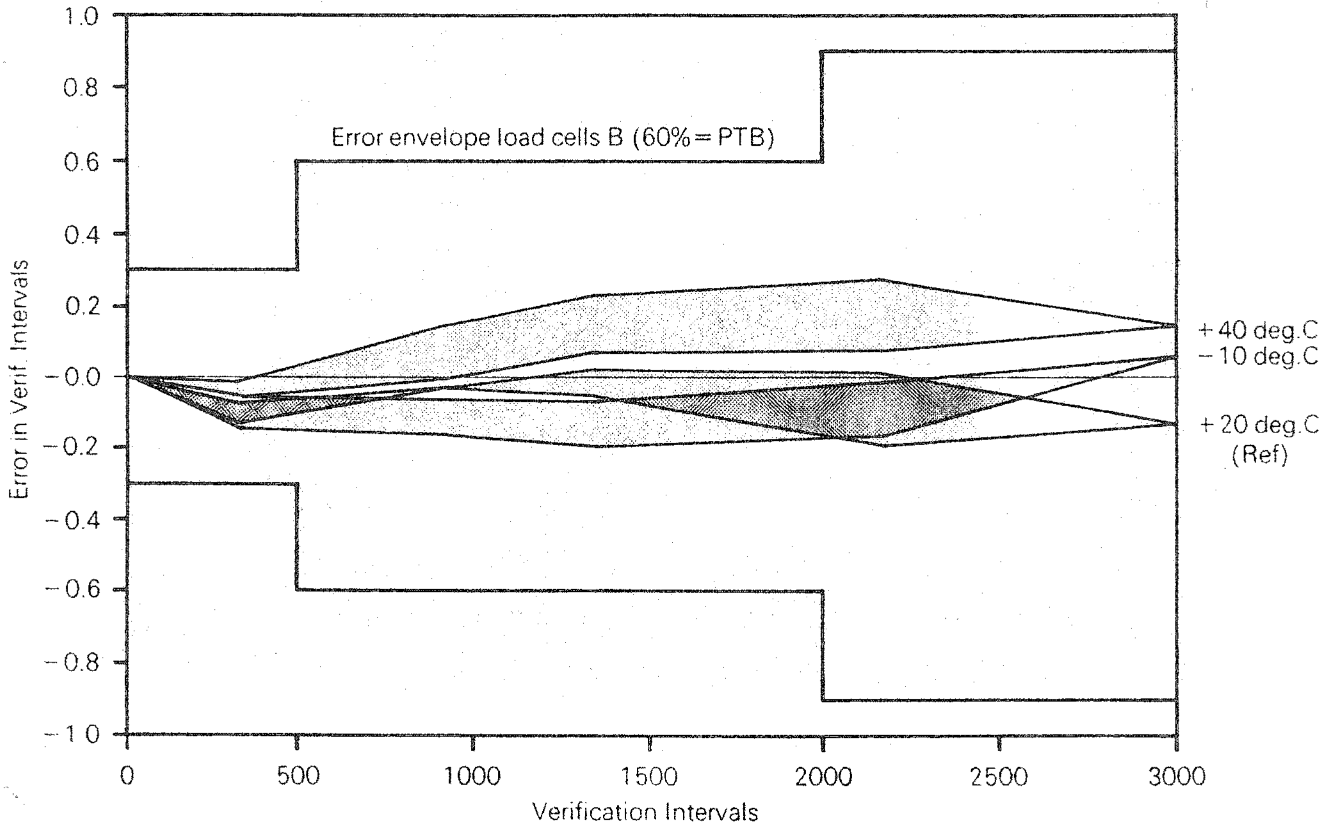

Fig. 3 — Typical temperature influence on a 40 t load cell (type CSP-M-40t-C3 Ser N° 940085).

In practice it is not commercially viable to test each load cell for span over the full temperature range. For a good quality load cell, the temperature effect on span is predictable and is expressed as a percentage of rated load not rated output. However it is vital that each cell is tested over its complete load range using dead weight equipment at one temperature.

This test involves incremental step loading in both directions. In this way, linearity, creep, hysteresis and minimum dead load return can be tested for each and every cell. On a regular basis, sample cells should be subjected to full temperature testing and any adverse trends corrected. It is particularly important to monitor creep at different temperatures.

As and when test data is obtained it should be monitored to ensure that the results fit inside the required error envelope. Normally, in-house tolerances are set inside the actual requirements. All the data obtained must be documented against the individual serial number of each cell and these must receive their own calibration certificate to be packed with the product.

Dead weight test equipment

It is relatively straightforward to build low capacity dead weight equipment up to 2 tons.

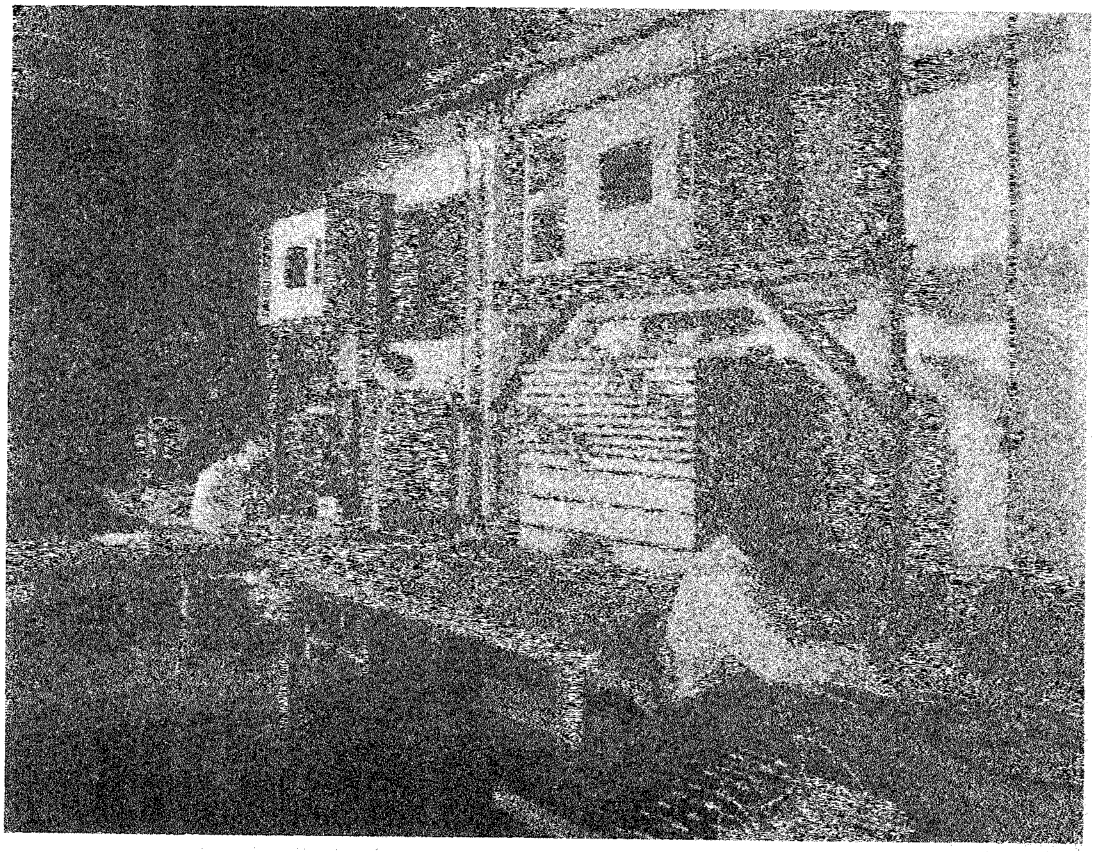

Fig. 4 — Low capacity dead weight test equipment (2 and 5 ton).

However the capital outlay to install higher capacity test machines is very high and few companies around the world have such facilities. For weighbridge load cells equipment up to 60 tonnes is necessary.

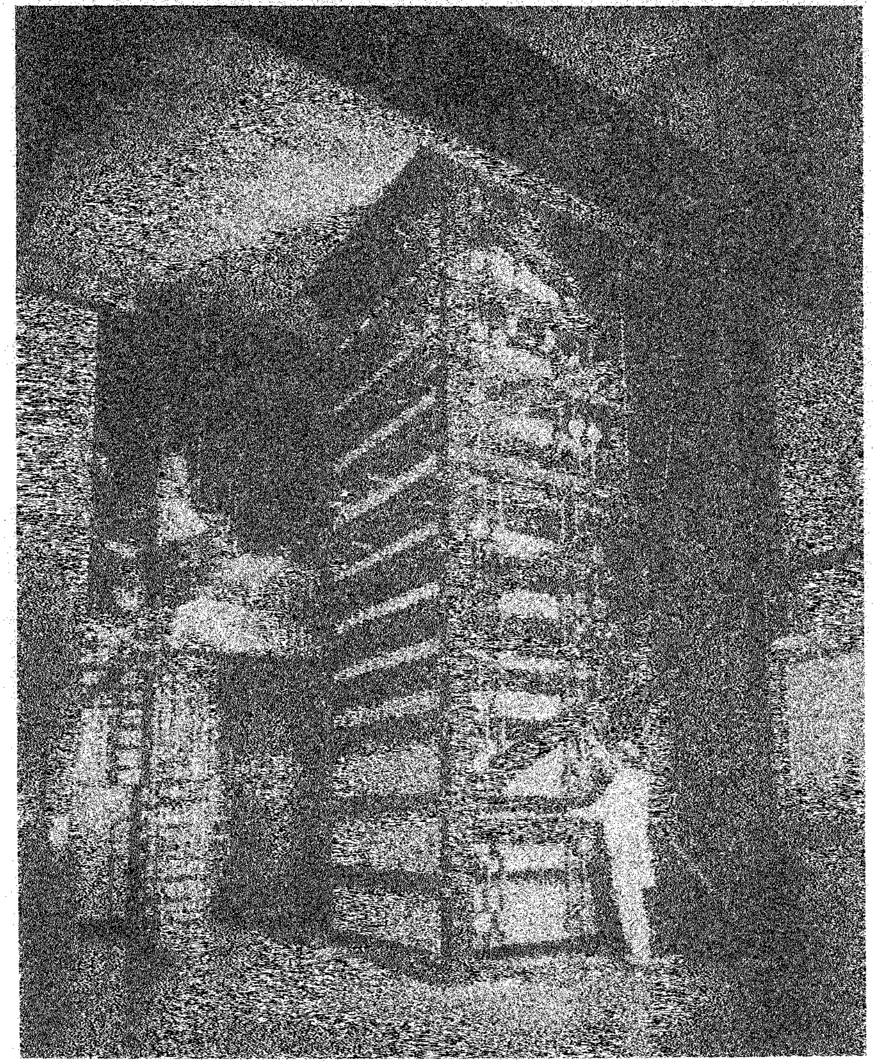

Fig. 5 — 60 tonne dead weight test machine, at Revere transducers' factory in Breda, Holland.

The design of such equipment is critical. Smooth repeatable operation is essential together with very accurate load application. The equipment must be in a carefully controlled environment to prevent draughts and humidity affecting any results. An hydraulic test rig utilising a standard cell may be adequate for general process load cells but it totally unsuitable for calibrating approved application ones.

Equipment traceability

It is vitally important that all test equipment is carefully monitored to ensure any results obtained are repeatable and meaningful. This is especially important for

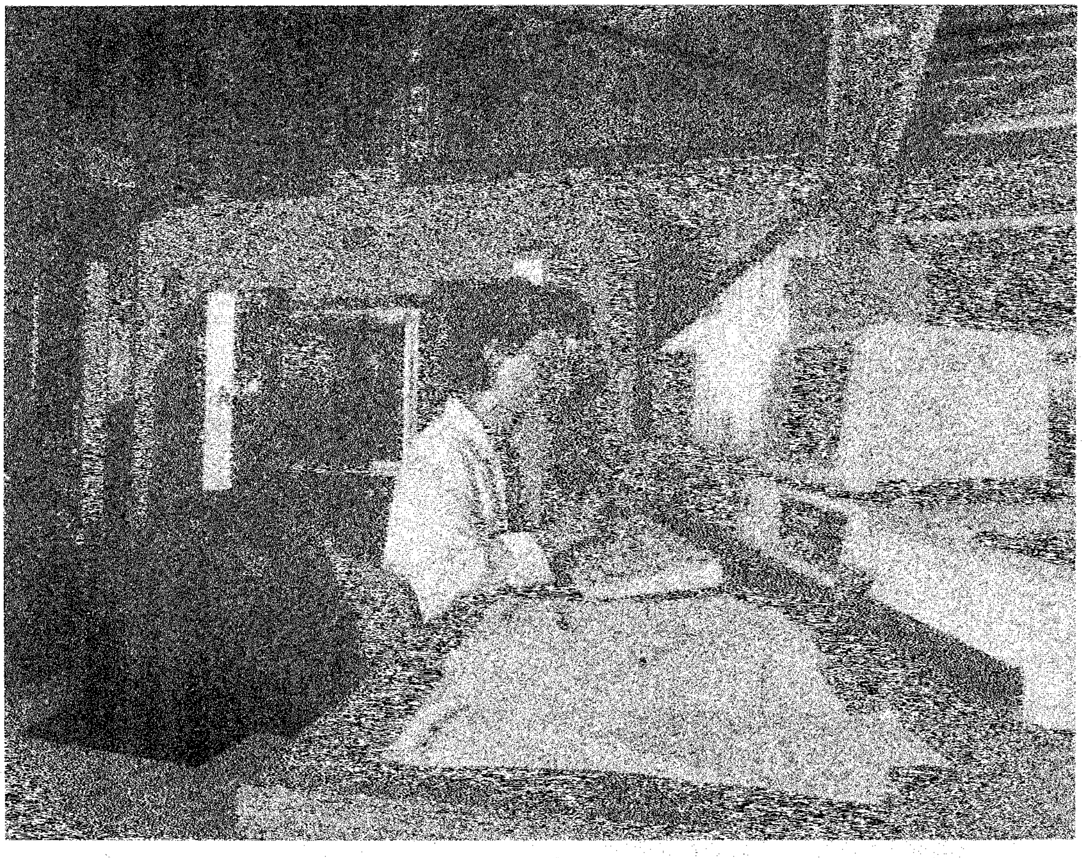

Fig. 6 — The control room for the 60 tonne machine showing the temperature chamber and computer monitoring system.

the dead-weight testers where the same load cell is taken in and out of the machine during calibration. The load application must be completely repeatable. Although the weights themselves need not be exact, they must be calibrated against known standards. This also applies to other critical measuring equipment, especially the high resolution digital indicators used during the tests.

All procedures must be very carefully documented and each stage of the production should be as operator-independent as possible. If problems arise through systematic errors then parallel checks through quality control should highlight these at the earliest possible stage.

Conclusion

Thus it can be seen that in order to consistently produce load cells that meet the requirements laid down by the OIML, extremely rigorous and regimental manufacturing and quality routines must be adopted by the manufacturer. Moreover the design of the load cell itself must be capable of offering the required accuracy when used in practice. If the load cell is only marginally capable of this, then it will be very difficult to produce it to a consistently high quality.

In order that Weights and Measures Authorities have confidence in a particular manufacturer, then they should visit such companies and assess for themselves how competent, or not, they are in being able to produce load cells to the required standards.

INFORMATIONS

MEMBRES DU CIML

AUTRICHE — Le Gouvernement vient de désigner Monsieur R. GALLE, Directeur du Service de la Métrologie, Bundesamt für Eich- und Vermessungswesen, pour représenter son Pays au CIML, en remplacement de Monsieur R. LEWISCH.

YOUGOSLAVIE — Monsieur M. MEZEK, Directeur du Bureau Fédéral des Mesures et Métaux Précieux, a terminé son mandat et quitté ses fonctions de représentant de la Yougoslavie au CIML. Son successeur devrait être prochainement désigné.

FRANCE — Métrologie historique

Le Conservatoire National des Arts et Métiers possède des collections très importantes d'instruments scientifiques et d'objets de métrologie, qui forment aujourd'hui le Musée National des Techniques. Ce musée vient d'éditer, sous la direction de Madame Elise PICARD, un catalogue détaillé de sa collection de poids français et étrangers. Ce catalogue de 146 pages, très documenté et joliment illustré, contient également en introduction des renseignements sur le Conservatoire et sur l'origine de ses différentes collections.

Le catalogue a pour titre "Inventaire des Poids 1989" et il peut être acquis au prix de 75 FRF auprès du Musée National des Techniques, 270, rue Saint-Martin, 75003 Paris.

ROYAUME-UNI

Une conférence sur la technologie du pesage, la législation dans ce domaine et l'étalonnage dans le domaine de masse, a été organisée à Sheffield les 13 et 14 février 1990 par l'autorité régionale de vérification, le South Yorkshire Trading Standards Unit. Douze exposés très intéressants y furent présentés ainsi qu'un aperçu des différentes activités de l'OIML.

Le recueil des exposés de cette conférence ayant pour titre "Weighing, Calibration and Quality Standards in the 1990s" est disponible, en nombre limité, en s'adressant à

Mr J. Buckley
Manager
South Yorkshire Trading Standards Unit
Thorncliffe Lane
Chapeltown
Sheffield S30 4XX

INFORMATION

CIML MEMBERS

AUSTRIA — The Government has designated to represent his country within CIML Mr R. GALLE, Director of the Metrology Service, Bundesamt für Eich- und Vermessungswesen, in replacement of Mr R. LEWISCH.

YUGOSLAVIA — Mr M. MEZEK, Director of the Federal Bureau of Measures and Precious Metals, has relinquished his post and ceased to serve as CIML Member for Yugoslavia. His successor is expected to be nominated within a short time.

FRANCE — Historical metrology

The Conservatoire National des Arts et Métiers has some very important collections of scientific instruments and metrology objects most of which are exhibited in its museum "Le Musée National des Techniques". This museum has recently, under the direction of Madame Elise PICARD, issued a detailed catalogue of its collection of French and Foreign weights. This largely documented and nicely illustrated catalogue of 146 pages also contains as introduction information about the origin of the Conservatoire and its different collections.

The catalogue has the title "Inventaire des Poids 1989" and can be purchased at the cost of 75 FRF from Musée National des Techniques, 270, rue Saint-Martin, 75003 Paris.

UNITED KINGDOM

A conference with the title Weighing, Calibration and Quality Standards in the 1990s was held in Sheffield on 13-14 February 1990, organized by the South Yorkshire Trading Standards Unit. Twelve very interesting papers on weighing technology and legislation within this field were presented as well as a review of the various OIML activities.

The conference proceedings are available in limited number on request addressed to the Editor:

Mr. J. Buckley
Manager
South Yorkshire Trading Standards Unit
Thorncliffe Lane
Chapeltown
Sheffield S30 4XX

Workshop
on
Medical Measuring Instruments
15-26 April 1991
Munich, Federal Republic of Germany

Jointly organized by Physikalish-Technische Bundesanstalt, PTB and Deutsche Akademie für Metrologie, DAM

Sponsor: Bundesministerium für wirtschaftliche Zusammenarbeit, BMZ

OBJECTIVES:

To familiarize verification inspectors with the

- measuring principles
- international recommendations and standards
- verification procedures

for clinical thermometers and blood-pressure instruments.

PARTICIPANTS' QUALIFICATIONS:

Participants should be employees of a national metrology service and familiar with practical verification work. Full proficiency in English is indispensible, as English will be the working language.

APPLICATION:

Application forms can be obtained from:

Physikalisch-Technische Bundesanstalt
Gruppe 8.5, Technische Zusammenarbeit
Postfach 33 45

D-3300 Braunschweig
Federal Republic of Germany

Telex: 952 822 ptb d
Telefax: 49 531 592 4006
Telefon: 49 531 592 8500

The application forms shall be returned to PTB not later than 1 October 1990.

COSTS:

The organizers will cover all the costs of training, board and lodging, international travelling expenses and local transportations for a certain number of participants. Self-financing would be appreciated.

SELECTION OF PARTICIPANTS:

Preference will be given to participants from those countries that already have legal requirements for medical measuring instruments or that have already started or will start verification work in this field. Confirmation of participation will be sent in January 1991.

QUELQUES EVENEMENTS A VENIR — SOME COMING EVENTS

20-23 août 1990 August	1990 Int. Symp. and Exhib. on Electromagnetic Compatibility, VA, USA Information: Mr Thomas W Doeppner, 8323 Orange Court, Alexandria, VA 22309, USA
28-31 août 1990 August	Int. Conf. on Electromagnetic Compatibility, York, UK Information: Conference Services, IEE, Savoy Place, London WC2R OBL, UK
29-31 août 1990 August	6th Conference on Measurements in Clinical Medicine (IMEKO TC 13), Sopron, Hungary Information: IMEKO Secretariat, H-1371 Budapest, P.O. Box 457
4- 7 septembre 1990	12th Conference on Weighing Technology (IMEKO TC 3), Szeged, Hungary Information: IMEKO Secretariat, H-1371 Budapest, P.O. Box 457
17-19 septembre 1990	4th Symposium on Temperature and Thermal Measurement in Industry and Science (IMEKO TC 12), Helsinki, Finland Information: Finnish Automation Support Ltd., Mämeentie 6A15, 00530 Helsinki
24-27 septembre 1990	Workshop on Measurement and Inspection in Industry by Computer Aided Laser Metrology (IMEKO TC 14) Balatonfüred, Hungary Information: IMEKO Secretariat, H-1371 Budapest, P.O. Box 457
26-29 septembre 1990	Symposium on Knowledge-based Measurement - Application Research, Education (IMEKO TC 7 and TC 1), Karlsruhe, FRG Information: VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik, D-4000 Düsseldorf 1, P.O. Box 1139
3- 5 octobre 1990	Industrial Noise Measurement, Analysis and Control, Cranfield, UK Information: Mr M.A. Tomlinson, School of Mechanical Engineering, Cranfield Institute of Technology, Cranfield, Beds MK43 OAL, UK
15-17 novembre 1990	4th Symposium on Intelligent Measurement of Electrical and Magnetic Quantities (IMEKO TC 4), Varna, Bulgaria Information: Dr. I. Adarski, Institute for Micro-processor Instruments- and Systems, Lenin Bd., 7th km, 1184 Sofia

REUNIONS OIML

	Groupes de travail	Dates	Lieux
SP 7-Sr 2	Masses. Problèmes généraux. Dispositifs électroniques *Mass. General problems. Electronic devices*	16-19 Juil./*July* 1990	WASHINGTON U.S.A.
SP 8	Poids *Weights*		
SP 8-Sr 5	Poids utilisés dans le commerce et l'industrie *Weights used in trade and industry*		
SP 8-Sr 6	Poids de précision *Weights of high accuracy*		
SP 22-Sr 4	Principes de la vérification des instruments *Principles of verification of instruments*	8-10 Oct./*October* 1990	BIML, PARIS
SP 5D-Sr 3	Compteurs d'eau *Water meters*	11-12 Oct./*October* 1990	BERLIN-OUEST
SP 5D	Mesurage dynamique des quantités de liquides *Dynamic measurement of quantities of liquids*	22-26 Oct./*October* 1990	WASHINGTON U.S.A.
SP 5D-Sr 1	Compteurs et ensembles de mesure de liquides autres que l'eau à chambres mesureuses ou à turbine *Meters and measuring systems for liquids other than water with measuring chambers or with turbines*		
SP 5D-Sr 10	Mesurage massique direct en dynamique des quantités de liquides *Mass flow assemblies for measuring quantities of liquids*		

25e Réunion du Comité International de Métrologie Légale *25th Meeting of the International Committee of Legal Metrology*	3-5 Oct./*October* 1990	PORTO PORTUGAL

Note: Liste à jour fin juin 1990
List as per end June 1990

PUBLICATIONS

— Vocabulaire de métrologie légale
Vocabulary of legal metrology

— Vocabulaire international des termes fondamentaux et généraux de métrologie
International vocabulary of basic and general terms in metrology

RECOMMANDATIONS INTERNATIONALES
INTERNATIONAL RECOMMENDATIONS

R N°

1 — Poids cylindriques de 1 g à 10 kg (de la classe de précision moyenne)
Cylindrical weights from 1 g to 10 kg (medium accuracy class)

2 — Poids parallélépipédiques de 5 à 50 kg (de la classe de précision moyenne)
Rectangular bar weights from 5 to 50 kg (medium accuracy class)

4 — Fioles jaugées (à un trait) en verre
Volumetric flasks (one mark) in glass

5 — Compteurs de liquides autres que l'eau à chambres mesureuses
Meters for liquids other than water with measuring chambers

6 — Dispositions générales pour les compteurs de volume de gaz
General provisions for gas volume meters

7 — Thermomètres médicaux (à mercure, en verre, avec dispositif à maximum)
Clinical thermometers (mercury-in-glass, with maximum device)

9 — Vérification et étalonnage des blocs de référence de dureté Brinell
Verification and calibration of Brinell hardness standardized blocks

10 — Vérification et étalonnage des blocs de référence de dureté Vickers
Verification and calibration of Vickers hardness standardized blocks

11 — Vérification et étalonnage des blocs de référence de dureté Rockwell B
Verification and calibration of Rockwell B hardness standardized blocks

12 — Vérification et étalonnage des blocs de référence de dureté Rockwell C
Verification and calibration of Rockwell C hardness standardized blocks

14 — Saccharimètres polarimétriques
Polarimetric saccharimeters

15 — Instruments de mesure de la masse à l'hectolitre des céréales
Instruments for measuring the hectolitre mass of cereals

16 — Manomètres des instruments de mesure de la tension artérielle (sphygmomanomètres)
Manometers for instruments for measuring blood pressure (sphygmomanometers)

17 — Manomètres, vacuomètres, manovacuomètres indicateurs
Indicating pressure gauges, vacuum gauges and pressure-vacuum gauges

18 — Pyromètres optiques à filament disparaissant
Visual disappearing filament pyrometers

19 — Manomètres, vacuomètres, manovacuomètres enregistreurs
Recording pressure gauges, vacuum gauges, and pressure-vacuum gauges

20 — Poids des classes de précision E_1 E_2 F_1 F_2 M_1 de 50 kg à 1 mg
Weights of accuracy classes E_1 E_2 F_1 F_2 M_1 *from 50 kg to 1 mg*

21 — Taximètres
Taximeters

22 — Tables alcoométriques internationales
International alcoholometric tables

23 — Manomètres pour pneumatiques de véhicules automobiles
Tyre pressure gauges for motor vehicles

24 — Mètre étalon rigide pour agents de vérification
Standard one metre bar for verification officers

25 — Poids étalons pour agents de vérification
Standard weights for verification officers

26 — Seringues médicales
Medical syringes

27 — Compteurs de volume de liquides (autres que l'eau). Dispositifs complémentaires
Volume meters for liquids (other than water). Ancillary equipment

29 — Mesures de capacité de service
Capacity serving measures

30 — Mesures de longueur à bouts plans (calibres à bouts plans ou cales-étalons)
End standards of length (gauge blocks)

31 — Compteurs de volume de gaz à parois déformables
Diaphragm gas meters

32 — Compteurs de volume de gaz à pistons rotatifs et compteurs de volume de gaz à turbine
Rotary piston gas meters and turbine gas meters

33 — Valeur conventionnelle du résultat des pesées dans l'air
Conventional value of the result of weighing in air

34 — Classes de précision des instruments de mesurage
Accuracy classes of measuring instruments

35 — Mesures matérialisées de longueur pour usages généraux
Material measures of length for general use

36 — Vérification des pénétrateurs des machines d'essai de dureté
Verification of indenters for hardness testing machines

37 — Vérification des machines d'essai de dureté (système Brinell)
Verification of hardness testing machines (Brinell system)

38 — Vérification des machines d'essai de dureté (système Vickers)
Verification of hardness testing machines (Vickers system)

39 — Vérification des machines d'essai de dureté (systèmes Rockwell B, F, T - C, A, N)
Verification of hardness testing machines (Rockwell systems B, F, T - C, A, N)

40 — Pipettes graduées étalons pour agents de vérification
Standard graduated pipettes for verification officers

41 — Burettes étalons pour agents de vérification
Standard burettes for verification officers

42 — Poinçons de métal pour agents de vérification
Metal stamps for verification officers

43 — Fioles étalons graduées en verre pour agents de vérification
Standard graduated glass flasks for verification officers

44 — Alcoomètres et aréomètres pour alcool et thermomètres utilisés en alcoométrie
Alcoholometers and alcohol hydrometers and thermometers for use in alcoholometry

45 — Tonneaux et futailles
Casks and barrels

46 — Compteurs d'énergie électrique active à branchement direct (de la classe 2)
Active electrical energy meters for direct connection (class 2)

47 — Poids étalons pour le contrôle des instruments de pesage de portée élevée
Standard weights for testing of high capacity weighing machines

48 — Lampes à ruban de tungstène pour l'étalonnage des pyromètres optiques
Tungsten ribbon lamps for calibration of optical pyrometers

49 — Compteurs d'eau (destinés au mesurage de l'eau froide)
Water meters (intended for the metering of cold water)

50 — Instruments de pesage totalisateurs continus à fonctionnement automatique
Continuous totalising automatic weighing machines

51 — Trieuses pondérales de contrôle et trieuses pondérales de classement
Checkweighing and weight grading machines

52 — Poids hexagonaux. Classe de précision ordinaire de 100 g à 50 kg
Hexagonal weights. Ordinary accuracy class, from 100 g to 50 kg

53 — Caractéristiques métrologiques des éléments récepteurs élastiques utilisés pour le mesurage de la pression. Méthodes de leur détermination
Metrological characteristics of elastic sensing elements used for measurement of pressure. Determination methods

54 — Echelle de pH des solutions aqueuses
pH scale for aqueous solutions

55 — Compteurs de vitesse, compteurs mécaniques de distances et chronotachygraphes des véhicules automobiles - Réglementation métrologique
Speedometers, mechanical odometers and chronotachographs for motor vehicles. Metrological regulations

56 — Solutions-étalons reproduisant la conductivité des électrolytes
Standard solutions reproducing the conductivity of electrolytes

57 — Ensembles de mesurage de liquides autres que l'eau équipés de compteurs de volumes. Dispositions générales
Measuring assemblies for liquids other than water fitted with volume meters. General provisions

58 — Sonomètres
Sound level meters

59 — Humidimètres pour grains de céréales et graines oléagineuses
Moisture meters for cereal grains and oilseeds

60 — Réglementation métrologique des cellules de pesée
Metrological regulations for load cells

61 — Doseuses pondérales à fonctionnement automatique
Automatic gravimetric filling machines

62 — Caractéristiques de performance des extensomètres métalliques à résistance
Performance characteristics of metallic resistance strain gages

63 — Tables de mesure du pétrole
Petroleum measurement tables

64 — Exigences générales pour les machines d'essai des matériaux
General requirements for materials testing machines

65 — Exigences pour les machines d'essai des matériaux en traction et en compression
Requirements for machines for tension and compression testing of materials

66 — Instruments mesureurs de longueurs
Length measuring instruments

67 — Ensembles de mesurage de liquides autres que l'eau équipés de compteurs de volumes. Contrôles métrologiques
Measuring assemblies for liquids other than water fitted with volume meters. Metrological controls

68 — Méthode d'étalonnage des cellules de conductivité
Calibration method for conductivity cells

69 — Viscosimètres à capillaire, en verre, pour la mesure de la viscosité cinématique
Glass capillary viscometers for the measurement of kinematic viscosity

70 — Détermination des erreurs de base et d'hystérésis des analyseurs de gaz
Determination of intrinsic and hysteresis errors of gas analysers

71 — Réservoirs de stockage fixes. Prescriptions générales
Fixed storage tanks. General requirements

72 — Compteurs d'eau destinés au mesurage de l'eau chaude
Hot water meters

73 — Prescriptions pour les gaz purs CO, CO_2, CH_4, H_2, O_2, N_2 et Ar destinés à la préparation des mélanges de gaz de référence
Requirements concerning pure gases CO, CO_2, CH_4, H_2, O_2, N_2 and Ar intended for the preparation of reference gas mixtures

74 — Instruments de pesage électroniques
Electronic weighing instruments

75 — Compteurs d'énergie thermique
Heat meters

76 — Instruments de pesage à fonctionnement non automatique
Non-automatic weighing instruments

Partie 1 : Exigences métrologiques et techniques - Essais
Part 1 : Metrological and technical requirements - Tests

Partie 2 : Rapport d'essai de modèle
Part 2 : Pattern evaluation report

77 — Ensembles de mesurage de liquides autres que l'eau équipés de compteurs de volumes. Dispositions particulières relatives à certains ensembles
Measuring assemblies for liquids other than water fitted with volume meters. Provisions specific to particular assemblies

78 — Pipettes Westergren pour la mesure de la vitesse de sédimentation des hématies
Westergren tubes for measurement of erythrocyte sedimentation rate

79 — Etiquetage des préemballages
Information on package labels

80 — Camions et wagons-citernes
Road and rail tankers

81 — Dispositifs et systèmes de mesure de liquides cryogéniques (comprend tables de masse volumique pour argon, hélium, hydrogène, azote et oxygène liquides)
Measuring devices and measuring systems for cryogenic liquids (including tables of density for liquid argon, helium, hydrogen, nitrogen and oxygen)

82 — Chromatographes en phase gazeuse pour la mesure des pollutions par pesticides et autres substances toxiques
Gas chromatographs for measuring pollution from pesticides and other toxic substances

83 — Chromatographe en phase gazeuse équipé d'un spectromètre de masse et d'un système de traitement de données pour l'analyse des polluants organiques dans l'eau
Gas chromatograph/mass spectrometer/data system for analysis of organic pollutants in water

84 — Capteurs à résistance thermométrique de platine, de cuivre ou de nickel (à usages techniques et commerciaux)
Resistance-thermometer sensors made of platinum, copper or nickel (for industrial and commercial use)

85 — Jaugeurs automatiques pour le mesurage des niveaux de liquide dans les réservoirs de stockage fixes
Automatic level gauges for measuring the level of liquid in fixed storage tanks

86 — Compteurs à tambour pour alcool et leurs dispositifs complémentaires
Drum meters for alcohol and their supplementary devices

87 — Contenu net des préemballages
Net content in packages

88 — Sonomètres intégrateurs-moyenneurs
Integrating-averaging sound level meters

91 — Cinémomètres radar pour la mesure de la vitesse des véhicules
Radar equipment for the measurement of the speed of vehicles

92 — Humidimètres pour le bois — Méthodes et moyens de vérification: exigences générales
Wood-moisture meters - Verification methods and equipment: general provisions

96 — Bouteilles récipients-mesures
Measuring container bottles

97 — Baromètres
Barometers

DOCUMENTS INTERNATIONAUX

INTERNATIONAL DOCUMENTS

D N°

1 — Loi de métrologie
Law on metrology

2 — Unités de mesure légales
Legal units of measurement

3 — Qualification légale des instruments de mesurage
Legal qualification of measuring instruments

4 — Conditions d'installation et de stockage des compteurs d'eau froide
Installation and storage conditions for cold water meters

5 — Principes pour l'établissement des schémas de hiérarchie des instruments de mesure
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