TECHNISCHE UNIVERSITÄT
ILMENAU

50. Internationales
Wissenschaftliches Kolloquium

September, 19-23, 2005

Maschinenbau von Makro bis Nano /

Mechanical Engineering from Macro to Nano

Proceedings

Fakultät für Maschinenbau /
Faculty of Mechanical Engineering

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

Impressum

Herausgeber:	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Peter Scharff
Redaktion:	Referat Marketing und Studentische Angelegenheiten Andrea Schneider
	Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurtz, Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte, Univ.-Prof. Dr.-Ing. habil. Gerhard Linß, Dr.-Ing. Beate Schlütter, Dipl.-Biol. Danja Voges, Dipl.-Ing. Jörg Mämpel, Dipl.-Ing. Susanne Töpfer, Dipl.-Ing. Silke Stauche
Redaktionsschluss: (CD-Rom-Ausgabe)	31. August 2005
Technische Realisierung: (CD-Rom-Ausgabe)	Institut für Medientechnik an der TU Ilmenau Dipl.-Ing. Christian Weigel Dipl.-Ing. Helge Drumm Dipl.-Ing. Marco Albrecht
Technische Realisierung: (Online-Ausgabe)	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau
Verlag:	isle Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16 98693 Ilmenau

© Technische Universität Ilmenau (Thür.) 2005

Diese Publikationen und alle in ihr enthaltenen Beiträge und Abbildungen sind urheberrechtlich geschützt.

ISBN (Druckausgabe):	3-932633-98-9	(978-3-932633-98-0)
ISBN (CD-Rom-Ausgabe):	3-932633-99-7	(978-3-932633-99-7)

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
19.-23. September 2005

T. Fröhlich / T. Fehling / D. Heydenbluth

Determination of Magnetic Properties of Weights using the Susceptometer Method

ABSTRACT

The International Recommendation OIML R 111 gives upper bounds for the magnetization and susceptibility for weights depending on the different error classes. Magnetization and susceptibility of mass standards should be known or determined. A widely accepted method is the susceptometer method. The Sartorius Susceptometer is a commercially available Susceptometer as described in the International Recommendation OIML R111. The maximum field at the bottom of the specimen and the initial measuring distance depending on the accuracy classes are given. The calibration procedure is described. A measurement comparing five calibrated susceptibility standards is discussed. The magnets used for calibration are monitored concerning the stability of the magnetic dipole moment over more than one year. A method for specifying the necessary geometric correction factors depending on shape and size of the weights is described. An example for such an approximation of a 1kg OIML-shaped mass standard with recessed base and practical hints for routine measurements are given.

INTRODUCTION

Accepted methods to determine the magnetization and the magnetic susceptibility of weights are described in [2]. Which of these methods are recommended for the various accuracy classes and nominal masses is also given in [2]. The Sartorius Susceptometer [6,7] works exactly on the principle described in [2] in the section "B.6.4 Magnetic susceptibility and permanent magnetization, the Susceptometer method". The fundamentals of the Susceptometer method are due to [1,3].

The force between the tested mass and a permanent magnet is measured using a mass comparator. The Sartorius Susceptometer have a unique apparatus that allows to change the orientation of the magnet from north-pole pointing up to pointing down without opening the draft shield of the mass comparator. Thermal disturbances and impreciseness of direct manual handling are therefore avoided. This permits convenient use and very stable measurements. The distance between base of weight and mid-height of magnet is selectable in fixed steps without the need of gauge blocks by simply turning the lid. Specimen have to be placed on the lid whereby correct centering is eased through visual markings. Together with the included software the Sartorius Susceptometer is a turnkey solution for testing mass standards according to [2].

Figure 1: The Sartorius Susceptometer

Traceable measurements require the vertical distance Z0 between the mid-height of the magnet and the bottom of the weight under test to be determined using one or more traceable susceptibility standards. Furthermore, the magnetic dipole moment md of the test magnet has to be known. Various methods for determining Z0 and md are described in [3]. Section 3 describes the calibration procedure.

2. MAGNETIC FIELD STRENGTH

A magnet with m_d produces a maximum field H at bottom of the specimen given by (see [1,2])

$$H = \frac{m_d}{2\pi \times Z_0^3} .$$

The field belonging to the distances Z_0 selectable by turning the lid is shown in table 1. In [2] is stated that initially, H should not exceed 2000 A/m when testing class E1, 800 A/m when testing class E2 weights and 200 A/m for classes F1 and F2. This is important to avoid permanent magnetization. The distance may be reduced only if the Susceptometer signal is too weak. The initial distance depending on the accuracy classes and the reduction steps are shown by the arrows in table 1.

The positions are labeled at the lid with Z5, Z4,…, Z1. This labels are coloured green, orange and red making the choose of first distance self-evident.

Table 1: Initial values for Z_0 and H when testing class E1, E2, F1 and F2

Marking	Colour of marking	Nominal Z_0 in mm	Field H in A/m	Class E1	E2	F1	F2
Z5	Green	43	200			⇩	⇩
Z4	Orange	35	360				
Z3	Orange	27	800		⇩		
Z2	Red	20	2000	⇩			
Z1	Red	18	2700				

3. CALIBRATION PROCEDURE

Prior to delivery of each Susceptometer, the distances of the five selectable vertical positions were determined by Sartorius using a combination of a so called cathetometer method (method A in [3]) and the method C in [3]. Method C requires a susceptibility standard to be used. At Sartorius, we use one cylindrical stainless steel weight calibrated at the PTB, Braunschweig. Detailed data is given below in table 2 in the PTB2419 column. The susceptibility value is given for different calibration field strengths between 5 and 30 kA/m, and the change is insignificant. The smallest calibration field strength 5 kA/m is greater than the highest field strength of the Susceptometer at the lowest vertical position Z1, which is 2.7 kA/m.

The height steps between the five vertical positions are determined after the milling and grinding process using a 3D coordinate measuring machine. The vertical distance of the lowest position is determined with the known susceptibility of the susceptibility standard. As a result of the extremely stable mechanical structure of the unit, the vertical distances on the Sartorius

Susceptometer are practically immune to changes. The values for the vertical distances determined by Sartorius are indicated in the calibration certificate that is given for each Susceptometer unit. The distance of the lowest position is known from the mounting and adjusting process (cathetometer method). This additional knowledge is used for checking the value from the calibration with the susceptibility standard.

The magnetic dipole moments of the test magnets used in Sartorius Susceptometers are determined and recorded in the calibration certificates, too. The method is based on measuring the force between pairs of the four magnets and solving the resulting system of equations with 6 equations and the 4 unknown magnetic dipole moments in least square sense as described in [3] and [7].

Redetermination of the vertical distances using one or more traceable susceptibility standards is supported by the included Susceptometer software [6]. It is also possible to redetermine the magnetic dipole moment using the procedure described in [3]. The 3 additional magnets and the spacer are available from Sartorius as a so-called calibration kit (see figure 2).

Figure 2: Calibration kit: 3 magnets and a spacer in a wooden box with sufficient dimensions in order to ensure a magnetic field strength that is less than 200A/m outside the box

3. EXAMPLE AND COMPARISON

As described above we calibrate each Susceptometer using one cylindrical stainless steel susceptibility standard. On addition, we purchased four iron acrylic susceptibility standards (see [5]) from the NPL/UK. All standards are cylindrical. The geometrical dimensions are relatively small due to the diameter restrictions during manufacture. The nominal values were chosen near the maximum acceptable limits given by the draft revision of the OIML R111 for the different error classes. Each iron acrylic susceptibility standard was calibrated at the NPL/UK. The calibration field strength agrees with the vertical positions of the Susceptometer given in the last line of table 2. With the iron acrylic susceptibility standards, we can check the Susceptometer calibration over the full range of use.

Table 2: Susceptibility standards: susceptibility, expanded uncertainty and magnetic field strength from calibration certificate, dimensions and vertical position used for calibration

	NPL1005	NPL 1024	NPL11	NPL16	PTB2419
χ	0.0055	0.02657	0.1173	0.693	0.004012
$U(\chi)$ k=2	0.00005	0.000205	0.00056	0.0034	0.000035
H in kA/m	2.7	2.0	0.8	0.2	5.0
Diameter in mm	39.67	39.81	39.60	25.00	59.20
Height in mm	26.60	25.25	27.50	25.00	45.30
Used at position	Z1	Z2	Z3	Z5	Z1

Table 3: Relative deviation of the susceptibility values

	$\Delta\chi/\chi$
NPL1005	-3.3%
NPL1024	-4.8%
NPL11	-5.2%
NPL16	-5.8%

The relative deviation of the measured susceptibility values from the calibration data is given in Table 3. It relates to the question as to which errors will occur if we perform regular factory calibration using the PTB2419 susceptibility standard. The PTB2419 and NPL1005 values (where χ<<1 holds) agree at a 3% level. For the higher values NPL1024, NPL11 and NPL16 the approximation of the demagnetization factor as explained in section 4.1.2. of [4] becomes more important. All the deviations are well below the estimated relative uncertainty stated in [2].

4. LONG TERM STABILITY OF m_d

As mentioned above, we always use the same set of three additional magnets for the Susceptometer factory calibration. Therefore, we have historical data on our magnets compiled over more than one year. Figure 3 shows the magnetic dipole moment m_d of one of these magnets. The data were collected from some different units from our production and calibration process as well as from two Susceptometers at our research laboratory. Good repeatability and no significant drift could be observed in Figure 3. The magnets used for the Sartorius factory calibration are stored in a wooden box as shown in Figure 2 under normal laboratory and office conditions.

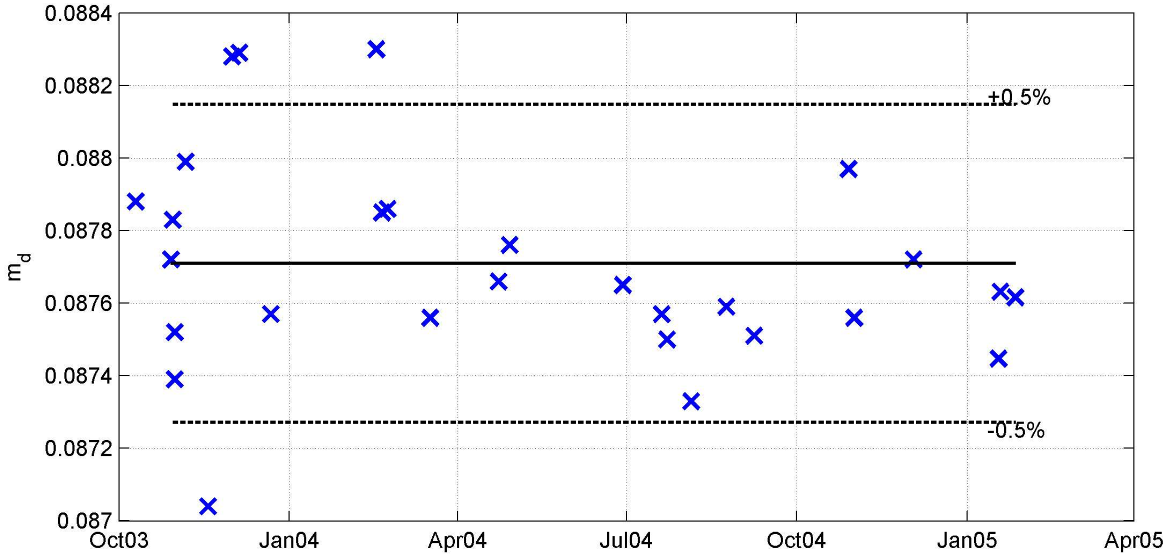

Figure 3: Several measurements of m_d for one magnet over more than 1 year; the mean value and the ±0.5% deviation are indicated by the lines

5. SPECIFYING THE NECESSARY SHAPE AND SIZE

Typical OIML-shaped mass standards have a lifting knob, rounded edges and sometimes a recessed base. Detailed approximation of the knob and also the rounded edges as a sum of cylinders would require a lot of slices. Alternatively the inner and outer limits estimation given in [1] have to be used. Therefore frustrums of cones are useful and supported by the suceptometer software for convenience. The geometric correction factors I_a and I_b (see [1]) are calculated automatically from a user supplied list of cylinders and cone frustrums. Cylinder layers are treated as given in [1] by equations (6a), (6b) and (10). Although we found an analytical formula for the calculation of the cone frustrums a simple numerical integration of the cylinder equations is used instead.

An example for such an approximation of a 1kg OIML-shaped mass standard with recessed base is given in figure 4 and accordingly in table 4. The heights h_1 and h_2 are measured from the bottom of the weight piece. Different diameters d_1 and d_2 indicate cone frustrums. The only cylinder in this example is the layer C that is the main body. Adding a recessed base is possible by defining an appropriate cylinder or cone frustrum with negative sign (see layer N in table 4). The I_a and I_b columns reveal the contribution to the geometric correction factors for each layer. The sum yields I_a=0.521 and I_b=1.840 respectively. Obviously, the contributions of the knob layers F…M to I_a and I_b is relative small in the normal orientation, but if the specimen is reversed a detailed approximation is beneficial. The geometric correction factors are easy to compute for reverse orientation with lifting knob down also (see [6]).

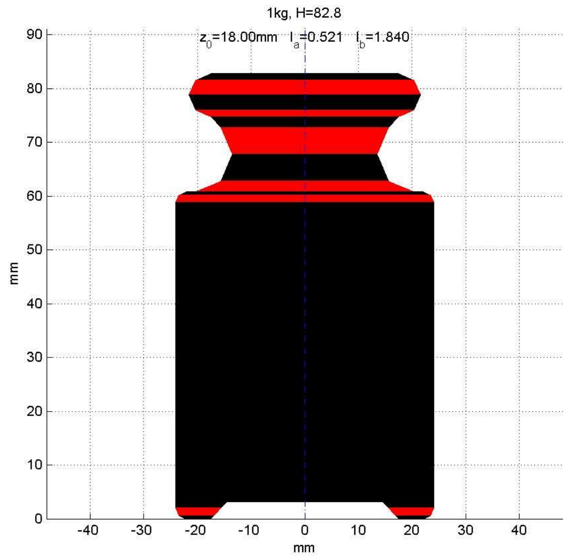

Figure 4: Shape approximation of a 1kg OIML-shaped mass standard, the layers are alternately coloured for visual clearness

Table 4: List of layers used for the shape approximation of the mass standard, contributions to I_a and I_b for Z_0=18mm

Layer	Dimensions in mm				Sign	I_a	I_b
	d_1	d_2	h_1	h_2			
A	44.00	46.83	0.00	0.59	+	0.117	0.089
B	46.83	48.00	0.59	2.00	+	0.218	0.195
C	48.00	48.00	2.00	58.80	+	0.589	2.01
D	48.00	46.83	58.80	60.21	+	6.39E-5	0.00598
E	46.83	44.00	60.21	60.80	+	2.27E-5	0.00221
F	41.00	31.10	60.80	62.85	+	4.84E-5	0.00495
G	31.10	27.00	62.85	67.80	+	5.94E-5	0.00688
H	27.00	31.10	67.80	72.75	+	3.93E-5	0.00545
I	31.10	35.00	72.75	74.80	+	1.58E-5	0.00247
J	35.00	40.66	74.80	75.97	+	1.03E-5	0.00169
K	40.66	43.00	75.97	78.80	+	2.58E-5	0.00451
L	43.00	40.66	78.80	81.63	+	2.12E-5	0.00404
M	40.66	35.00	81.63	82.80	+	6.38E-6	0.00129
N	35.00	29.00	0.00	3.00	–	–0.404	–0.495

6. PRACTICAL HINTS

The Suceptometer method allows the easy determination of the susceptibility and the magnetization. Due to the relatively rapid measurement procedure routine checks are possible on a regular basis. Under practical conditions the susceptibility measurements are very reproducible. For small weights the geometry approximation and the accurate centering become more important. Some weights have a non uniform magnetization. The result is often that the measured magnetization depends on the angular orientation of the weight.

In our experiences as well the magnetic dipole moment of the test magnet as the vertical distances don’t change over a long period of time. But the recalibration using a susceptibility standard and the recalibration routines of the Susceptometer software is not time-consuming. A quick test can be performed if the susceptibility standard is measured for both orientations of the test magnet. If the readings m_1 and m_2 are the same as last time a recalibration is not necessary.

The geometry approximation of OIML knob weights is easy because typical shapes are predefined in the software and simply to change. Very important is to proper take the recessed base into consideration because its relative contribution to the geometric correction factors is very high (see e.g. table 4). If a batch of weights of identical shape has to be tested, the comparison method explained in [3] may further increase the time efficiency.

REFERENCES

[1] Davis, R. S., Determining the Magnetic Properties of 1 kg Mass Standard, J. Res. Natl. Inst. Stand. Technol. 100 (1995), p. 209-225

[2] International Recommendation OIML R 111, Part 1: Metrological and Technical Requirements

[3] Chung, J.W., Ryu, K.S., Davis, R.S., Uncertainty analysis of the BIPM susceptometer, Metrologia 38 (2001), 535-541

[4] Davis, R. S., Gläser, M., Magnetic properties of weights, their measurements and magnetic interactions between weights and balances, Metrologia 40 (2003) 339–355

[5] Hall M., What the mass community need to know about magnetic properties and their traceable measurement, Proc. South Yorkshire International Weighing Conference, June 2003

[6] Fröhlich, T., Fehling, T., Heydenbluth, D., Sartorius Susceptometer for precise measurement of susceptibility and magnetization of weights, Proc. South Yorkshire International Weighing Conference, June 2003

[7] Fröhlich, T., Fehling, T., Gatzemeier, B., Heydenbluth, D., Sartorius Susceptometer for precise measurement of susceptibility and magnetization of weights, IMEKO TC 3, 19th. Int. Conference, Cairo (Egypt), Feb. 2005

Authors:

Dr.Thomas Fröhlich,
Sartorius AG
Mechatronic Division
Development of Mass Comparators
Weender Landstrasse 94-108
37075 Göttingen / Germany
Phone: ++49 3677 69 1449
Fax: ++49 3677 69 1412
E-mail: Thomas.Froehlich@sartorius.com

Thomas Fehling
Sartorius AG
Mechatronic Division
Head of Development and Manufacturing of Mass Comparators
Weender Landstrasse 94-108
37075 Göttingen / Germany
Phone: ++49 551 3083515
Fax: ++49 551 3083206
E-mail: Thomas.Fehling@sartorius.com

Dr. Detlef Heydenbluth,

Technische Universität Ilmenau

Inst. f. Prozeßmeß- und Sensortechnik

Postfach 100565

98684 Ilmenau / Germany

Phone: ++49 3677 469023

Fax: ++49 3677 469048

E-mail: Detlef.Heydenbluth@tu-ilmenau.de