INSTRUMENTS USED FOR MEASURINNG THE MAGNETIC PROPERTIES OF ONE KILOGRAM MASS STANDARD IN CENTER FOR MEASUREMENT STANDARDS (CMS)

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ABSTRACT

We measured the volume magnetic susceptibility and permanent magnetization of 1 kg mass standards are measured under the circumstances of CMS mass laboratory. The method and calculation of uncertainty described here are referred to the experimental method and procedure developed by Davis; while the distance between magnetic sample and the weighs were measured with aluminium guide and the distance was determined by reading of laser interferometer. The effects of volume magnetic susceptibility and permanent magnetization on weights was real-time measured .The degree of real-time measured dependent upon the transient time of the balance. These results of susceptibility measurement were compared to the results of samples when they arrived CMS.

1. INTRODUCTION

The magnetic susceptometer developed by Davis[1]at the Bureau International des Poids et Mesures(BIPM).This device was used to measure the volume magnetic susceptibility of the stainless-steel weight standards; under the assumption of linear ,homogeneous and weak susceptibility samples or standards. The susceptometer included the small magnetic source sample , lifting gauge blocks and a high precision commerial balance.

As this type of susceptometer was widely used ; Several results of the volume magnetic susceptibility measurement on the 1 kg standards was measured under the earth magnetic field [1,2,3] and shield the earth magnetic field [4,5].The relevant investigations on the magnetic interactions between weights and balances were found [6,7]. The method was used in assuming the magnetic source is the dipole source and the weight sample is semi-infinite slab. The nearest distances between magnetic source and the weight sample(Z_0) was evaluated by a convergent way. When the gauge blocks were used to change lifting distances values Z in a discrete way; we can get readings of the balance which showed the magnetic effects on the stain-steel weight standard.

About this work, we modified the gauge lifting device by combining the aluminium slide guide and a compact three axis laser interferometer to measure the Z_0 and the other values of lifting heights Z. During the experiment; the heights of the lifting stainless-steel samples and the readings of the balance were recorded by computer simultaneously. According these access datum; we could calculated the volume magnetic susceptibility χ and the magnetic effect to the height continuously.

2. BASIC PRINCIPLES

We assumed the magnetic field of earth was uniform in our area of experiment and assumed the field produced by the small cylinder magnetic disc is a dipole field. The dipole field acted on a sample with the form of a semi-infinite slab and approximated the magnetic flux as being uniformly along its axis. These force equations can be expressed as follows [2]:

$$F = \chi F_{\max} I_a + \frac{\mu_0}{4\pi}\left(\chi H_{E_Z} + M_Z\right)\frac{m}{Z_0} I_b \qquad \equiv F_a + F_b \qquad (1)$$

where

$$\frac{3\mu_0 \chi m^2}{64\pi Z_0^{\ 4}} \equiv \chi F_{\max}, \qquad (2)$$

and

$$I_a = -\frac{32\pi}{3m^2}\frac{\partial}{\partial Z_{0n}}\iiint_{V_n} H_{mag} \cdot H_{mag} dV = -\frac{2}{3\pi}\frac{\partial}{\partial Z_{0n}}\iiint_{V_n}\frac{\rho^2 + 4z^2}{\left(\rho^2 + z^2\right)^4}\rho d\rho d\theta dz, \qquad (3)$$

$$I_b = -\frac{4\pi}{m}\frac{\partial}{\partial Z_{0n}}\iiint_{V_n}\left(H_{mag}\right)_z dV = -\frac{\partial}{\partial Z_{0n}}\iiint_{V_n}\frac{\rho^2 - 2z^2}{\left(\rho^2 + z^2\right)^{5/2}}\rho d\rho d\theta dz, \qquad (4)$$

where χ is the effective volume magnetic susceptibility of the standard, the parameter μ_0 is the vacuum permeability, identically equal to $4\pi \times 10^{-7} N \cdot A^{-2}$. And χH_{E_Z} is an induced magnetization that has the same effect as a permanent magnetization M_Z. The parameter m is the moment of the magnet and Z_0 is the distance between the center of the magnet and the sample, as shown in Figure 1.

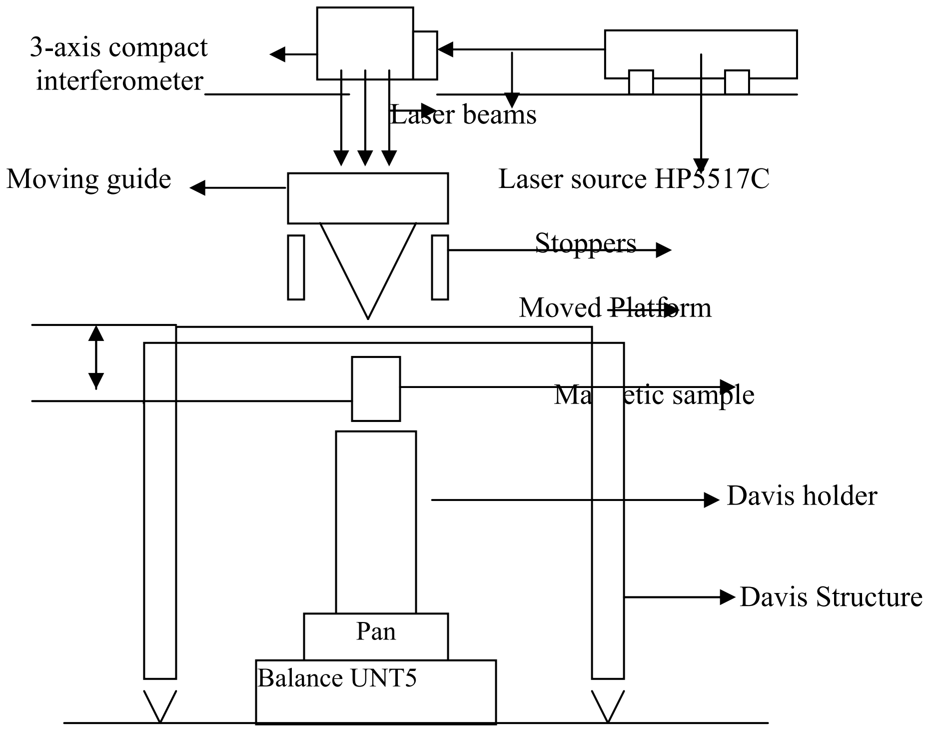


Figure1: Note how the text is centered under the figure

The first term in Eq. (1) is given by $F_a = \left(F_1 + F_2\right)/2$ and the second term by $F_b = \left(F_1 - F_2\right)/2$. The initial force measurement F_1 is made with the north pole of the magnet pointing down and a second measurement F_2 is made (at the same Z_0) with the north pole pointing up. As we have measured the Z by laser interferometer directly; so the formula were modified as following:

$$F_1 = \chi F_{\max} I_a + \frac{\mu_0}{4\pi}\left(\chi H_{E_Z} + M_Z\right)\frac{m}{Z_0} I_b = \Delta m_1 \times g$$

$$F_2 = \chi F_{\max} I_a + \frac{\mu_0}{4\pi}\left(\chi H_{E_Z} + M_Z\right)\frac{(-m)}{Z_0} I_b = \Delta m_2 \times g$$

$$F_1 + F_2 = 2\chi F_{\max} I_a = (\Delta m_1 + \Delta m_2) \times g$$

$$\chi = (\Delta m_1 + \Delta m_2) \times g / (2F_{\max} I_a)$$

where g is the gravitational acceleration in the laboratory. Δm_1 and Δm_2 are the corresponding readings of balance when the direction of north pole were down and up.

The measurement principle of Z can be shown in Fig. 2[8].This distances Z were determined by the average of the optical paths X_1, X_2 and X_3 measured by the 3-axis compact interferometer. The uncertainties could be caused by cosine error and Abbe error were considered. When we measured the distance Z; the pitch and yaw were measured .They can be expressed by X_1, X_2, X_3, L and d:

$$Pitch = \vartheta_y = \frac{(X_2 + X_3)/2 - X_1}{d} \qquad (5)$$

$$Yaw = \vartheta_x = \frac{X_2 - X_3}{L} \qquad (6)$$

where L and d are equal to 14,38 mm(the distance between the incident laser beams).Then the standard uncertainty of the Z measurement due to the Abbe□ error, u_{Abbe} , can be determined by the sum of the yaw multiplied by its own Abbe□ offset and the pitch multiplied by its own Abbe offset, with

$$\Delta X_{Abbe} = Yaw \times \Delta X = \vartheta_x \times \Delta X \qquad (7)$$

$$\Delta Y_{Abbe} = Pitch \times \Delta Y = \theta_y \times \Delta Y \qquad (8)$$

where

ΔX_{Abbe}: Abbe error in yaw-direction;

ΔY_{Abbe}: Abbe error in pitch-direction;

ΔX : Abbe offset in yaw-direction;

ΔY : Abbe offset in pitch-direction

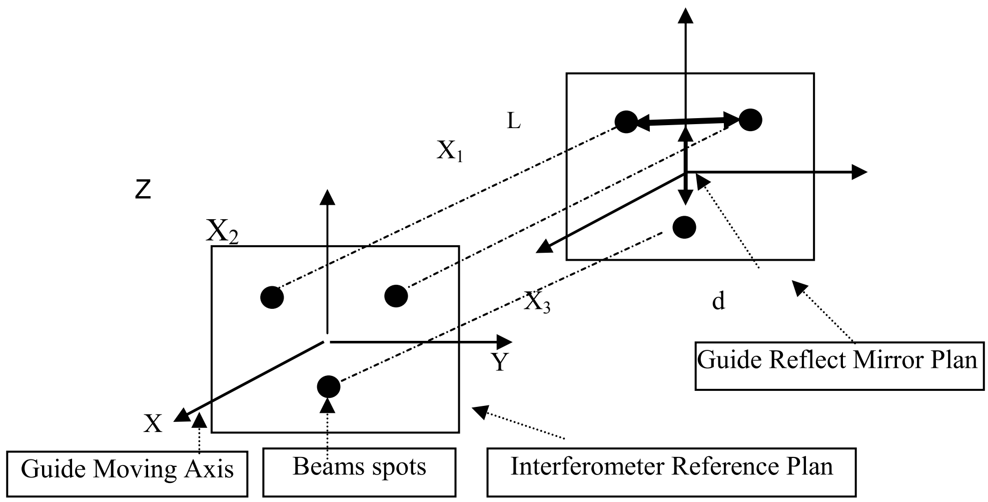


Figure2: Note how the text is centered under the figure

3. SYSTEM SET UP AND EXPERIMENTS

The system included the UMT5 balance, 3-axis compact laser interferometer, the lifting devices in moving guide and samples lifting platform (in the figure 3). The moving guide was used to indicate the distance between the sample platform and top of magnetic source sample; there were two moving measure fixed along the moving guide. When the moving guide approaches the magnetic source on the pan; these moving measure will be used as the proper stoppers alternately. As the moving guide touches the top of magnetic source lightly; the reading of the UMT5 balance will change. The readings corresponding to the laser interferometer and the balance will be recorded by control program in PC. We can analysis from these datum and get the distance Z_0.

As the response of the balance was slow. When we lifts the sample platform in one new distance Z, the same position will be hold in one minute and let the readings of balance be recorded. The readings of balance, laser interferometer will be recorded simultaneously.

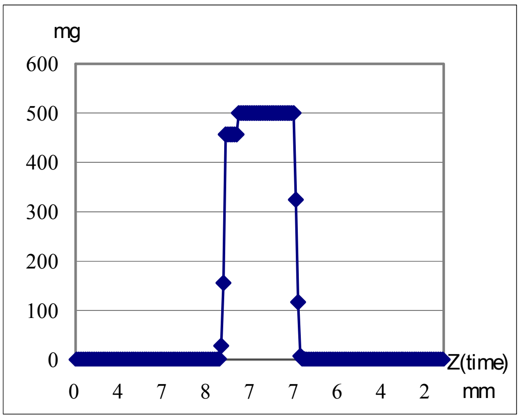
The cylindrical neodymium-iron-boron magnet was used as the source of the magnetic field; the dimensions of the simple cylinder are nominally 6 *mm* in diameter and 5 *mm* in height. The magnet was manufactured by IBS (Magnet Berlin Germany). The volume magnetic susceptibilities m of two standard samples were determined with respect to working standards of the BIPM.

4. RESULT

The figure 3 shows when the moving guide approached and left the top of magnetic source; the response of the balance and the value of Z was recorded. When the moving guide touched the top of magnetic sample; the reading of balance changes largely. After we analyzed these measurements; the distance Z_0 was determined. The results of distances Z_0 were presented in table 1. The figure 4 expressed the pitch and yaw as the Z_0 was measured. The uncertainties by pitch and yaw were also evaluated; the figure 4 shows the measurements of pitch and yaw. The figure 5 represented the reading of balance when the distance (Z) varied and north pole of the magnetic pointed up and down respectively. The variation of χ value with the distance (Z) was shown in figure 6. The value of χ value decreased as the distance (Z) increased.

Table1: The result of Z_0

Z_0	Statistics	Cosine-Error	Abbe□ Error	Total (2-sigma)
10.514 mm	2.7 µm	15.0 µm	9.0 µm	35.4 µm



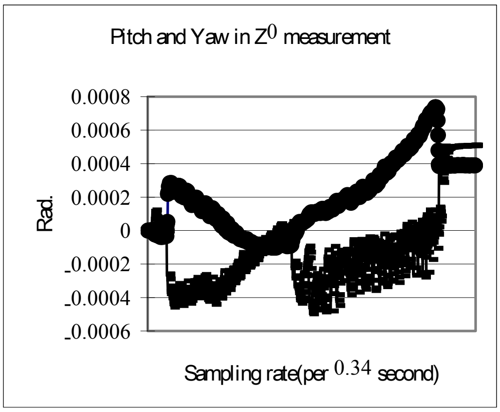


Figure 3: The approaching and leaving of the guide

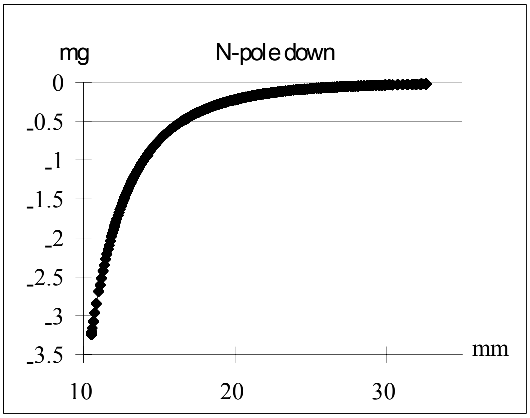


Figure 4: Pitch and yaw of the distances Z_0 measurements

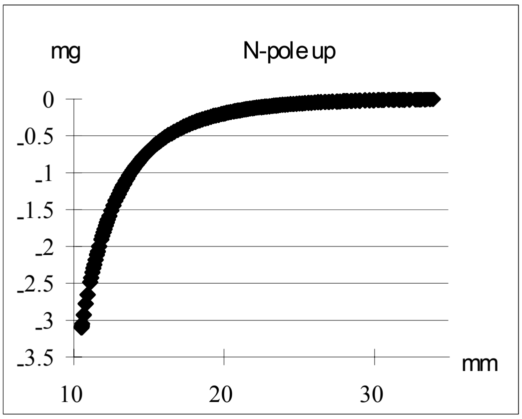
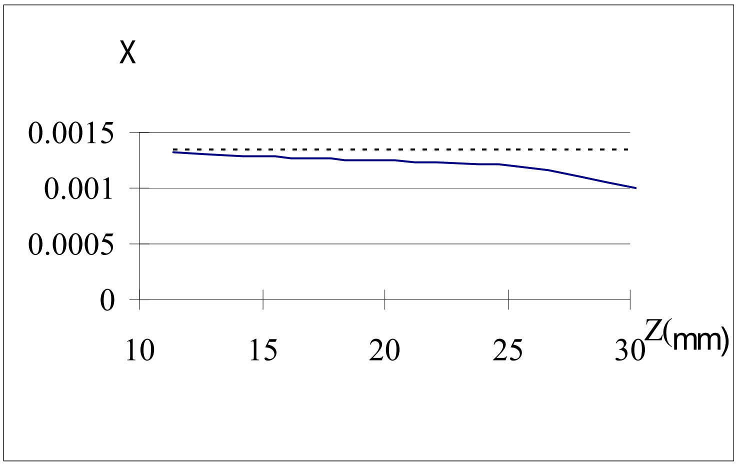


Figure 6: The measurements of χ value

Figure 5: The measurements of Z_0 distances corresponds to the readings of balance



5. SUMMARY

We have modified the magnetic susceptometer developed by Davis with the laser interferometer and a proper moving guide system. Although the samples was confined in low χ and low external field used, but the modified magnetic susceptometer has three novel differences with the original magnetic susceptometer as the following:

1.The distances Z and Z_0 were measured directly by laser interferometer and proper guiding system.

2.The form of uncertainty evaluated was different from the method of Davis.

3.The measurement of χ value was in real time that dependent upon the response time of balance in a new equilibrium state.

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REFERENCES

[1] R.S.,Davis, ew method to measure magnetic susceptibity" ,Meas. Sci. Technol. **4** (1993) pp:141-147

[2] R.S., Davis, Determining the magnetic properties of 1 kg mass standards, J. Res. Natl. Inst. Stand. Technol.,**100** (1995) pp: 209-225

[3] H.C. Lu and C. S. Chang, Evaluating the Magnetic Property of One Kilogram Mass Standard in Center For Measurement, APMF'2003 Proceeding, pp: 57-60

[4] J.W. Chung, J.-Y. Do,B.-S. Chon and R.S. Davis, ffect of earth magnetic field on measurement of volume magnetic susceptibility of mass, Metrologia,2000,**37**,pp: 65-70

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

[6] Michael Glaser, agnetic interactions between weights and weighing instruments, Meas. Sci. Technol. **12**(2001) pp: 709-715

[7] R Davis and M Glaser, agnetic properties of weights,their measurements and magnetic interactions between weights and balances, Metrologia **40** (2003), pp: 339-355

[8] Sheau-shi Pan, Chiu-Hsien Chen and Chi-Sheng Chang ,Evaluation of the uncertainty due to Abbe☐ error for primary Rockwell hardness standard system, XVII IMEKO World Congress Meterology in 3rd Millennium June 22-27,Dubrovnik, Croatis, 2003, pp: 1000-1004

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