RESEARCH ON AUTOMATIC MEASUREMENT OF WEIGHTS FROM 1 mg TO 10 g

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To reduce the effect of environment factor against mass measurement of high accuracy, robot system with three-axis motion, data acquisition of environment parameters and function of remote communication is developed for realizing automatic remote measurement of high accurate weights. The system consists of function of automatic centering, combined weights to be load and unload, combined comparison measurement and function of automatic measuring for temperature, humidity and air pressure. Weights from 1 mg to 10 g are determined by the system with method

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of direct comparison and combined comparison. The experimental results show extended uncertainty of direct comparison and combined comparison from 1 mg to 10 g is better than 4.3 μg ($k=2$).

Keywords: Mass; weights; remote communication; direct comparison; combined comparison.

1. Introduction

Non-automatic mass comparator is operated to determine mass of weights by professional operator. It is not convenient for small weights as 1 mg to 10 g to take and move by tweezers. Weights may be fallen on the platform due to fault of person. The environment parameters including temperature, humidity, air pressure and CO₂ are affected by personal influence as breathing, body temperature and moving at the process of measurement. Thus uncertainty due to air buoyancy correction may be increased. In order to improve the condition of measuring environment and reduce the uncertainty of measuring weights, an automatic measurement system of mass ranging from 1 mg to 10 g with data acquisition of environment parameters and remote communication function is introduced in this paper.

2. Automatic comparison scheme and results

Because surface sorption and gravity gradient are neglected in the process of mass measurement, equation (1) is obtained as follows:

$$m_t = m_r + \rho_a \times (V_t - V_r) + (I_t - I_r) \times \frac{m_s}{\Delta I_s} \quad (1)$$

where m_t is mass of test weight, m_r is mass of reference weight, ρ_a is air density, V_t is volume of test weight, V_r is volume of reference weight, I_t is indication of mass comparator for measuring test weight, I_r is indication of mass comparator for measuring reference weight, m_s is mass of sensitivity weight, ΔI_s is difference of indication after loading sensitivity weight.

The type of automatic mass comparator is CCR 10 ranging from 1 mg to 10 g, which readability is 0.1 μg . Four sets of weights including cyc1, cyc2, 0012 and 05 from 1g to 10 g are reference weights and test weights to be measured by direct and combined comparison. The cyc1 and cyc2 are used as reference weights. The 0012 and 05 are used as test weights. The measurement scheme from 1 g to 10 g is shown in Table 1. Where ΔI_i ($i=1,2,\dots,7$) is difference of indication between reference weight and test weight, m10-r is reference weight of 10 g, m10-t test weight of 10 g, m5-r is reference weight of 5 g, m5-t is test weight of 5 g, m2-r is reference weight of 2 g, m2-t is test weight of 2 g, m1-r is reference weight of 1 g, m1-t is test weight of 1 g.

Table 1 The measurement scheme from 1 g to 10 g.

Number	Reference weight	Test weight
1	$m_{10-r} + \Delta I_1$	m_{10-t}
2	$m_{10-r} + \Delta I_2$	$m_{5-r} + m_{5-t}$
3	$m_{5-r} + \Delta I_3$	m_{5-t}
4	$m_{5-r} + \Delta I_4$	$m_{2-r} + m_{2-t} + m_{1-r}$
5	$m_{2-r} + \Delta I_5$	$m_{1-r} + m_{1-t}$
6	$m_{2-t} + \Delta I_6$	$m_{1-r} + m_{1-t}$
7	$m_{1-r} + \Delta I_7$	m_{1-t}

Equations from 1 g to 10 g:

$$m_{10-t} = m_{10-r} + \Delta I_1 \quad (2)$$

$$m_{5-r} = \frac{m_{10-r} + \Delta I_2 - \Delta I_3}{2} \quad (3)$$

$$m_{5-t} = \frac{m_{10-r} + \Delta I_2 + \Delta I_3}{2} \quad (4)$$

$$m_{2-r} = \frac{2m_{5-r} + 2\Delta I_4 - 3\Delta I_5 + 2\Delta I_6 + \Delta I_7}{5} \quad (5)$$

$$m_{2-t} = \frac{2m_{5-r} + 2\Delta I_4 + 2\Delta I_5 - 3\Delta I_6 + \Delta I_7}{5} \quad (6)$$

$$m_{1-r} = \frac{m_{2-r} + \Delta I_5 - \Delta I_7}{2} \quad (7)$$

$$m_{1-t} = \frac{m_{2-r} + \Delta I_5 + \Delta I_7}{2}. \quad (8)$$

The results of measurement from 1 g to 10 g are shown in Table 2.

Table 2 The results of measurement from 1 g to 10 g.

Position A	Position B	Nominal (g)	Average value (mg)	Standard deviation (μ g)
I1	I5	10	-0.07279	0.32
I1	I2 I6	10	-0.04100	0.13

I2	I6	5	-0.04298	0.09
I2	I3 I7 I4	5	0.15906	0.11
I3	I4 I8	2	-0.03402	0.08
I7	I4 I8	2	0.07956	0.08
I4	I8	1	-0.07215	0.10
I9	I13	10	-0.12237	0.15
I9	I10 I14	10	-0.06272	0.15
I10	I14	5	-0.04789	0.09
I10	I11 I15 I12	5	0.14434	0.13
I11	I12 I16	2	-0.07093	0.07
I15	I12 I16	2	0.05949	0.14
I12	I16	1	-0.05575	0.06

The standard deviations of measurement results from 1 g to 10 g are shown in Fig. 1.

Fig. 1 The standard deviations of measurement results from 1 g to 10 g.

The results of measurement and standard deviations from 1 mg to 500 mg are shown in Figs. 2 and 3.

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Jobname: 10g_1g_2012_11_29	taskId	Date	Time	Pos. A	Pos. B	Nominal (A)/g	Value/mg	Std.Dev/μg
000001	29-11-2012	15:58:08	I4	G1 F1	1.000	-0.06739	0.10	
000002	29-11-2012	17:08:02	G1	F1	0.500	0.00635	0.09	
000003	29-11-2012	18:15:14	G1	G2 F2 G3	0.500	0.00216	0.10	
000004	29-11-2012	19:27:21	G2	G3 F3	0.200	0.00224	0.12	
000005	29-11-2012	20:37:21	F2	G3 F3	0.200	0.00758	0.10	
000006	29-11-2012	21:47:09	G3	F3	0.100	0.00100	0.10	
000007	29-11-2012	22:54:38	G3	F4 G4	0.100	0.00068	0.13	
000008	30-11-2012	00:04:38	G4	F4	0.050	0.00047	0.11	
000009	30-11-2012	01:12:04	G4	G5 F5 G6	0.050	0.00256	0.10	
000010	30-11-2012	02:24:38	G5	G6 F6	0.020	0.00076	0.11	
000011	30-11-2012	03:34:48	F5	G6 F6	0.020	0.00077	0.12	
000012	30-11-2012	04:44:52	G6	F6	0.010	0.00076	0.09	
000013	30-11-2012	05:52:38	G6	G7 F7	0.010	0.00227	0.13	
000014	30-11-2012	07:03:03	G7	F7	0.005	-0.00163	0.09	
000015	30-11-2012	08:11:11	G7	G8 F8 G9	0.005	-0.00316	0.11	
000016	30-11-2012	09:23:57	G8	G9 F9	0.002	-0.00170	0.12	
000017	30-11-2012	10:34:20	F8	G9 F9	0.002	0.00356	0.13	
000018	30-11-2012	11:44:34	G9	F9	0.001	-0.00226	0.14	
000019	30-11-2012	12:52:53	H3	H11	0.200	0.00032	0.12	
000020	30-11-2012	14:01:33	H6	H12	0.020	-0.00005	0.15	
000021	30-11-2012	15:10:27	H9	H13	0.002	0.00034	0.15	
000022	30-11-2012	16:19:02	G2	G10	0.200	-0.00001	0.11	
000023	30-11-2012	17:27:37	G5	G11	0.020	-0.00050	0.12	
000024	30-11-2012	18:36:11	G8	G12	0.002	0.00005	0.16	
000025	30-11-2012	19:44:58	F2	F10	0.200	0.00814	0.09	
000026	30-11-2012	20:53:57	F5	F11	0.020	-0.00541	0.08	
000027	30-11-2012	22:02:51	F8	F12	0.002	0.00501	0.08	

Fig. 2 The results of measurement from 1 mg to 500 mg.

Fig. 3 The standard deviations of measurement results from 1 mg to 10 mg.

3. The uncertainty of measurement results

The combined standard uncertainties of measurement results from 1 g to 10 g are shown as Table 3. The extended uncertainties are shown as Table 4.

Table 3 The combined standard uncertainties of measurement results from 1 g to 10 g.

Equations of standard uncertainty	Uncertainty of reference weights (μg)	Combined uncertainty (μg)
$u_{10\text{ g}} = \sqrt{u^2(m_r) + u_1^2}$	$u(m_r) = 2.0755$	2.142611
$u_{5\text{ g}} = \frac{1}{2}\sqrt{u^2(m_r) + u_1^2 + u_2^2 + 2u_1u_2}$	$u(m_r) = 2.0755$	1.118956

$u_{5g^*} = \frac{1}{2} \sqrt{u^2(m_r) + u_1^2 + u_2^2 + 2u_1u_2}$	$u(m_r) = 2.0755$	1.118956
$u_{2g} = \frac{2}{5} \sqrt{u_{5g}^2 + u_4^2 + u_5^2 + u_6^2 + u_7^2 + 2u_4u_5 + 2u_4u_6 + 2u_4u_7 + 2u_5u_6 + 2u_5u_7 + 2u_6u_7}$	$u_{5g} = 1.118956$	0.560940
$u_{2g^*} = \frac{2}{5} \sqrt{u_{5g}^2 + u_4^2 + u_5^2 + u_6^2 + u_7^2 + 2u_4u_5 + 2u_4u_6 + 2u_4u_7 + 2u_5u_6 + 2u_5u_7 + 2u_6u_7}$	$u_{5g} = 1.118956$	0.560940
$u_{1g} = \frac{1}{2} \sqrt{u_{2g}^2 + u_5^2 + u_7^2 + 2u_5u_7}$	$u_{2g} = 0.560940$	0.288102
$u_{1g^*} = \frac{1}{2} \sqrt{u_{2g}^2 + u_5^2 + u_7^2 + 2u_5u_7}$	$u_{2g} = 0.560940$	0.288102

Table 4 The extended uncertainties of measurement results.

Combined uncertainties u_c (μg)	Extended uncertainties U ($k=2$) (μg)
$u_{c10g}=2.142611$	4.3
$u_{c5g}=1.118956$	2.3
$u_{c5g^*}=1.118956$	2.3
$u_{c2g}=0.560940$	1.2
$u_{c2g^*}=0.560940$	1.2
$u_{c1g}=0.288102$	0.58
$u_{c1g^*}=0.288102$	0.58

4. Conclusions

In order to improve experimental environment of mass measurement, automatic mass comparator is installed in NIM. The comparator has function of data acquisition of mass and air density and function of remote communication. The system consists of function of automatic centering, combined weights to be load and unload, combined comparison measurement and function of automatic measuring for temperature, humidity and air pressure. Weights from 1 mg to 10 g are determined by the system with method of direct comparison and combined comparison. The experimental results show that extended uncertainty of direct comparison and combined comparison from 1 mg to 10 g is better than 4.3 μg ($k=2$).

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