IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference
11 – 13 October 2022, Cavtat-Dubrovnik, Croatia

RESEARCH ON WEIGHING DESIGN OF CLASS E GROUP WEIGHTS BASED ON INTELLIGENT MEASUREMENT SYSTEM

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Abstract:

Based on the characteristics of automatic intelligent measurement device and the demand of class E group weights value transmission, this paper proposes two measurement design methods for combined verification of class E group weight, establishes the mathematical model and analyses the uncertainty. The two combination methods are compared with the direct comparison method given by “OIML R111-1:2004”. The analysis verifies that the two component combination algorithms suitable for intelligent measurement device are effective and feasible, which is helpful to promote the application of intelligent measurement technology in the field of high-accuracy group weights transmission.

Keywords: metrology; weight; intelligent detection; value transfer; measurement design

1. INTRODUCTION

In recent years, comparator manufacturers and technical institutions have been committed to developing automatic intelligent measurement device to improve measurement efficiency and accuracy. Due to the limited operating space in the wind hood of the comparator and the influence of the eccentric load of the comparator, if multiple weights of different specifications are simply tiled, because the great difference of weight specifications, the eccentric load error of the comparator will seriously affect the quality measurement results in the measurement process [1], [2]. At present, there are two advanced intelligent measurement device, one is able to compare up to one weight with three weights (hereinafter referred to as one-to-three component combination method [3]), and the other is able to compare up to one weight with four weights (hereinafter referred to as one-to-four component combination method [4]). Therefore, in order to realise the intelligent and automatic measurement of the combined method of quantity transmission into groups of weights, this paper analyses the weighing design of one-to-three component combination method and one-to-four component combination method respectively, establishes a mathematical model, calculates the conventional mass of the test weight, and analyses the uncertainty of different methods [5].

2. AUTOMATIC INTELLIGENT MEASUREMENT SYSTEM

According to “OIML R111-1: 2004” and the China national verification regulation“JJG99-2006 weights”, the equipment required for weight value transmission includes not only reference weights, but also comparators or balances with different measurement ranges and divisions [6], [7].

The fully automatic intelligent measurement device orderly places the reference weight, test weight, weighing instrument and intelligent manipulator in a closed space, and arranges independent temperature monitoring instrument, humidity monitoring instrument and atmospheric pressure monitoring instrument in three-dimensional space. It realises the measurement of group weights in the same inspection platform, the same temperature, the same humidity, the same atmospheric pressure and the same isolation space. It effectively reduces the impact of environmental changes on the accidental error in the weight measurement process and improves the accuracy of weight measurement [8], [9]. The intelligent measurement system can realise the intelligent quantity transmission into groups of weights according to the pre-set program. On the one hand, there should be an appropriate weighing design program, on the other hand, it needs the supporting hardware such as weight bin, manipulator and comparator weighing pan. The weight bin, the manipulator fork and the comparator weighing pan all adopt the comb design to take and place the weight. The one-to- three component combination intelligent measurement device manipulator fork and the comparator weighing pan surface all adopt the rectangular comb design. The weights are placed in a flat and symmetrical arrangement on the comparator weighing pan, as shown in Figure 1.

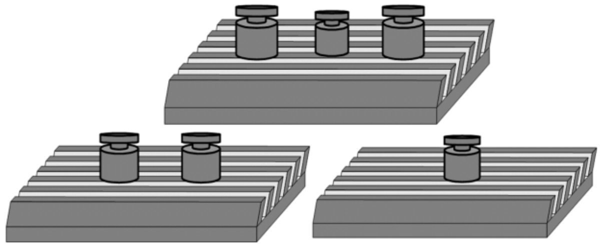

Figure 1: Schematic diagram of weighing pan of comparator (one- to- three component combination)

The one-to-four component combination intelligent measurement device manipulator has two fork shapes, one is the rectangular comb design, and the other is the “凸” comb design. The rectangular fork can fork one or two weights at same time, and the“凸” fork can fork one-to-four weights at same time. The weighing pan of the comparator adopts the “凸”comb design, and the weights are placed in the central position, as shown in Figure 2.

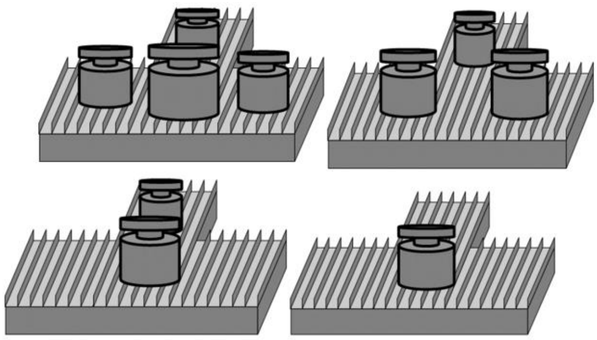

Figure 2: Schematic diagram of weighing pan of comparator (one- to- four component combination)

The full-automatic intelligent control system can realise intelligent automatic loading and unloading weights, automatic comparison, automatic collection of weighing data and environmental parameters, and automatically providing original verification records [10]. The whole process is automatically completed according to the pre-set program, which truly realises intelligent automatic measurement, saves manpower and greatly improves the measurement efficiency.

3. WEIGHING DESIGN OFGROUP WEIGHT COMBINATION METHOD

The combination method is used to measure group weights. A reference weight is compared with a complete set of test weights. For example, the class E_1 gram and kilogram reference weight are used to measure class E_2 weight. The transmission route is: the class E_1 gram reference weight is used to measure class E_2 milligram group weights, and the class E_1 kilogram reference weight is used to measure class E_2 gram group weights [11].

3.1. Weighing Design of One-to-three Component Combination Method

Mathematical Model of One-to-three Component Combination Method

Quality measurement experts in various countries are committed to the research on the weighing design of group weights. The one-to-three component combination method is targeted at $(5, 5, 2, 2, 1, 1) \times 10^n$ g, $n \in \{\cdots, -2, -1, 0, 1, 2, \cdots\}$ in reference [3] a weighing design is recommended for the combined weight sequence, and the design is discussed, analysed and calculated in detail and evaluated for uncertainty. The weight sequences widely used in China are（5, 2, 2, 1）$\times 10^n$ g, $n \in \{\cdots, -2, -1, 0, 1, 2, \cdots\}$ combination. If this method is directly adopted, the measurement process is complex, and the number of weights borrowed is too many, so the practicability and operability are not good. Referring to the weighing design in reference [3], combined with the existing weight series in China, the method of measuring two sets of weights at the same time in one weighing cycle is adopted $(5, 5, 2, 2, 2, 2, 1, 1) \times 10^n$ g, $n \in \{\cdots, -2, -1, 0, 1, 2, \cdots\}$ complete the quantity transmission of group weights.

The measurement sequence of each group is given below, and the reference weight and test weight with the following nominal values are selected:

Table 1: Weighing design of two groups of weights at the same time /g

Serial	A Weight	Compare	B Weight	Difference value
1	1000（reference weight）	VS	500+500’	Δm_1
2	500	VS	500’	Δm_2
3	500	VS	200+200*+100	Δm_3
4	500’	VS	200’+200*’+100’	Δm_4
5	200	VS	100+100’	Δm_5
6	200*	VS	100+100’	Δm_6
7	200’	VS	100+100’	Δm_7
8	200*’	VS	100+100’	Δm_8
9	100	VS	100’	Δm_9

Reference weight A:

1×10^{n}, $n \in \{\cdots, -2, -1, 0, 1, 2, \cdots\}$ unit: g

Test weight B: (5, 2, 2*, 1) × 10^{n-1}, unit: g

Take the weight combination of $n = 3$ as an example, that is, the reference weight A is 1000 g; One set of test weights B is 500 g, 200 g, 200* g and 100 g, and the other set is 500' g, 200' g, 200*' g and 100' g. The common operation sequence is shown in Table 1.

The difference Δm_{i} is the mass difference between the test weight B and the reference weight A. The conventional mass of the first set of test weights 5, 2, 2*, 1 are expressed as m_{c5}, m_{c2}, $m_{\mathrm{c2*}}$, and m_{c1}, and the conventional mass of the second set of test weights are expressed as $m_{\mathrm{c5}}^{'}$, $m_{\mathrm{c2}}^{'}$, $m_{\mathrm{c2*}}^{'}$, and $m_{\mathrm{c1}}^{'}$.

The first set of linear equations of the test weights is equation (1). The second set of linear equations of the test weight is equation (2).

$$\begin{cases} m_{\mathrm{c5}} + m_{\mathrm{c5}}^{'} = \Delta m_1 + m_{\mathrm{cr}} \\ -m_{\mathrm{c5}} + m_{\mathrm{c5}}^{'} = \Delta m_2 \\ -m_{\mathrm{c5}} + m_{\mathrm{c2}} + m_{\mathrm{c2*}} + m_{\mathrm{c1}} = \Delta m_3 \\ -m_{\mathrm{c2}} + m_{\mathrm{c1}} + m_{\mathrm{c1}}^{'} = \Delta m_5 \\ -m_{\mathrm{c2*}} + m_{\mathrm{c1}} + m_{\mathrm{c1}}^{'} = \Delta m_6 \\ -m_{\mathrm{c1}} + m_{\mathrm{c1}}^{'} = \Delta m_9 \end{cases}, \tag{1}$$

$$\begin{cases} m_{\mathrm{c5}} + m_{\mathrm{c5}}^{'} = \Delta m_1 + m_{\mathrm{cr}} \\ -m_{\mathrm{c5}} + m_{\mathrm{c5}}^{'} = \Delta m_2 \\ -mc_5^{'} + m_{\mathrm{c2}}^{'} + m_{\mathrm{c2*}}^{'} + m_{\mathrm{c1}}^{'} = \Delta m_4 \\ -m_{\mathrm{c2}}^{'} + m_{\mathrm{c1}} + m_{\mathrm{c1}}^{'} = \Delta m_7 \\ -m_{\mathrm{c2*}}^{'} + m_{\mathrm{c1}} + m_{\mathrm{c1}}^{'} = \Delta m_8 \\ -m_{\mathrm{c1}} + m_{\mathrm{c1}}^{'} = \Delta m_9 \end{cases}. \tag{2}$$

The mathematical model is obtained by solving the equations. First set is equation (3).

$$\begin{cases} m_{\mathrm{c5}} = \frac{1}{2}(m_{\mathrm{cr}} + \Delta m_1 - \Delta m_2) \\ m_{\mathrm{c2}} = \frac{1}{5}\begin{pmatrix} 2m_{\mathrm{c5}} + 2\Delta m_3 - 3\Delta m_5 \\ +2\Delta m_6 + \Delta m_9 \end{pmatrix} \\ m_{\mathrm{c2*}} = \frac{1}{5}\begin{pmatrix} 2m_{\mathrm{c5}} + 2\Delta m_3 + 2\Delta m_5 \\ -3\Delta m_6 + \Delta m_9 \end{pmatrix} \\ m_{\mathrm{c1}} = \frac{1}{2}(m_{\mathrm{c2}} + \Delta m_5 - \Delta m_9) \end{cases}. \tag{3}$$

Second set is equation (4).

$$\begin{cases} m_{\mathrm{c5}}^{'} = \frac{1}{2}(m_{\mathrm{cr}} + \Delta m_1 + \Delta m_2) \\ m_{\mathrm{c2}}^{'} = \frac{1}{5}\begin{pmatrix} 2m_{\mathrm{c5}}^{'} + 2\Delta m_4 - 3\Delta m_7 \\ +2\Delta m_8 - \Delta m_9 \end{pmatrix} \\ m_{\mathrm{c2*}}^{'} = \frac{1}{5}\begin{pmatrix} m_{\mathrm{c5}}^{'} + 2\Delta m_4 + 2\Delta m_7 \\ -3\Delta m_8 - \Delta m_9 \end{pmatrix} \\ m_{\mathrm{c1}}^{'} = \frac{1}{2}(m_{\mathrm{c2}}^{'} + \Delta m_7 + \Delta m_9) \end{cases}. \tag{4}$$

Uncertainty Analysis of One-to-three Component Combination Method

According to the circulation mode of ABBA, since the measurement is completed on the same comparator, regardless of the influence of air buoyancy, the uncertainty component introduced by the measuring instrument is $u(\Delta m) = d/2\sqrt{3}$.

According to the mathematical model of one-to-three component combination method, it can be obtained that:

$$u(m_{\mathrm{c5}}) = \left\{\left(\tfrac{1}{2}\right)^2 u^2(m_{\mathrm{cr}}) + \left(\tfrac{1}{2}\right)^2 [u^2(\Delta m_1) + u^2(\Delta m_2)]\right\}^{\frac{1}{2}} = \tfrac{1}{2}[u^2(m_{\mathrm{cr}}) + 2u^2(\Delta m)]^{\frac{1}{2}} \tag{5}$$

$$\begin{aligned} u(m_{\mathrm{c2}}) = \Bigg\{\left(\frac{1}{5}\right)^2 u^2(m_{\mathrm{cr}}) + \left(\frac{1}{5}\right)^2 [u^2(\Delta m_1) \\ + u^2(\Delta m_2) \\ + 2^2 u^2(\Delta m_3) + 3^2 u^2(\Delta m_5) \\ + 2^2 u^2(\Delta m_6) + u^2(\Delta m_9)]\Bigg\}^{\frac{1}{2}} \\ = \left[\frac{1}{25} u^2(m_{\mathrm{cr}}) + \frac{4}{5} u^2(\Delta m)\right]^{\frac{1}{2}} \end{aligned} \tag{6}$$

$$\begin{aligned} u(m_{\mathrm{c2*}}) = \Bigg\{\left(\frac{1}{5}\right)^2 u^2(m_{\mathrm{cr}}) + \left(\frac{1}{5}\right)^2 [u^2(\Delta m_1) \\ + u^2(\Delta m_2) \\ + 2^2 u^2(\Delta m_3) + 2^2 u^2(\Delta m_5) \\ + 3^2 u^2(\Delta m_6) + u^2(\Delta m_9)]\Bigg\}^{\frac{1}{2}} \\ = \left[\frac{1}{25} u^2(m_{\mathrm{cr}}) + \frac{4}{5} u^2(\Delta m)\right]^{\frac{1}{2}} \end{aligned} \tag{7}$$

$$\begin{aligned} u(m_{\mathrm{c1}}) = \Bigg\{\left(\frac{1}{10}\right)^2 u^2(m_{\mathrm{cr}}) + \left(\frac{1}{10}\right)^2 [u^2(\Delta m_1) \\ + u^2(\Delta m_2) \\ + 2^2 u^2(\Delta m_3) + 2^2 u^2(\Delta m_5) \\ + 2^2 u^2(\Delta m_6) \\ + 4^2 u^2(\Delta m_9)]\Bigg\}^{\frac{1}{2}} \\ = \Bigg[\frac{1}{100} u^2(m_{\mathrm{cr}}) \\ + \frac{3}{10} u^2(\Delta m)\Bigg]^{\frac{1}{2}}. \end{aligned} \tag{8}$$

3.2. Weighing Design of One-to-four Component Combination Method

Mathematical Model of One-to-four Component Combination Method

According to the weighing design recommended in “OIML R111-1:2004”, the reference weights are 1 kg and 1 g, and three stable check standards with known mass are added respectively. Three groups of comparison are designed for each group, and each group has 12 step comparison cycle, which can complete the quantity transfer of the mass value of 1 g ~ 500 g and 1 mg ~ 500 mg weights.

This paper gives the weighing design of each group, and the reference weight and test weight of the nominal value selected are:
Reference weight A:
1×10^n, $n \in \{\cdots, -2, -1, 0, 1, 2, \cdots\}$, unit: g
Tested weight B: (5, 2, 2* , 1) × 10^{n-1}, unit: g
Check standard weight: 1* × 10^{n-1}, unit: g

Take the weight combination of n = 3 as an example, that is, the reference weight A is 1000 g; The test weight B is 500 g, 200 g, 200* g and 100 g; The check standard weight is 100* g. The common operation sequence is shown in Table 2.

Table 2: Weighing design of four position component combination method /g

Serial	A Weight	Compare	B Weight	Difference value
1	1000（reference weight）	VS	500+200+200*+100	Δm_1
2	1000（reference weight）	VS	500+200+200*+100*	Δm_2
3	500	VS	200+200*+100	Δm_3
4	500	VS	200+200*+100*	Δm_4
5	200+100	VS	200*+100*	Δm_5
6	200+100	VS	200*+100*	Δm_6
7	200+100*	VS	200*+100	Δm_7
8	200+100*	VS	200*+100	Δm_8
9	200	VS	100+100*	Δm_9
10	200	VS	100+100*	Δm_{10}
11	200*	VS	100+100*	Δm_{11}
12	200*	VS	100+100*	Δm_{12}

Because there are repeated measurements in the operation sequence, two sets of general linear equations and equations can be obtained according to the operation sequence.

Equation group I is equation (9) and equation group II is equation (10).

$$\begin{cases} m_{c5} + m_{c2} + m_{c2*} + m_{c1*} = m_{cr} + \Delta m_1 \\ -m_{c5} + m_{c2} + m_{c2*} + m_{c1} = \Delta m_3 \\ -m_{c5} + m_{c2} + m_{c2*} + m_{c1*} = \Delta m_4 \\ -m_{c2} + m_{c2*} - m_{c1} + m_{c1*} = \Delta m_5 \\ -m_{c2} + m_{c2*} + m_{c1} - m_{c1*} = \Delta m_7 \\ -m_{c2} + m_{c1} + m_{c1*} = \Delta m_9 \\ -m_{c2*} + m_{c1} + m_{c1*} = \Delta m_{11} \end{cases} \tag{9}$$

$$\begin{cases} m_{c5} + m_{c2} + m_{c2*} + m_{c1*} = m_{cr} + \Delta m_2 \\ -m_{c5} + m_{c2} + m_{c2*} + m_{c1} = \Delta m_3 \\ -m_{c5} + m_{c2} + m_{c2*} + m_{c1*} = \Delta m_4 \\ -m_{c2} + m_{c2*} - m_{c1} + m_{c1*} = \Delta m_6 \\ -m_{c2} + m_{c2*} + m_{c1} - m_{c1*} = \Delta m_8 \\ -m_{c2} + m_{c1} + m_{c1*} = \Delta m_{10} \\ -m_{c2*} + m_{c1} + m_{c1*} = \Delta m_{12} \end{cases} \tag{10}$$

The mathematical model of a set of (5, 2, 2*, 1) weights can be obtained by solving equation (11).

$$\begin{cases} m_{c5} = \frac{1}{4}\begin{pmatrix} 2m_{cr} + \Delta m_1 + \Delta m_2 \\ -\Delta m_3 - \Delta m_4 \end{pmatrix} \\ m_{c2} = \frac{1}{10}\begin{pmatrix} 4m_{c5} + 2\Delta m_3 + 2\Delta m_4 \\ -\Delta m_5 - \Delta m_6 - \Delta m_7 \\ -\Delta m_8 - \Delta m_9 - \Delta m_{10} \end{pmatrix} \\ m_{c2*} = \frac{1}{10}\begin{pmatrix} 4m_{c5} + 2\Delta m_3 + 2\Delta m_4 \\ +\Delta m_5 + \Delta m_6 + \Delta m_7 \\ +\Delta m_9 - \Delta m_{11} - \Delta m_{12} \end{pmatrix} \\ m_{c1} = \frac{1}{4}\begin{pmatrix} 2m_{c2} + \Delta m_7 + \Delta m_9 \\ +\Delta m_{11} + \Delta m_{12} \end{pmatrix} \end{cases} \tag{11}$$

Uncertainty Analysis of One-to-four Component Combination Method

According to the mathematical model of one-to-four component combination method, it can be obtained that:

$$u(m_{c5}) = \left\{\left(\frac{1}{2}\right)^2 u^2(m_{cr}) + \left(\frac{1}{4}\right)^2 [u^2(\Delta m_1) + u^2(\Delta m_2) + u^2(\Delta m_3) + u^2(\Delta m_4)]\right\}^{\frac{1}{2}} = \frac{1}{2}[u^2(m_{cr}) + u^2(\Delta m)]^{\frac{1}{2}} \quad (12)$$

$$u(m_{c2}) = \left\{\left(\frac{1}{5}\right)^2 u^2(m_{cr}) + \left(\frac{1}{10}\right)^2 [u^2(\Delta m_1) + u^2(\Delta m_2) + u^2(\Delta m_3) + u^2(\Delta m_4) + u^2(\Delta m_5) + u^2(\Delta m_6) + u^2(\Delta m_7) + u^2(\Delta m_8) + u^2(\Delta m_9) + u^2(\Delta m_{10})]\right\}^{\frac{1}{2}} = \left[\frac{1}{25}u^2(m_{cr}) + \frac{1}{10}u^2(\Delta m)\right]^{\frac{1}{2}} \quad (13)$$

$$u(m_{c2*}) = \left\{\left(\frac{1}{5}\right)^2 u^2(m_{cr}) + \left(\frac{1}{10}\right)^2 [u^2(\Delta m_1) + u^2(\Delta m_2) + u^2(\Delta m_3) + u^2(\Delta m_4) + u^2(\Delta m_5) + u^2(\Delta m_6) + u^2(\Delta m_7) + u^2(\Delta m_8) + u^2(\Delta m_{11}) + u^2(\Delta m_{12})]\right\}^{\frac{1}{2}} = \left[\frac{1}{25}u^2(m_{cr}) + \frac{1}{10}u^2(\Delta m)\right]^{\frac{1}{2}} \quad (14)$$

$$u(m_{c1}) = \left\{\left(\frac{1}{10}\right)^2 u^2(m_{cr}) + \left(\frac{1}{20}\right)^2 [u^2(\Delta m_1) + u^2(\Delta m_2) + u^2(\Delta m_3) + u^2(\Delta m_4) + u^2(\Delta m_5) + u^2(\Delta m_6) + 4^2u^2(\Delta m_7) + 4^2u^2(\Delta m_8) + u^2(\Delta m_9) + u^2(\Delta m_{10}) + 5^2u^2(\Delta m_{11}) + 5^2u^2(\Delta m_{12})]\right\}^{\frac{1}{2}} = \left[\frac{1}{100}u^2(m_{cr}) + \frac{9}{40}u^2(\Delta m)\right]^{\frac{1}{2}} \quad (15)$$

4. COMPARISON OF MEASUREMENT UNCERTAINTY ANALYSIS

The mathematical model of the direct comparison method given by "OIML R111-1:2004" is shown in equation (16).

$$m_{ct} = m_{cr} + \Delta m_c \quad (16)$$

The uncertainty can be obtained according to the mathematical model of the conventional mass of the test weight.

$$u(m_{ct}) = \sqrt{u^2(m_{cr}) + u^2(\Delta m)} \quad (17)$$

According to the mathematical model of each method, the uncertainty of the analysis measurement method is summarised in Table 3.

Table 3: Comparison of measurement uncertainty of different methods

Standard uncertainty	**One-to-three component combination method**	**One-to-four component combination method**	**Direct comparison method**
$u(m_{c5})$	$\frac{1}{2}\sqrt{u^2(m_{cr}) + 2u^2(\Delta m)}$	$\frac{1}{2}\sqrt{u^2(m_{cr}) + u^2(\Delta m)}$	$\sqrt{u^2(m_{cr}) + u^2(\Delta m)}$
$u(m_{c2})$	$\sqrt{\frac{1}{25}u^2(m_{cr}) + \frac{4}{5}u^2(\Delta m)}$	$\sqrt{\frac{1}{25}u^2(m_{cr}) + \frac{1}{10}u^2(\Delta m)}$	$\sqrt{u^2(m_{cr}) + u^2(\Delta m)}$
$u(m_{c2*})$	$\sqrt{\frac{1}{25}u^2(m_{cr}) + \frac{4}{5}u^2(\Delta m)}$	$\sqrt{\frac{1}{25}u^2(m_{cr}) + \frac{1}{10}u^2(\Delta m)}$	$\sqrt{u^2(m_{cr}) + u^2(\Delta m)}$
$u(m_{c1})$	$\sqrt{\frac{1}{100}u^2(m_{cr}) + \frac{3}{10}u^2(\Delta m)}$	$\sqrt{\frac{1}{100}u^2(m_{cr}) + \frac{9}{40}u^2(\Delta m)}$	$\sqrt{u^2(m_{cr}) + u^2(\Delta m)}$

The uncertainty comparison diagram of the three methods is shown in Figure 3. In the figure, nominal value of the weight （$\times 10^n$) g is the abscissa and the uncertainty caused by the weighing instrument is the ordinate.

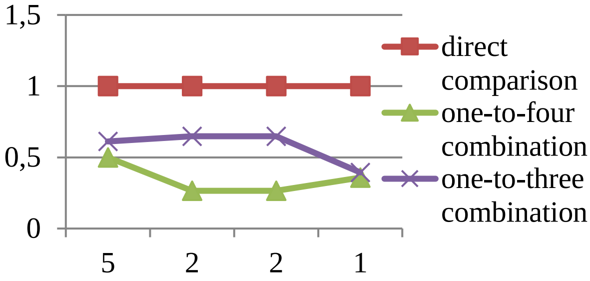

Figure 3: Comparison of uncertainty

It can be seen from Figure 3 that the uncertainty of the measurement results of the two component combination methods is lower than that of the direct comparison method. That is the two algorithms described in this paper are effective and feasible for intelligent measurement device.

5. SUMMARY

Based on the characteristics of intelligent measurement system and the requirements of group weights verification, this paper gives two kinds of weighing designs and establishes mathematical models. After analysis and uncertainty evaluation, the two weighing designs are scientific and reasonable, which are helpful to promote the application of intelligent measurement technology in the field of group weights transmission. Furthermore, these methods help to improve the measurement ability and technical level of the weights, and promote the development of the weight value transmission technology.

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