TRIAL CONSTRUCTION OF AN AUTOMATIC CALIBRATION DEVICE FOR STANDARD WEIGHTS
- DIRECT SUBMULTIPLE CALIBRATION OF TEST STANDARD WEIGHT SET -

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Abstract: To establish a national mass standard, submultiple and multiple systems are employed to calibrate highly accurate sets of weights based on national prototype kilograms. However, calibration techniques require great skill and many years for the measurement of weights. To promote an efficient calibration process, an automatic calibration device with built-in standard weights is being developed. In the first step, a device was manufactured on an experimental basis; this device automatically calibrates a set of built-in ring-shaped standard weights (100 g ~ 1 kg) using the submultiple method. Then, preliminary experiments were performed. In the second step, a weight-exchange mechanism which directly calibrates test standard weights (1000, 500, 200, 200, 100 g) using the submultiple method was added to the device and calibrations were carried out. Results of preliminary measurements reveal a standard deviation of approximately 0.04 ~ 0.02 mg.

Keywords: National mass standard, Establishment of mass standard, Calibration of standard weights, Submultiple and multiple calibration

1. INTRODUCTION

The fundamental unit for mass, the kilogram (kg), is defined by the international prototype kilogram. A mass scale is therefore needed to obtain an arbitrary mass value for the national mass standard. For this purpose, at the National Research Laboratory of Metrology (NRLM), highly accurate weight sets (1 mg ~ 20 kg) are calibrated by submultipe and multiple method on the basis of the national prototype kilogram (No.6) [1] to establish a national mass standard [2][3].

Establishment of national mass standard requires great skill and many years for the calibration. Therefore, to improve calibration efficiency, the development of an automatic calibration device with built-in high-accuracy standard weights is planned. In the first step, a device was manufactured on an experimental basis which automatically calibrates a set of built-in ring-shaped standard weights (1000, 500, 200, 200, 100, 100 g) by the submultiple method. Results of preliminary experiments were reported [4].

In this study, a weight-exchange device which directly calibrates test standard weights (1000, 500, 200, 200, 100 g) using the submultiple method was added to the device. This paper reports the structure of the weight exchange device, the measurement method and results of preliminary measurements.

2. DESCRIPTION OF THE DEVICE

A previously reported automatic calibration device [4] calibrates built-in standard weights by the submultiple method on the basis of a 1 kg outside standard weight to establish a mass standard, and it also calibrates test standard weights on an equal weight basis by comparing them with built-in standard weights. This device consists of four main components: 1. built-in standard weights (standard weights and balancing weights), 2. weight-exchange mechanism (for built-in weights and the outside standard weights), 3. a weighing unit, and 4. a control unit. In this study, a weight-exchange device is added to enable submultiple calibration of test standard weights. Just as in the submultiple calibration of built-in standard weights, the control unit directly calibrates test weights using the submultiple method, not on an equal weight basis which relies on built-in standard weights. Using the submultiple method, uncertainties in calibration values which are one rank superior in regard to their consistency than those obtained by equal calibration were obtained. The structure and function of

individual components were described in the previous report [4]. A weight exchange device for test weights, which is added in this study, is described subsequently.

As shown in Table 1, a weight-exchange device for test weights directly calibrates test weights in a series of 5,2,2,1,1 by the submultiple method. To minimize the dimensions of the weight-exchange device, which is added to calibrate test weights by the submultiple method, to the greatest extent, an exchange load mechanism for the outside standard weights is used. Four weights, such as the 1 kg standard weight, 1 kg, 500 g and 100B g test weights, are set on four pans which contain four weights for outside standard weights. Only one of the four weights is weighed. The remaining three weights, such as 200A g, 200B g and 100A g, are set on the test weight-exchange device added in this study. The weight-exchange device for test weights enables three weights to be loaded individually on pans or to be unloaded; it also allows the weighing of arbitrary combinations of the three weights. The control unit is used to directly calibrate test weights using the submultiple method based on measuring combinations of test weights and balancing weights, as listed in Table 1.

Table 1. Combination of test standard weights and balancing weights

Test standard weights (g) (5,2,2,1,1 series)						Diff. mass	Balancing weights (g) (5,2,2,1 series)			
500	200A	200B	100A	100B	1000		500	200A	200B	100
+	+	+	+		-	a1				
+	-	-	-			a2	+			
+	-	-		-		a3	+			
	+	-	+	-		a4	+	+		
	+	-	-	+		a5	+	+		
	+	-				a6	+	+		+
	+		-	-		a7	+	+		+
		+	-	-		a8	+	+		+
			+	-		a9	+	+	+	
Diff. mass is different mass between + and - weight for example, (500 + 200A + 200B + 100A) - 1000 = a1							Each + weight is loaded for filling capacity of 1 kg			

By direct submultiple calibration, test weights are made to be standard weights which offer consistent calibration values and whose uncertainties are evaluated. Standard weights are usually a series of 5,2,2,1 therefore, 100B g of test weights is used to evaluate the validity of submultiple calibration measurements using high-rank standard weights whose calibration values are obtained. Balancing weights are incorporated into the device for a total mass of 1 kg to be loaded onto the balance capacity during the submultiple calibration measurement.

The added test weight-exchange mechanism is made of nonmagnetic materials, and its shape is designed to cause no defects in the test weights. In addition, it is structured to produce no undesirable influences on weighing. In particular, the contact part between the load exchange mechanism and the weights is designed to avert wear on weights as much as possible.

The control unit is designed to perform submultiple calibration of built-in weights efficiently and safely, comparing outside standard weights with built-in weights, comparing outside test standard weights with built-in weights on an equal basis and submultiple calibrations of outside test standard weights. Safety measures are included for external disturbances such as earthquakes.

3. RESULTS OF MEASUREMENT AND CONSIDERATION

At first, a 1 kg test standard weight was calibrated on an equal weight basis by the outside 1 kg standard weight. Next, the mass of another test standard weight, i.e., 500, 200A, 200B, 100A, 100B g was calibrated using the submutiple method based on the test 1 kg standard weight. The mass difference, a_1-a_9, was measured following the combinations shown in Table 1. Each measurement was made from seven exchanges between the two weight groups alternately at equal time intervals; thus, each mass difference was obtained without drift. Both outside and test standards weights were made of the same materials with the same volume to eliminate the influence of changes in air density. The calibration value of each test weight was obtained by the least squares method from the calibration value of the 1 kg test weight and the values observed for a_1-a_9. The outside 1 kg standard weight was calibrated to be exactly 1 kg; therefore the correction value was zero. Each measurement takes approximately 1 hr. The standard deviations of nine consecutive measurements listed in Table 2

reveal that differences among measured values decrease in accordance with a decrease in the nominal values. The nine consecutive measurements were carried out on a quiet night. On the basis of the results of consecutive measurements by automatic submultiple calibration, the standard deviation in the calibrated value for test weights is calculated to be approximately 0.04 ~ 0.02 mg.

This result is considered legitimate given the performance of electronic balances and pans that tremble when weights were changed and considering results in the previous report [4].

Experiments were performed emphasizing the construction of an automatic load exchange mechanism for submultiple calibration not intended high accuracy in calibrated values since both the budget and time period allocated for experiments

Table 2. Results of preliminary direct submultiple calibration of test weights (mg)

Nominal value	1000	500	200A	200B	100A	100B
Measurement No. 1	12.568	6.301	2.715	2.706	1.225	1.92265
2	12.603	6.333	2.659	2.674	1.259	1.907
3	12.604	6.295	2.654	2.666	1.264	1.920
4	12.622	6.269	2.640	2.640	1.263	1.918
5	12.597	6.307	2.625	2.645	1.256	1.910
6	12.681	6.335	2.655	2.691	1.259	1.910
7	12.591	6.294	2.624	2.641	1.243	1.887
8	12.659	6.346	2.643	2.649	1.247	1.892
9	12.595	6.279	2.639	2.663	1.264	1.915
Average	12.613	6.306	2.650	2.664	1.253	1.914
Stndard deviation	0.035	0.026	0.027	0.023	0.013	0.022

were limited. As a result of these experiments, standard uncertainties in submultiple measurements were smaller than expected. The direct submultiple calibration of test weights has realized achievements greater than expected, given that the calibration was only at the first step. Even if other uncertainties are considered, on an experimental basis, the device can be used for the automatic calibration of F1 class weights. Recently, a highly accurate electronic balance with an exchanging device of weights (a handler) became available on the commercial market. The use of this balance shortens the calibration period and offers good environments for calibration. However, even though the balance is used, longstanding experience and great skill are still needed to combine measurement weights on the basis of submultiple and multiple calibration theory and the setting of some weights on pans. Our manufactured device enables automatic weight calibration without requiring great skill by merely putting each test weights on each pans. In this respect, the device is highly convenient and expected to be put into practical use. To develop a practically usable device and improve its accuracy, many issues such as the correction of operating environments for buoyancy, confirmation of reproducibility, making calibration values absolute and checking the stability of the device need to be improved or resolved. By resolving these issues one by one, a practically usable device with high accuracy, durability and operability will be developed.

4. CONCLUSION

Previously, built-in ring-shaped standard weights were successfully automatically calibrated using the submultiple method which utilized a computer-controlled automatic weight device [4]. In this study, the weight-exchange device which directly performs submultiple calibrations of test standard weights (1000, 500, 200A, 200B and 100A g) was incorporated into the device and measurement was carried out. Results of measurements were favorable and the standard deviation of calibrated values was calculated to be approximately 0.04 ~ 0.02 mg.

These estimated values indicate the potential for the automatic calibration of high-accuracy standard weights. On an experimental basis, this device can be used to automatically calibrate F1 class weights. When compared to a device with built-in standard weights, the device has equivalent ability for checking and evaluating weights. Since the device measures weights automatically, the calibration cycle can be shortened arbitrarily. Accordingly, this device has much merit. A device which can perform the automatic calibration of E1 class weights or higher is being developed by improving the device and its accuracy and solving other problems.

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