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# The repeatability optimization of an automated weighing comparator

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**Abstract**

Manual mass comparison encumbers essentially a measurement or calibration with frequent interventions. Recently, an a5 automatic comparator (for the range of 1 mg ~ 5 g) from Mettler-Teledo (MT) has been introduced to Korea Research Institute of Standards and Science (KRISS) to ensure concretely the traceability of national standard. The stabilization time, the integration time and the number of measurements are selected as optimization parameters. The repeatability is obtained in more than 350 measurements. In the viewpoint of uncertainty, no preference condition is found from the result. The criterion to choose the stabilization time was proposed for 5 g weight range, and the time performance of a5 in legal metrology was commented.

*Keyword*: automated balance; weight; mass standard; stabilization time; optimization

## 1. Introduction

Known as weighing balances, in principle, mass comparators are used mainly to determine the mass of reference grade weight standards by measuring the force which is exerted by a sample on its support within the gravitational field of the earth.

Historically, Mettler Instrumente AG introduced in 1973 the first fully electronic precision (Class 1) balance for manual operation, the model PT1200 with the single weighing top pan and 0.01 grams readability. A manual comparator requires human operation and judgement to control the loading or unloading of the mass standard and to record readings.

Recently, an automated comparator which was quipped with robotic arms and/or weight pan handler for automatic determination has been developed mainly by National Metrology Institutes (NMIs) and commercial companies in order to use to minimize the need for human intervention. Despite of its convenience, they generally require more planning before measurement and careful setting of the operating parameters to apply in the mass standard dissemination or industry where needs to measure in high accuracy. The automatic balance introduces several time-consuming factors, e.g. the stabilization or data averaging (integration) time, which affect the accuracy or repeatability of the mass comparators. Unfortunately, these factors are not presented clearly in anywhere or defined as a numerical value. For example, International Organization of Legal Metrology (OIML) recommendation R 111-1 gives only a short comment on the time consuming factors as an indefinite constant time interval between weightings and the minimum number of weighing cycles for a weight class [1]. Therefore, it will be a meaningful work to pursuit finding the proper setting of the operating parameters for independent weighing instrument to achieve optimal, repeatable, and reliable measurement results. Only one research was found for this trial. Lee et al. has explained in detail the meaning of parameters and has tried to optimize the Mettler-Toledo (MT) a5 and a100 automated comparators by simple comparison one time in the varying of parameters [2].

In this paper, we performed the optimization of an automated balance to determine a set of operating parameters that optimises the operation of the comparators to achieve optimal repeatability in the shortest time. The optimized condition parameters of the MT a5 mass comparator were investigated using a set of stainless steel weights through a series of weighing. The repeatability of the mass difference and its operation time were obtained in varying the parameters of the comparator.

## 2. Experimental

The MT a5 comparator consists of a cabinet, containing a weight magazine, a mass comparator (UMX 5), and a three-axes handling robot arm as shown in Figure 1. The robot arm loads or unloads the comparator with the weights [3]. The control parameters and sequence can either be entered on a PC or they can be downloaded from a host by means of a script command language.

The measurements were performed at normal ambient conditions accredited by ISO 17025; pressure of average 995.7 (standard deviation: 4.3 during this experiment) hPa, temperature of 20.5 (0.3) ˚C, and relative humidity of 54.0 (1.2) % [4]. The environmental data were collected one time just before starting one series measurement.

The MT and Häfner E1 class stainless steel weights were used in this experiment: 5 g, 100 mg, 50 mg, 20 mg, and 10 mg for simple comparison and weighing scheme, and 5 mg as a check weight in the weighing scheme.

In order to compare the automated result, the manual type balance, the former model the UMT 5 of the UMX 5, was used in the similar conditions with the automated case; environment and setting parameters.

Several home-made software programs developed in the National Instruments LabVIEW, were used in reading and analyzing more than three hundreds of a5 data files and operating or monitoring the UMT 5 similar to the a5 measurement routine through the serial communication for comparison with manual balance.

Fig. 1. The example of the automated comparator, Mettler-Toledo a5 installed at the Korea Research Institute of Standards and Science

## 3. Results and discussions

The first part of experiment was regarding to the optimization of the time consuming parameters such as stabilization time (ST), integration time (IT), and the number of measurement (NM). In this experiment, the nominal weights (S and T) of 5 g were chosen at the almost maximum range of the balance. To minimize the effect of linear drift, the mass comparison (one series) was achieved by using the single substitution weighing method, the repetition of Reference-Test-Reference (R-T-R) and Test-Reference-Test (T-R-T), which defined in the comparison scheme in a5 control software. The parameters were selected by considering if influence on the measurement results directly. The operational meaning of each parameter was explained well in the manufacturer’s operating instruction. Table 1 summarize the numerical value range of the variable parameters. Therefore, one series can be identified with “ST-IT-NM” for time consuming parameters. The measurement was repeated five times for each series to check the reliable measurement. The result of each series was used to extract the average and standard deviation in a specific interesting group using the home-made program. It takes a much longer time to take one series data for ST-IT-NM with a5 comparing to the manual case, for example, 24 min in a5 (automated) and 8 min in UMT 5 (manual) for 10-10-5, and 42 min (automated) and 24 min (manual) for 40-40-5. The total number of series we done was 320, 4 (the number of available ST) × 4 (IT) × 4 (NM) × 5 (total repetition).

| *Parameter* | Value | Remark |
|---|---|---|
| *Start delay* | 0 min | |
| *No. of non-reported pre-weight per group* | 1 | stable positioning on the pan |
| *No. of reported comparison per group* | 2, 3, 5, 7 | variable parameter |
| *No. of series* | 1 | |
| *Stabilization time (sec)* | 10, 20, 30, 40 | variable parameter |
| *Integration time (sec)* | 10, 20, 30, 40 | variable parameter |
| *Comparison scheme* | A-B-A | S-T-S + T-S-T |
| *Sensitivity check* | No check | |

Table 1. Parameters used in optimization experiment with a5 and UMT 5.

Figure 2 estimates the measurement result for each parameter set (ST-IT-NM). The each data point was calculated from the standard deviation from the five (the number of repetition) data set. As for another analysis, Table 2 shows the repeatability result in automated measurement for each independent parameter; the standard deviation (STD) was obtained from the average of single series which took from the average in the a5 report files. The pooled STD was evaluated in the parenthesis for the reference. All the differences between two readings were extracted from the 320 report files by another home-made program, and then were used to calculate the pooled STD. Because only the repeatability was interested in this optimization study and under the assumption of constant environmental parameter during one series measurement time, it was not necessary to do the buoyancy correction from the environmental parameters.

Figure 2 and Table 2 were useful to choose the bests of specific parameters and general parameter range, respectively. As shown in Table 2, there is very slightly difference between parameters in the range of below 0.01 µg. 20 (ST) – 20 (IT) – 3 or 5 (NM) was the best choice in the viewpoint of optimization, but 20-20-3 should be a good condition in considering the whole measurement time. We have to note the result may be changed slightly depending how to select the group population in statistics. To precise result, more analysis between sets should be performed analyzing of variance (ANOVA) [9] which was beyond this paper. However, for simplicity, we considered only the standard deviation value in Table 2. This conclusion was consistent in the lowest STD point at 20-20-3 in Fig 2. On the other hand, all measured repeatability was satisfied within the proposed repeatability (0.4 µg for 5 g) in manufacturer's specifications [5], as shown in Figure 2 and Table 2. Therefore, it can be said all parameters are acceptable to any weighing processes in legal metrology.

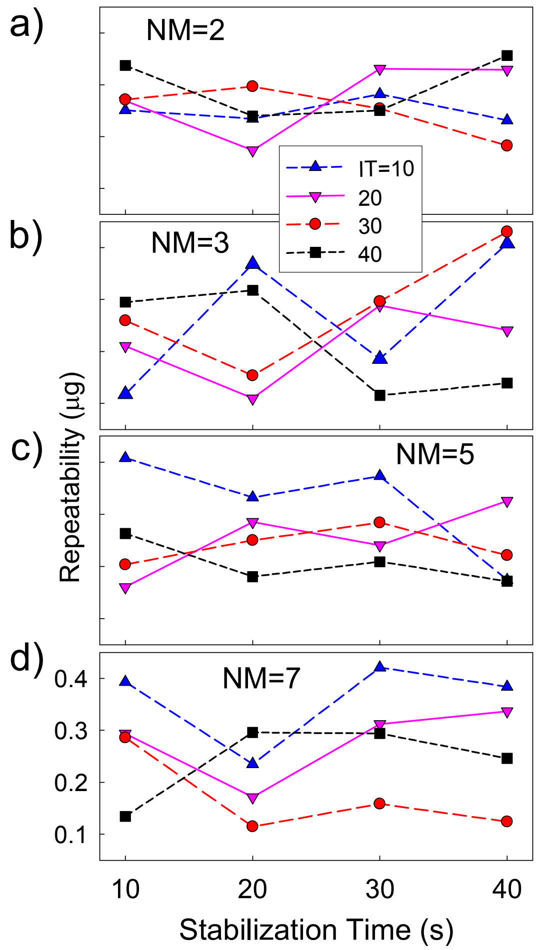


Figure 2. The measurement result with reference to the stabilization time. The number of reported comparisons: a) 2, b) 3, c) 5, and d) 7. The integration time (IT) presented as the up-triangle (10), down-triangle (20), circle (30) and square (40). Each data point was obtained from standard deviation of the five data.

| Stabilization Time (ST) | | Integration Time (IT) | | Number of Measure. (NM) | |
|---|---|---|---|---|---|
| Time | Deviation | Time | Deviation | Number | Deviation |
| 10 | 0.26 (0.44) | 10 | 0.26 (0.39 ) | 2 | 0.31 (0.39) |
| 20 | 0.24 (0.37) | 20 | 0.25 (0.37) | 3 | 0.24 (0.38) |
| 30 | 0.27 (0.39) | 30 | 0.25 (0.44) | 5 | 0.24 (0.37) |
| 40 | 0.27 (0.36) | 40 | 0.28 (0.37) | 7 | 0.24 (0.42) |

Table 2. The independent repeatability result (in µg) of automatic weighting with the a5. P-STD, the pooled standard deviation in µg, shown in the parenthesis. Each parameter has the eighty numbers of sampling data.

Manual weighing was compared to automated weighing in Figure 4. As expected due to manual weighting's unstable processes (such as eccentricity), the result in manual was out of range from the proposed repeatability. Consequently, the performance in weighing with the a5 automated comparator was better than the way of manual.

We also inspected the exact meaning on the stabilization time. Some kind of feedback loop, which represented as the combination of proportional – integral – derivative time values, may have been used in almost all precise electronic balance to stabilize the electromagnetic force compensation against to the weighing pan [6]. Figure 3 shows the typical example of real-time response in UMT 5 balance as a 5 g weight was loaded. If a value was stable for 5 sec interval as a criterion to identify the stabilization time, it took around 22 sec after loading the weight for the weighing value approached to the stable value, 4999.9904 mg. The 5 s, was a reasonable time interval because it is also recommended as the stable indication time in automatic zero-setting device part in OIML [7]. In more trials, average 19.2 s, was obtained to satisfy the criterion. Despite of its relative low repeatability for the 10 s case for nominal mass, 5 g, as shown in Figure 2 and Table 2, therefore, the true mass may not be indicated in the balance. We should also point out again the result was validated for the nominal value, 5 g, in UMT 5 because any electronic balance has a proper time constant according to weighing regions and instruments.

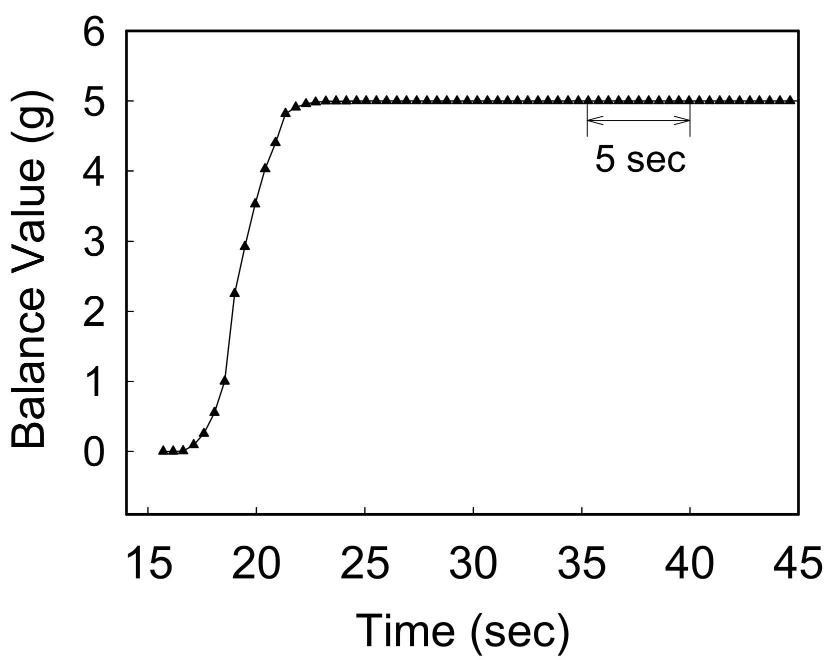


Figure 3. Typical example of the balance's response in real time when a weight was loaded on the pan in MT-UMT 5. In this study, the stabilization time was taken the point where start to be in stable (not to change the balance value) for 5 sec.

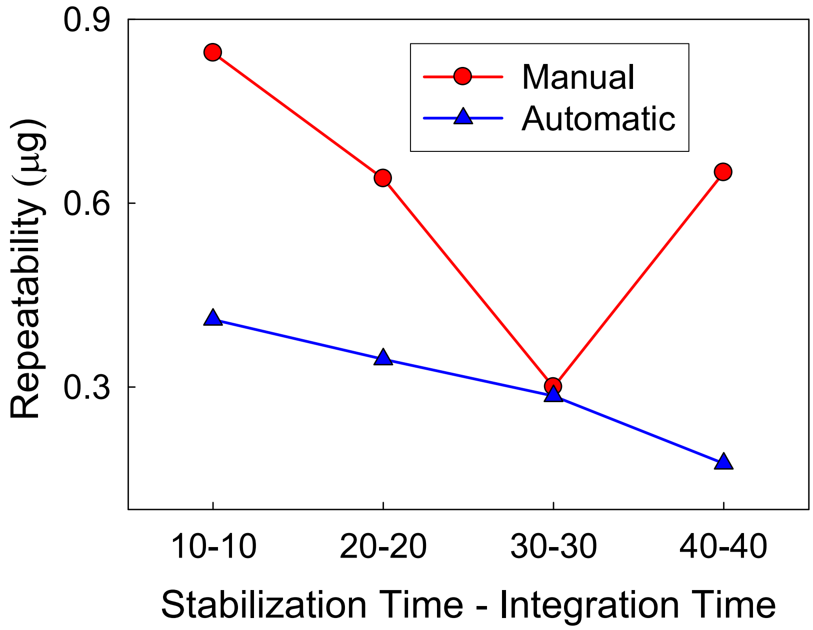


Figure 4. Comparison of the automatic and manual weighing. Each data point for ST and IT was obtained in five the number of measurements. The measurement was done in turn continuously, manual – automatic – manual, to ensure the same environmental conditions.

As the final work, we considered a weighing design, which required to done by A-B-B-A (double substitution), with the automated balance. Because of the restriction of at most three loading weights (for wire shape only) in the automated balance, a traditional four weights weighing design for 10-5-2-2-1 has been recently replaced with a pseudo orthogonal weighing design, 10-5-5-2-2-1-1 shown in Table 3 [8]. We obtained the total process times of one-to-one comparison by A-B-A for each weight and weighing design in the range of 10 mg – 100 mg in the 20-20-2 condition were 79 min and 292 min, respectively. We believe there was no advantage of the performance in weighing design with a5 in the viewpoint of saving time. Therefore, the weighing design in 5a was not suitable to apply in legal metrology where time performance was one of importance factor.

| | 100 mg | 50 mg† | 50 mg | 20 mg† | 20 mg | 10 mg† | 10 mg |
|---|---|---|---|---|---|---|---|
| 1 | +1 | -1 | -1 | | | | |
| 2 | +1 | -1 | -1 | | | | |
| 3 | +1 | -1 | -1 | | | | |
| 4 | | +1 | -1 | | | | |
| 5 | | +1 | -1 | | | | |
| 6 | | +1 | | -1 | -1 | | -1 |
| 7 | | | +1 | -1 | -1 | -1 | |
| 8 | | | | +1 | -1 | | |
| 9 | | | | +1 | | -1 | -1 |
| 10 | | | | | +1 | -1 | -1 |
| 11 | | | | | | +1 | -1 |
| 12 | | | | | | +1 | -1 |

Table 3. The weighing design matrix used in this experiment. The standard weights were represented by "†"

## 4. Conclusions

We have performed the optimization of the automatic balance which has being been developed recently. In the view of optimization, we found some optimal parameter condition to lower the uncertainty though all observed uncertainties were in the range of the repeatability specification. In addition, we discuss on finding the optimal stabilization time. In applying the weighing design to the automated balance, we conclude the time performance is not suitable to use in legal metrology despite of the high accuracy of balance. However, MT a5 is more adaptable to the field of disseminating national mass standard where the time performance is not considered severely.

However, as one of future works, more robust analysis should be performed with respect to true balance readings with uncertainty according to a weight.

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