

ESTABLISHMENT OF 5 TON MASS STANDARDS

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Abstract: The 5 t standard weight was constructed to support the newly design of 1 MN deadweight force standard machine in Korea according to International Organization of Legal Metrology (OIML)'s requirements. The weight consists of five pieces of 1 t weight and was considered safety and convenience in handling of large capacity. We have also set up a commercial mass comparator with auto-centering pan for calibration of up to 5 t deadweights. Each 1 t piece was compared with 1 t mass standard by the method of double substitution. We have tested the repeatability of comparator with the newly manufactured 5 t weight. In this presentation, however, we summarize the manufacturing procedures of weight and the preliminary test result of comparator's performance.

Keywords: Mass Standard, Mass Comparator, Heavy Industry, Heat Treatment, Auto-Centering Pan

1. INTRODUCTION

It has been increased the needs of calibration of large capacity in mechanical metrologies such as mass, force, pressure and torque, in various industries. For example, in constructing of ship crane, only structural design was inspected by an inspector. The torque sensor of (3,000 ~ 25,000) Nm cannot be calibrated in Korea. Especially, Korea has a good competitive power in area of heavy industries such as shipbuilding plant and large bridge where load-cell measurement of large force is quite often required at the field of construction.

Currently, the maximum capacity and its uncertainty of the calibration and measurement capabilities (CMCs) in KRISS mass standard are 1 t and 5 g at $k=2$, respectively. The standard weight of 1 ton in one-body has just finished in a former project but no careful consideration in its structural design was done because it will be used in routine calibration of mass standard. However, 5 t is too large scale to buy a commercial product or to handle easily in the level of laboratory; it had better make it by applying much experience of manufacturing in the last project.

2. DESIGN AND MANUFACTURING PROCESS

As it mentioned, the design of 5 t weight was considered the safety in handling and convenience in the calibration of dead weight in the deadweight force standard. The 5 t weight consists of five 1 t weights (main body and four

Antler shafts). Here, the shaft has a ring shape to be used conveniently in handling.

The general specification of the weights was set to comply with requirements of class E₂ according to OIML documents [1]. The stainless steel - grade 316 was adopted as a main material of the weight to ensure the good magnetic property, hardness, resistance to wear as a standard weight.

The shape of each 1 t weight was cylindrical with a diameter of 1 m and a thickness of 156 mm, as shown in Fig. 1. We expected the density of the weight was approximately 7.9 g/cm³, a permissible value as E class but will be calibrated with the same material extracted just before and after the processing.

Generally, class E₂ weights greater than 50 kg may have an adjusting cavity of which volume shall not exceed 1/1000 of the total volume of the weight [1], but in our case the each piece of weights is solid and one-body and has no the adjusting cavity to control the small mass.

The overall manufacturing process is following. 1) Preparation of untreated stainless steel-grade 316, 2) Forging. 3) Turning to make 1 t in a main body, 4) Boring, 5) 2nd turning, 6) Manufacturing of Antler shaft to make 12 kg (each), 7) Precise turning with the shaft to make 10.77 kg (each). 8) Welding of Antler shaft, 9) Turning of main body (1002.087kg), 10) Buffing in several times while monitoring the mass, 11) Precise buffing of upper surface of main body, 12) Calibration and complete. The manufacturing process was composed of thermal and rough/precise mechanical processes with checking the mass. In steps 1) and 2), the sample around 200 g was picked for determination of density and other physical properties.

3. MANUFACTURING OF WEIGHTS

The untreated stainless steel - Grade 316 for main body was produced in Outokumpu of England and purchased five blocks of 300 mm × 72 mm × 79 mm and weight of 1,356 kg. The cylindrical shaped steel (ø102 mm × 6000 mm) for Antler shafts had the standard quality of ASTM A182 F316 and was produced through electric arc furnace (EAF), vacuum oxygen decarburization (VOD), ingot, rolling, and thermal treatment in Pohang Steel corp. of Korea.

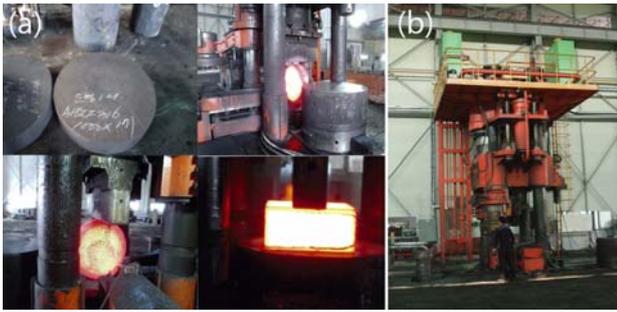


Fig. 2 (a) Forging process of weight material and (b) 30 t batch forging press

The forging was performed with 30 t batch furnace in Metal Core corp. of Korea as shown in Fig. 2. The temperature was increased from room temperature to 1250 °C in rate of 100 °C/h. The process was started after waiting for at least 5 h. The size of the block according to the temperature was changed from $\phi 1,050 \times 198$ t (room temperature) to $\phi 1,030 \times 195$ mm (1250 °C), so the heat shrinkage was found. The age hardening heat treatment was also applied in this process by using the same furnace. The temperature was increased from room temperature to 1040 °C in the maximum rate of 100 °C/h. Then, water cooling process (like quenching) was applied after waiting for at least 4 h. Table 1 lists the change of size after forging and heat treatment for each piece.

Table 1. The result of dimension the final machined and after hot forging and heat treatment

Piece No.	Final Cylinder	After Treatment
1	$\phi 1,000 \times 171$ mm	$\phi 1,035 \times 195$ mm
2		$\phi 1,030 \times 200$ mm
3		$\phi 1,035 \times 195$ mm
4		$\phi 1,030 \times 200$ mm
5		$\phi 1,030 \times 200$ mm

Figure 3 shows the snapshot of turning process on a machine table and the constructed 5 t weight through the whole processes. The cutting of turning process was performed in body's rotational speed of 150 rpm and the cutting speed of 16 mm/min to keep it from giving a mechanical stress, which could change the magnetic property. After this cutting process, the body was inspected by a non-destructive material testing method with ultrasonic. The result confirmed there was no recordable indication of the main bodies in this ultrasonic test.

The constructed 5 t weight was calibrated simply with 1 t standard weight by using a commercial mass comparator (KC1000, Mettler-Toledo, Switzerland). The comparator has the maximum capacity of 1.2 t and readability of 0.5 g. Each 1 t piece of 5 t weight shows the standard deviation of about 1.5 g in repeatability test in five times. In near future, it needs to be calibrated more to get the standard uncertainty of 5 t weight. However, the magnetic property and density will also be checked with the sample of stainless steels.

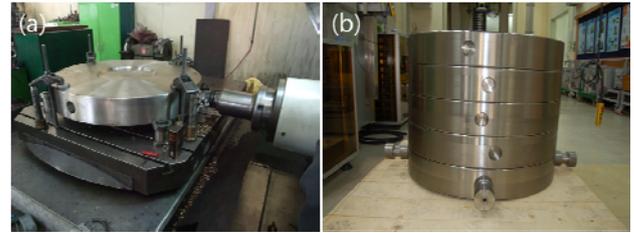


Fig. 3 (a) Turning work of 1 t main body and (b) home-made 5 t weight

4. MASS COMPARATOR FOR 5 TON WEIGHT

As seen in Fig. 4, we have recently introduced a commercial 5 ton mass comparator (XP6002KL, Mettler-Toledo, Switzerland) to calibrate between the constructed weight and dead weights of force standard. The comparator has an auto-centering pan which ensures the weight is positioned to the centre of the pan. The comparator has the maximum capacity of 5.4 ton, readability of 10 g, eccentricity of 240 g (2 t), and standard deviation of 70 g (5 t), which is suitable specification for calibration of dead weights.

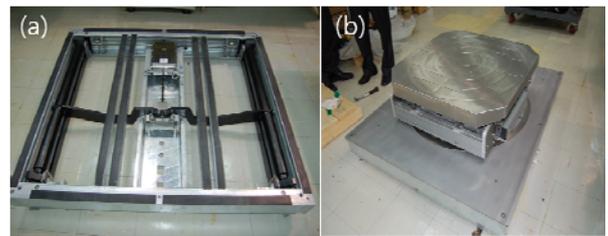


Fig. 4 (a) Base frame of comparator (b) commercial 5 t mass comparator with the auto-centering pan

We have found the eccentricity could be ignored after checking the good performance of auto-centering. In our case, the comparator is intended to be used in the maximum capacity of 5 t. So, the linearity test is not required at this time. However, the standard deviation of repeatability with the constructed weight could be 30 g, though the testing was performed at the laboratory without any protections of wind flow.

Table 2. Preliminary result of calibration with each piece of having 1 t nominal value in 5 t weight.

No.	Conventional mass (kg)	Uncertainty ($k=2$), g
1	999.996 8	2.7
2	999.996 3	2.7
3	999.997 1	2.7
4	999.997 9	2.7
5	999.997 0	2.7

5. PRELIMINARY CALIBRATION OF WEIGHT AND BALANCE

As shown in Table 2, we have calibrated five pieces of 1 t weight by using a 1 t standard weight with double substitution method. The result indicated undervalue of weight comparing to the nominal value. However, we are going to perform the calibration continuously.

There were two dominant contributions in calculation of uncertainty budget of large capacity weight. The repeatability of measurement was normally around 0.25 g using a comparator. On the other hand, the air buoyancy should be at least 0.75 g due to the small density difference between standard and test weights but 1.2 g was given to this factor as appeared in Table 3. It was required to have the precise sensors for measuring environmental parameters to minimize the uncertainty. However, each piece's uncertainty was 2.7 g less than the current CMC of KRISS for 1 t declared long before installation of new 1 t comparator. Therefore, when the each piece was stacked together to make 5 t, the expanded uncertainty of 5 t weight could be maximally 13.5 g with assumption of correlation term in calculation of uncertainty is very high.

Table 3. The budget of uncertainty for the calibration of each piece of 5 t weight.

Parameter	Uncertainty	Unit
Reference weight	0.5	g
Repeatability	0.24	g
Density		
- test	0.001	g/cm ³
- standard	0.001	g/cm ³
Air Buoyancy	~1.2	g
Air Density	2.9×10 ⁻⁷	g/cm ³
- temperature	0.05	°C
- pressure	10	Pa
- humidity	1	%
Comparator	0.79	g
- resolution	0.04	g
- sensitivity	4.2×10 ⁻⁵	g
Expanded uncertainty (<i>k</i> =2)	2.7	g

The performance test was done with the newly installed 5 t comparator [2]. First, the span calibration was performed to warm-up the comparator mechanically. Using the sensitivity weight of 100 g, the sensitivity test recorded the weight very reliably: 0 of standard deviation. The repeatability test displayed 0.016 kg, less than 2 digits of readability. The test of eccentricity could be omitted due to auto-centering pan. Unfortunately, the bearing of auto-centering pan on comparator pan was broken during the linearity test (1 ~ 5 t in both directions of loading and unloading) and needed to be replaced with new one.

6. SUMMARY

We have constructed 5 t standard weight (five pieces of 1 t weight) by our own technique and installed the commercial mass comparator having the maximum capacity of 5 t. The newly manufactured weight is complied with OIML's technical requirement but the conventional mass is a little bit less than the nominal value. The detail factors of uncertainty are evaluated in this paper. Therefore, we anticipate the constructed weight contributes in extension of CMCs at KRISS. However, this project could be applied in evaluation of dead weights used in 1 MN dead weight force standard, which is also actively being constructing in progress at KRISS.

7. REFERENCES

- [1] "Weights of classes E₁, E₂, F₁, F₂, M₁, M₂, M₃", OIML R 111-1 (2004)
- [2] "Non-automatic weighing instrument", OIML R 76-1 (2007)