ESTABLISHMENT OF FORCE STANDARDS IN KOREA UP TO 2 MN BY HYDRAULIC FORCE STANDARD MACHINE

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ABSTRACT

The force unit generated by the 2 MN hydraulic force standard machine in KRISS was changed to Newton from kilogram-force. This paper describes the estimation of the hydraulic force standard machine. First, the machine was compared with a 500 kN deadweight force standard machine in KRISS. The relative deviation between two force machines was less than $2x10^{-5}$. In order to estimate the hydraulic force machine in the whole range, we made an intercomparison with a 2 MN deadweight force standard machine in PTB. Intercomparison test revealed that the relative deviation between the KRISS hydraulic force machine and the PTB deadweight force machine is less than $8.1x10^{-5}$ in the range of 400 kN to 2000 kN.

1. INTRODUCTION

The SI unit of force is Newton(N). Therefore, a force standard machine in a national metrology institute must generate force with the unit of Newton. However, the 2 MN hydraulic force standard machine in Korea Research Institute of Standards and Science(KRISS) had generated force with the unit of kilogram-force(kgf) instead of Newton. The hydraulic force machine consists of a loading frame, a deadweight machine and a hydraulic control system. The machine has two ram/cylinder systems in which one is the main ram/cylinder system in the loading frame and the other is the measuring ram/cylinder system in the deadweight machine. The force generated by the deadweights is amplified about 200 times by the ram/cylinder systems.

KRISS modified the 2 MN hydraulic force machine to generate force with the SI unit, Newton, by changing the deadweights. Each deadweight was replaced with a new one that was precisely designed, manufactured and calibrated to fit the Newton force. After changing the deadweights, the control scheme of the 2 MN hydraulic force machine was precisely re-adjusted to operate the new deadweights system.

The 2 MN hydraulic force machine was intercompared with a 500 kN deadweight force standard machine in KRISS. The relative deviation was less than $2x10^{-5}$ for entire measurement step.

An intercomparison with other force standard machines of other NMIs is a common method to evaluate a force standard machine. For this reason, many NMIs have performed lots of intercomparisons [1, 2]. The hydraulic force standard machine was intercompared with a 2 MN deadweight force standard machine in Physikalisch-Technische Bundesanstalt (PTB) of Germany. The intercomparison was performed in compression mode using two transfer standards of 1 MN and 2 MN. The force step was 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 MN for the 1 MN force transfer standards and 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0 MN for the 2 MN force transfer standards. The time interval was set to 3 minute except for the pre-loading. The time interval in the pre-loading procedure was 6 minute because the loading time of the hydraulic force machine was almost 3 minute. Initial measurements of both force transfer standards were carried out first at the KRISS in October 2003. These initial measurements were followed by similar measurements at the PTB in November 2004. Final set of measurements was performed at the

KRISS in February 2004. The relative deviation was less than $8.1x10^{-5}$ for entire measurement step. The deviation was less than the relative uncertainty of the hydraulic force machine, $1.0x10^{-4}$.

2. 2 MN HYDRAULIC FORCE STANDARD MACHINE

The hydraulic force machine consists of a loading frame, a deadweight machine and a hydraulic control system. The loading frame consists of a fixed frame with a lower bed, a upper bed and four columns, a moving frame on which a force measuring device is installed and a main ram/cylinder system. The maximum permissible size for force measuring devices is about 1.2 m in length for compression test and 1.6 m for tension test.

The machine has two ram/cylinder systems. One is the main ram/cylinder system in the loading frame and the other is the measuring ram/cylinder system in the deadweight machine. The ram/cylinder systems are designed in geometrically similar form to cancel effects of the elastic distortion of the cylinders each other due to loading on the uncertainty of the machine. The force generated by the deadweights is amplified about 200 times by the ram/cylinder systems.

The unit of the 2 MN hydraulic force standard machine had been kgf instead of Newton, the SI unit of force. The unit of the hydraulic force machine has been changed to Newton by changing the deadweights of the machine. The deadweight machine has 3 weights for each generating 250 N, 10 weights for 500 N and 6 weights for 1 kN. All the deadweights are re-designed, manufactured, compensated and calibrated carefully. Then, the deadweights are replaced with the new ones. Owing to this replacement of deadweights, KRISS can build SI traceable force standards up to 2 MN using hydraulic amplification method.

3. INTERCOMPARISON BETWEEN 2 MN HYDRAULIC FORCE MACHINE AND 500 kN DEADWEIGHT FORCE MACHINE

In order to estimate the newly modified hydraulic force standard machine, we compared it with the 500 kN deadweight force machines in KRISS. One strain gage type force transducer having capacity of 500 kN was used in the intercomparison. The rated outputs of the force transducers are about 2 mV/V. To minimize the uncertainty associated with the indicating instrument, a high-precision indicator, HBM DMP40, was used. Its indicating resolution is 0.000001 mV/V.

The measuring procedure was carefully decided to minimize the parameters that are known to contribute to the measurement uncertainty. When a loading condition to a force transducer is changed, the transducer experiences mechanical, thermal, and electrical responses in the various interconnected elements, followed by a delayed creep responses of drift in the output of the transducer as the elements approach a new state of equilibrium. Although different force transducers show different creep behaviour, the creep rate decreases rapidly during the first few minutes following loading or unloading, in general. It was found that a 3-minute time delay between the start of the loading and the actual reading was adequate [3]. Therefore, a 3-minute time interval was used to minimize the creep effect of the force transducer. However, the operating time to reach the maximum load from zero and to be zero from the maximum load was quite long, because both machines load and unload each deadweight step by step. Therefore, a 5-minute time interval was used for pre-loading procedure and for returning procedure to zero from maximum load.

The output of force transducer was measured at four positions relative to the axis of the machine(0^o, 90^o, 180^o, 270^o). The load steps selected for the intercomparison of the machines were 200, 300, 400 and 500 kN. At the 0^o position, the force transducer was exercised by 3 pre-loadings prior to the start of a measurement cycle. After the pre-loading and a 5-minute delay, three sets of measurements were carried out, separated by a 5-minute interval. Then, the force transducer was rotated by 90°, and one set of measurement was carried out. The same procedure was performed at 180° and 270°.

Figure 1 shows the relative deviation between the 2 MN force machine and the 500 kN force machine in which the reference is the 500 kN force machine. The relative deviation is less than $2x10^{-5}$ for entire force step. From this internal intercomparison, we could confirm that the 2 MN hydraulic force machine was in good agreement with the 500 kN force machine within the range of 200 kN to 500 kN.

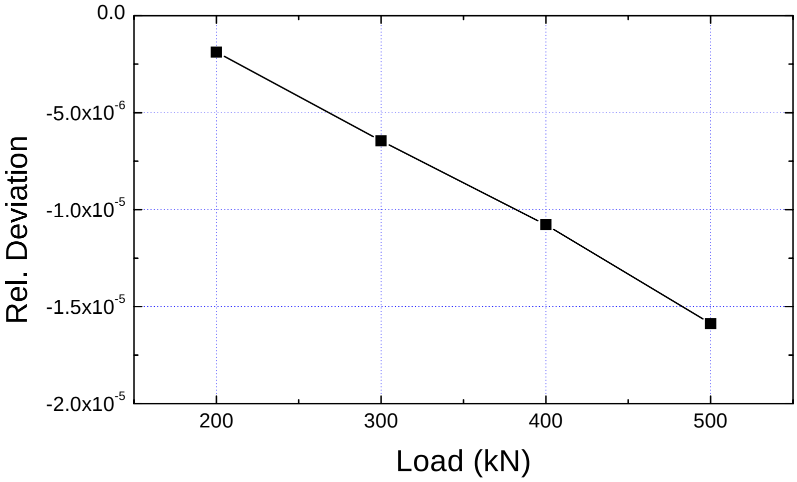

Figure 1 : Relative deviation between 2 MN and 500 kN force machines in KRISS

4. INTERCOMPARISON WITH PTB 2 MN DEADWEIGHT FORCE STANDARD MACHINE

By the intercomparison with the 500 kN deadweight force machine, the accuracy of the 2 MN hydraulic force standard machine was checked internally. However, to get more general international agreement on the hydraulic force standard machine and to evaluate the machine in the whole force range, additional intercomparison with other force machines of other NMIs was needed. For this reason, we performed an intercomparison with PTB of Germany.

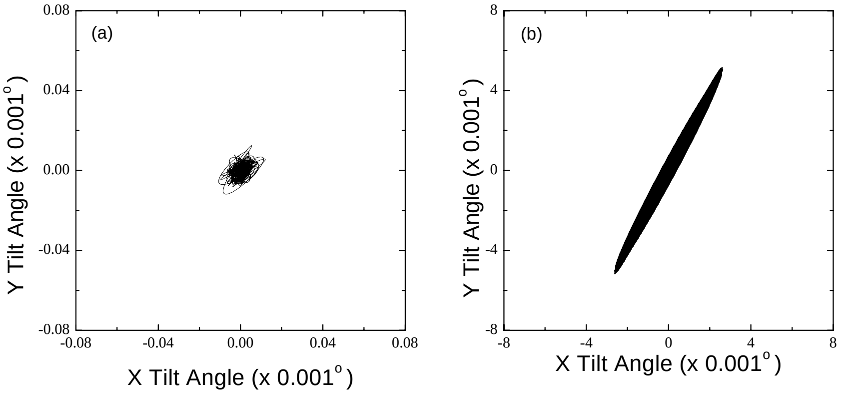

Figure 2 : Pendulum motion in PTB deadweight force machines

PTB recently re-build a 2 MN hydraulic deadweight force standard machine. For the details of the machine, please see [4]. The machine has air bearing guides at the bottom, therefore it shows very low vibration level due to pendulum motion. Figure 2 shows the pendulum motion.

Figure 2 (a) represents the pendulum motion of the 2 MN deadweight force machine when 500 kN is loaded and figure 2 (b) does the pendulum motion of 1 MN deadweight force machine in PTB when 300 kN is loaded. The level of pendulum motion of the 2 MN machine is less than 1 % of the 1 MN machine. The pendulum motions were estimated by using a build-up system technique [5].

The 2 MN deadweight force standard machine in PTB was compared with the 2 MN hydraulic force machine of KRISS. A 1 MN and a 2 MN force transfer standards were used for the intercomparison. The 1 MN transducer was made by HBM and the 2 MN transducer was made by GTM. A high-precision indicator, HBM DMP40, was used to read the values of force transfer standards. The measurements were carried out at (22±0.5) ^{o}C. Both the force transducer and indicator were kept at this temperature for several days prior to the start of the measurements.

As already mentioned, the time interval should be decided carefully to minimize the creep effect. A 3-minute time interval was used for measurement. However, a 6-minute time interval was used for pre-loading procedure and for returning procedure to zero from maximum load by considering the loading time of the 2 MN hydraulic force machine.

At the 0^{o} position, the force transducer was exercised by 3 pre-loadings prior to the start of a measurement cycle. After the pre-loading and a 6-minute delay, three sets of measurements for increasing force were carried out, separated by a 6-minute interval. Then, the force transducer was rotated by 90^{o}, and two sets of measurement for increasing force were carried out. The same procedure was performed at 180^{o} and 270^{o}. At 360^{o}, one set of measurement for increasing force and one set of measurement for increasing and decreasing force were carried out. The force step was 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 MN when using the 1 MN force transfer standard and 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0 MN when using the 2 MN force transfer standard.

The first measurement was done at the 2 MN hydraulic force machine in KRISS, then the second one was done at the 2 MN deadweight force machine in PTB and the final measurement was done at the 2 MN hydraulic force machine again in KRISS. Figure 3 shows experimental situation in PTB.

Figure 3 : Experimental scene in PTB 2 MN deadweight force standard machine

Figure 4 shows the relative deviation between the first and the last measurements in KRISS. The sensitivity drift was less than $5x10^{-5}$ for entire force step. By considering the low deviation, we can confirm the stability of the force transfer standards.

Figure 5 shows the intercomparison result with the PTB 2 MN daedweight force machine. The graphs represent the relative deviations between the PTB 2 MN deadweight force machine and the KRISS 2 MN hydraulic force machine in which the reference is the KRISS force machine. The reference was the mean value of the first and the last measurements in 2 MN hydraulic force machine in KRISS. In the figure, the rectangle represents the result when using the 1 MN force transfer standard and the circle does the result when using 2 MN force transfer standard.

This deviation was less than 8.1×10^{-5} in case of using the 1 MN transducer and it was less than 6.3×10^{-5} in case of using the 2 MN transducer. Overall, the relative deviation was less than the common relative uncertainty of a hydraulic force machines, 1×10^{-4}.

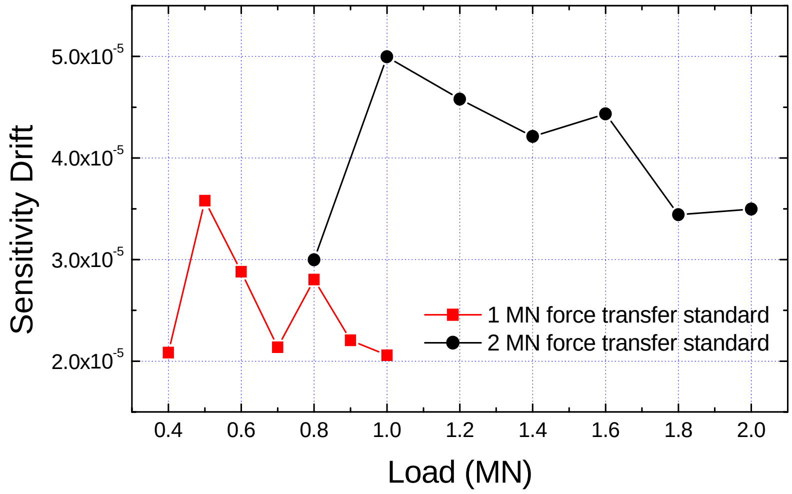

Figure 4 : Sensitivity drift of the force transfer standards

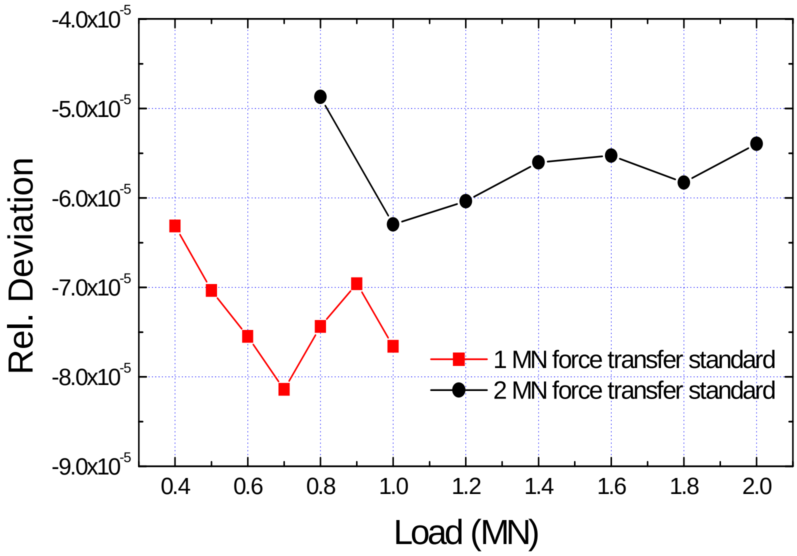

Figure 5 : Relative deviation between KRISS 2 MN hydraulic force machine and PTB 2 MN deadweight force machine

5. CONCLUSIONS

We modified the 2 MN hydraulic force standard machine to generate force with the SI unit, Newton. To do this, we changed the deadweights of the hydraulic force standard machine.

To check the performance of the modified hydraulic force machine, we compared it with a 500 kN deadweight force machine in KRSS. The two machines showed good agreement.

In order to estimate the hydraulic force machine in the whole range, we made an intercomparison with a 2 MN deadweight force standard machine in PTB. The relative deviation was less than 8.1×10^{-5}. It was less than 1×10^{-4}, the common relative uncertainty of a hydraulic force machine. Therefore, this intercomparison result can be used as an evidence to declare the uncertainty of the 2 MN hydraulic force standard machine.

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