XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

TRACEABILITY OF LARGE FORCE STANDARDS IN KOREA

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Abstract – This paper describes traceability of large force standards up to 30 MN in Korea. 15 material testing machines of each having more than 10 MN capacity in industrial companies have been used for evaluating performances of mechanical components such as a pot bearing or an elastic bearing which is one of the important components in bridges. We have10 MN force standard machine with relative uncertainty of 5×10^{-4} (k=2). We designed build-up force measuring systems of having 30 MN capacity to be used in calibrating material testing machines above 10 MN capacity. We have evaluated uncertainty budgets of build-up systems. Also, this paper summarizes calibration results of a material testing machine of 30 MN in Korea.

Keywords: force standards, force calibration machine, pot bearing testing machine, build-up force measuring system

1. INTRODUCTION

Force measuring devices should be calibrated to guarantee their test results. To establish the force standards in Korea, four deadweight machines of each having 5 kN, 20 kN, 100 kN and 489.2 kN capacity and 2 MN hydraulic force standard machine were installed at the Korea Research Institute of Standards and Science(KRISS). As heavy industries in Korea have been developed, lager forces exceeding the range of available force transducers and force standard machines should be measured precisely. It is, therefore, necessary to establish the large force standards above 2 MN. Some national institutes of metrology achieve large forces using hydraulic force standard machines which amplify smaller deadweight forces using piston/cylinder systems of different diameters. These systems are cheaper than a deadweight force machine but are still expensive. A force calibration machine that is traceable to the national force standards by using a build-up force transfer standard may be an efficient method to solve this problem. Debnam et al. established standards of large force up to 30 MN by means of this technique. Gizmajer and Gosset established large force standards up to 10 MN in which a build-up force transducer that is traceable to the national standards is connected in series to a force transducer to be calibrated in a loading frame. We designed a force standard machine of 10 MN with built-in force transducers for establishing large force standards in Korea. Experimental results revealed that relative uncertainty of this machine is less than 5×10^{-4} (k=2).

15 material testing machines above 10 MN capacity in industrial companies have been used for evaluating performances of mechanical components such as a

pot bearing or an elastic bearing which is one of the important components in bridges. We designed build-up force measuring systems of having 30 MN capacity to be used in calibrating material testing machines. We have evaluated uncertainty budgets of a build-up system. This paper describes traceability of large force standards up to 30 MN to assure the calibration results of material testing machines. Also, this paper summarizes calibration results of a material testing machines above 10 MN in Korea.

2. TRACEABILITY OF FORCE STANDARDS AT KRISS

Flowchart for realization of force standards at KRISS is shown in Fig. 1. Deadweight force standards machines of each having 5 kN, 20 kN, 100 kN and 500 kN capacity are used for primary force standards up to 500 kN. A hydraulic force standard machine of 2 MN and a build-up force standard machine of 10 MN are also used for large force standards up to 10 MN.

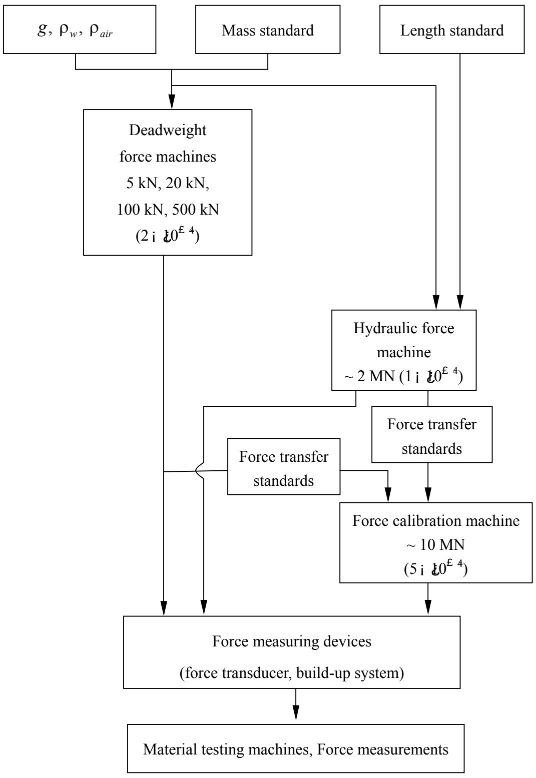

Fig. 1 Traceability of force standards

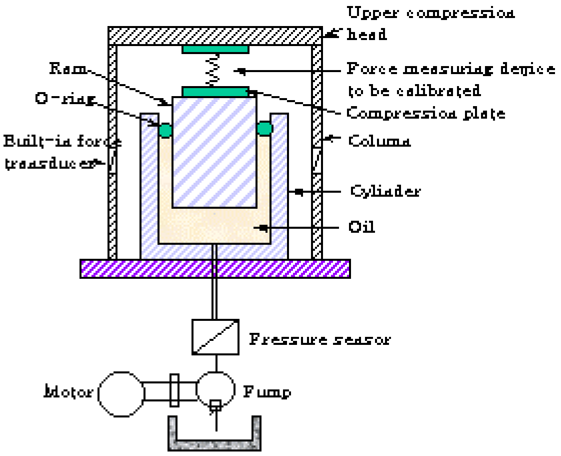

Fig. 2 Schematic diagram of 10 MN force calibration machine

3. 10 MN FORCE CALIBRATION MACHINE

10 MN force calibration machine consists of a loading frame, a hydraulic generating unit and a force control system as shown in Fig. 2. The loading frame consists of four columns, a cylinder, a piston, a upper frame, a lower frame and bearing platens. We can select bearing platens to accommodate the various size of a force transducer to be calibrated. Four columns are elongated as the result of reaction forces when compression force is applied to the force transducer by the hydraulic generating system. We can assume that the longitudinal surface strain and the circumferential surface strain in the middle of each column are uniform, respectively. Therefore we made a built-in force transducer with column as a sensing element.

To make a built-in force transducer, four strain gages (code : N2A-06-T004R-350) were bonded along the longitudinal direction and the circumferential direction for each column, respectively, by using M-Bond 610 adhesive which is cured at 135℃ for two hours. A balco gage of 60 Ω, a nickel-iron alloy, and a copper gage were used to compensate the temperature effects on the sensitivity and the zero output of a built-in force transducer, respectively. The sensitivity of the built-in force transducer is about 0.65 mV/V.

To calibrate the 10 MN force machine, we used the build-up force transfer standard of 10.8 MN capacity. This consisted of nine force transducers of each having 1.2 MN capacity. The force transducers were calibrated using the 500 kN deadweight force standard machine with uncertainty of 2×10^{-5} and the 2 MN hydraulic force standard machine with uncertainty of 1×10^{-4}.

To reduce hysteresis error of the force machine we calibrated the built-in force transducer in increasing mode and decreasing mode ; calculated a calibration curve for each mode ; input a calibration curve into a computer.

The relative uncertainty of the force calibration machine, w, can be calculated by considering the relative uncertainty of the force transfer standard used for the calibration of the force machine, w_{fs}, and the relative uncertainty of the force machine oneself, w_{fcm}, as follows:

$$w = \sqrt{w_{fcm}^2 + w_{fs}^2} \qquad (1)$$

w_{fcm} can be determined by the following equation:

$$w_{fcm} = \sqrt{w^2_{zero} + w^2_{msta} + w^2_{mro} + w^2_{res} + w^2_{creep} + w^2_{cuit} + w^2_{temp} + w^2_{inst}} \qquad (2)$$

where

w^2_{zero} : zero error of a built-in force transducer.

(rectangular distribution)

w^2_{msta} : stability of force control

(triangular distribution)

w^2_{mro} : rotation error of force machine

(rectangular distribution)

w^2_{res} : resolution of a measuring unit

(rectangular distribution)

w^2_{creep} : creep error of a built-in force transducer

(rectangular distribution)

w^2_{cuit} : parallel circuit error of a built-in force transducer (triangular distribution)

w^2_{temp} : sensitivity variation of a built-in force transducer with variation of temperature in surrounding air (rectangular distribution)

w^2_{inst} : sensitivity drift of a built-in force transducer with time (triangular distribution)

Table 1. Uncertainty components of 10 MN force calibration machine

Force (MN)	1	1.5	2	2.5	3	3.5	4	4.5
w^1_{fs}	$3x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$1x10^{-9}$
w^2_{zero}	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$	$2x10^{-9}$
w^2_{msta}	$7x10^{-9}$	$7x10^{-9}$	$2x10^{-9}$	$7x10^{-11}$	$7x10^{-11}$	$7x10^{-11}$	$7x10^{-11}$	$7x10^{-11}$
w^2_{mro}	$8x10^{-9}$	$8x10^{-9}$	$8x10^{-9}$	$8x10^{-9}$	$8x10^{-9}$	$8x10^{-9}$	$8x10^{-9}$	$8x10^{-9}$
w^2_{res}	$1.7x10^{-10}$	$7.5x10^{-11}$	$4.3x10^{-11}$	$2.7x10^{-11}$	$1.9x10^{-11}$	$1.4x10^{-11}$	$1.1x10^{-11}$	$8.4x10^{-12}$
w^2_{creep}	$1x10^{-8}$	$1x10^{-8}$	$1x10^{-8}$	$1x10^{-8}$	$1x10^{-8}$	$1x10^{-8}$	$1x10^{-8}$	$1x10^{-8}$
w^2_{cuit}	$8.3x10^{-10}$	$8.3x10^{-10}$	$8.3x10^{-10}$	$8.3x10^{-10}$	$8.3x10^{-10}$	$8.3x10^{-10}$	$8.3x10^{-10}$	$8.3x10^{-10}$
w^2_{temp}	$5.3x10^{-10}$	$5.3x10^{-10}$	$5.3x10^{-10}$	$5.3x10^{-10}$	$5.3x10^{-10}$	$5.3x10^{-10}$	$5.3x10^{-10}$	$5.3x10^{-10}$
w^2_{inst}	$4.2x10^{-10}$	$4.2x10^{-10}$	$4.2x10^{-10}$	$4.2x10^{-10}$	$4.2x10^{-10}$	$4.2x10^{-10}$	$4.2x10^{-10}$	$4.2x10^{-10}$
w_c	$1.97x10^{-4}$	$1.76x10^{-4}$	$1.61x10^{-4}$	$1.55x10^{-4}$	$1.55x10^{-4}$	$1.55x10^{-4}$	$1.55x10^{-4}$	$1.55x10^{-4}$

Resolution of a measuring unit is 0.00001 mV/V. In order to reduce parallel circuit error of built-in force transducer within 0.01 %, output resistance of each built-in force transducer in each column was adjusted within maximum deviation of 0.01 %. We assumed that temperature effect on sensitivity of a built-in force transducer is ±0.002 % of load/°C and temperature control in laboratory is in the range of 23 ±2°C.

Table 1. shows the relative uncertainty components calculated by eq. (2). The relative expanded uncertainty (k=2) of the force transfer standard was less than 1×10^{-4} in the range of 1 ~ 4.5 MN irrespective of loading direction[5]. Uncertainty component owing to creep error of built-in force transducer is the biggest component among all uncertainty components. The relative expanded uncertainty(k=2) of the force calibration machine is less than 4×10^{-4} in the range of 1 MN ~ 4.5 MN.

4. 30 MN BUILD-UP SYSTEM

We designed a 30 MN build-up system in which three force transducers of each having 10 MN capacity are arranged in parallel. A column spring element was adopted as a shape of a strain gage type force transducer. Fig. 3 shows photograph of 30 MN build-up system fabricated. We calibrated each 10 MN force transducer by using 10 MN force calibration machine. Calibration results reveal that the expanded uncertainty of 30 MN build-up system is less than 2×10^{-3} .

Fig. 3 Photograph of 30 MN build-up system

Fig. 4 30 MN pot bearing testing machine

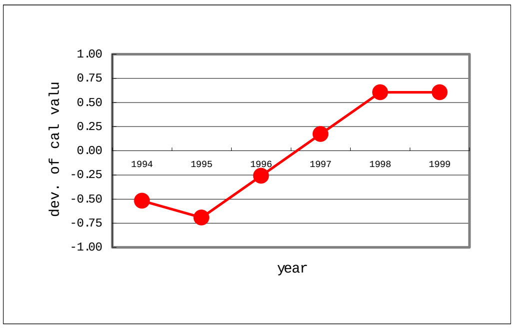

Fig. 5 Relative deviation of calibration value

5. CALIBRATION EXAMPLE OF A 30 MN MATERIAL TESTING MACHINE

Fig. 4 shows a 30 MN pot bearing testing machine in industry in Korea. We have been calibrated this machine by using 30 MN build-up system since 1994. Fig. 5 shows that relative deviation of calibration value which means long term stability of the testing machine. The long term stability of the machine is less than ±7.5×10^{-3} during 5 years. Fig. 5 shows the behavior of accuracy error of the machine for each force step. Accuracy error of the machine for every force step is less than ±1×10^{-2} during 5 years.

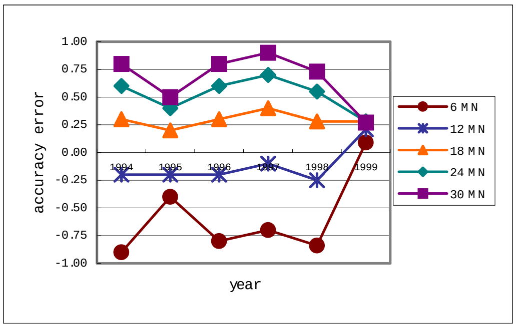

Fig. 6 Accuracy error of a testing machine

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