Development of a High Precision Hydraulic Force Calibration System

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Abstract

A high precision hydraulic force calibration system was developed, and the Best Measurement Capability(BMC) was evaluated for the system with maximum load capacities of of 100 kN and 500 kN, respectively. The calibration system consists of mechanical frame, hydraulic loading and contol system, reference force transducer, automated operating software, and data acquisition and analysis software. In addition to the conventional servo-controlled hydraulic system, a specially designed precision pressure controller was developed for minute load control during holding period at each load step, the control stability which is 0.0005 % for 2 mV/V of the reference force transducer's signal. The BMC of the 100 kN force calibrator is less than 4.28×10^{-4} in range of 20~100 kN, and that of the 500 kN force calibrator is less than 3.81×10^{-4} in range of 50~490.3 kN.

1. Introduction

It is necessary that a force measuring device should be calibrated by force calibration machine which has proper measuring capability with accurate force generation function should generate a force precisely like a force standard machine.

The type of force generation by gravitation applied to dead weight is one of the most accurate method when the range of generated force level is relatively low. However, for higher force range, the system using dead weight should be very large and expensive.

Force generation by hydraulic loading method with reference force generation can be considered as force calibrator for very high load range. For this purpose, the conventional hydraulic loading and control system is not good without significant improvement of controllability.

In this study, a high precision hydraulic type calibration system is to be introduced with evaluation of the system accuracy in terms of BMC. Also, the operation environment including data acquisition and analysis software is briefly introduced

2. Hydraulic Force Calibration System

2.1. Technical Specification

The specifications of the force calibration machines to be evaluated are as follows.

- Rated capacity: 100 kN, 500 kN

- Calibration mode:Tension and compression

- Indicator Resolution: Up to 0.00001 mV/V

- Hydraulic unit: Max. Pressure 200 bar

    Operating pressure 150 bar

- Compression test volume(WxDxH) :

    130 x 130 x 230 mm for 100 kN

    200 x 200 x 350 mm for 500 kN

- Tension test volume(WxDxH) :

    440 x 460 x 500 mm for 100 kN

    540 x 550 x 650 mm for 500 kN

Figure 1. High precision hydraulic force calibration system

2.2. Mechanical Structure

The force calibration system consists of 3 parts: mechanical, hydraulic and electronics which includes control, data acquisition and software as in Fig.1.

The mechanical structure is schematically shown in Fig.2, as; The framework is composed of four columns, which are combined by a loading table and a lower base. A force-generating hydraulic cylinder is put on the loading table and the reference force transducer is mounted on the top of this cylinder the signal

of which is to be used as the reference value for calibration as well as the system control.

The loading frame consists of two load plates positioned on top and bottom of the loading table. The two load plates are arranged vertically, with the reference force transducer in the upper side of the loading table and a force transducer in the lower side when the compression test is performed. For the tension test, the specimen is to be mounted with the special device between the lower plate of the loading frame and the base of the framework. This composition allows the same force to be applied simultaneously to both the reference force transducer and specimen to be tested.

By means of the yoke and the screw driving mechanism, the height of specimen installation space can be easily adjusted.

2.3. Hydraulics and Precision Control

A ultra-high precision hydraulic controller was developed for minute load control to prevent load disturbance during holding period of each load step. The hydraulic system consists of a hydraulic supply system, a hydraulic control block, a precision pressure controller and a
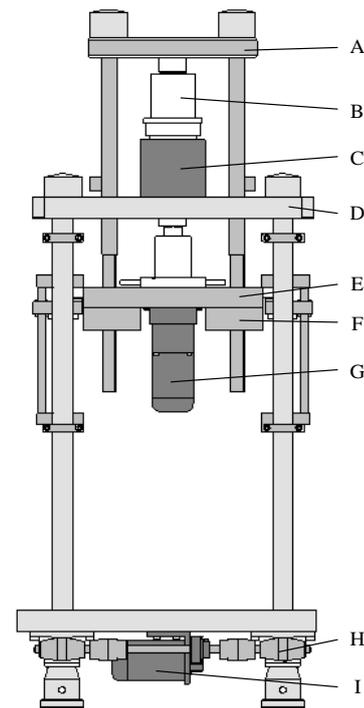
hydraulic cylinder.

Figure 2. Schematics of Mechanical Structure

 A- loading frame

 B- reference force transducer

 C- hydraulic cylinder

 D- loading table

 E- lower plat

 F- F-yoke

 G- lower plate drive motor

 H- screw jack

 I- screw jack drive motor

The hydraulic supply system supplies the hydraulic pressure to the loading cylinder for generating the force. The loading cylinder

mounted on the upper surface of the middle of loading table is used to apply the same force, except the weight of yoke, to the reference force transducer the specimen to be calibrated.

The dual process pressure control system, a newly developed precision controller as well as conventional hydraulic loading system, has developed for controlling very high precision pressure to maintain the required load accuracy without disturbance. The conventional hydraulic loading system, which has some parts such as a pressure gage, an accumulator, proportional relief valves, and proportional flow control valves, supply the pressure to the system to reach up to 99 % of the given load level, and then the precision controller, which has a volume control cylinder and a stepping motor to drive the volume control cylinder, performs the remaining control process.

The control capability of this controller is found to be ±0.00001 mV/V based on the load cell's output which is used as the feedback signal and the reference value of the load. Therefore the control stability is 0.0005 % for 2 mV/V of the reference force transducer's signal.
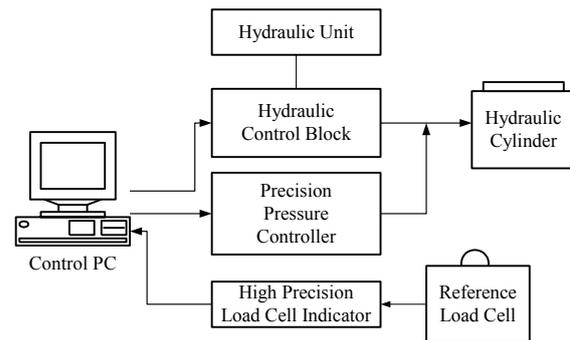
Fig 3. Block diagram of the control system

3. Operation Environment

This calibration system has been developed as to operate fully automated procedure; one-touch operation from specimen set-up to final test report generation. It also contains manual operation functions for using in setting force transducers and for emergency. This control system includes the following feature:

- MS-Windows Graphical user interface.

- Test procedures are in accordance with EN10001-3 and ASTM E74-95.

- One touch start button to obtain all test procedure.

- Automated test report printing.

4. Evaluation of BMC

BMC evaluation of the systems with max loading capacities of 100kN and 500kN was done according to the following procedures;

Step 1. (W_{fsm})

Two force standard machines of Korea Research Institute of Standard and Science (KRISS) with capacities of 100kN and 500kN has been used, and the expanded relative uncertainty of the force standard machine used as the reference for comparison has been estimated in 0.001% from inter-comparison between international standards metrological institutes like as PTB of Germany and NRLM of Japan.

Step 2 (W_{tsd})

The Transfer standards used to characterize the calibration force machine have been the fallowing:

- Force transfer standard of 100 kN (C4, F21707, HBM)

- Force transfer standard of 500 kN (C3H3, H07294, HBM)

The values of repeatability and drift(short time) of the force transfer standards are taken

$$W_{refv} = k \times \sqrt{w^2(F_{fsm}) + w^2(K_{tsd})} \qquad (3)$$

into account to estimate the expanded relative uncertainty, W_{tsd}, where the probability distributions assumed are rectangular distribution and triangular distribution, respectively. W_{tsd} is determined as the vector sum of each deviation of the indicated mean value $w^2(\bar{x})$ and the sensitivity drift of transfer standard $w^2(D)$.

$$w(K_{tsd}) = \sqrt{w^2(\bar{x}) + w^2(D)} \qquad (1)$$

$$W_{tsd} = k \times w(K_{tsd}) \qquad (2)$$

Step 3. (W_{refv})

The expanded relative uncertainty of the reference values W_{refv} is calculated as

Step 4. (W_{fcm})

The expanded relative uncertainty W_{fcm} related to force generation by the calibration system. W_{fcm} is composed of the tree value as

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follows :

- $w^2(\Delta_D)$ - relative deviation between reference values of force and values realized in the force calibrator

- $w^2(\Delta_R)$ - relative lack of repeatability of force calibrator determined with unchanged position of the force transducer

- $w^2(\Delta_H)$ - relative deviation of hysteresis between the transfer standard and the force calibrator.

$$w_{fcm} = k \times \sqrt{w^2(\Delta_D) + w^2(\Delta_R) + w^2(\Delta_H)} \quad (4)$$

$$W_{fcm} = k \times w_{fcm} \quad (5)$$

Step 5. (W_{bmc})

Final step is to calculate the best measurement capability W_{bmc} as follows :

$$W_{bmc} = k \times \sqrt{w_{refv}^2 + w_{fcm}^2 + w_{ref.tra}^2 + w_{ref.instb}^2} \quad (6)$$

where :

$w_{ref.tra}^2$: uncertainty of the transfer standard

$w_{ref.instb}^2$: the long-term instability of the reference force transducer

We evaluated 100 kN and 500 kN hydraulic

force calibrator and the results are shown in Table 1, 2, 3 and 4.

In Table 1, 2 and Fig 4, BMCof the 100 kN force calibrator is better than 4.28 x 10⁻⁴ in range of 20~100 kN.

In Table 3, 4 and Fig 5, BMC of the 500 kN force calibrator is less than 3.81 x 10⁻⁴ in range of 50~490.3 kN.

Table 1. BMC with 50 kN transfer standard for 100 kN force calibrator

Force(kN)	w_{fcm}	w_{refv}	W_{bmc}
20	1.24 x 10⁻⁴	2.50 x 10⁻⁵	4.28 x 10⁻⁴
30	1.22 x 10⁻⁴	1.97 x 10⁻⁵	3.75 x 10⁻⁴
40	9.17 x 10⁻⁵	3.01 x 10⁻⁵	3.10 x 10⁻⁴
50	8.57 x 10⁻⁵	2.12 x 10⁻⁵	2.77 x 10⁻⁴

Table 2. BMC with 100 kN transfer standard for 100 kN force calibrator

Force(kN)	w_{fcm}	w_{refv}	W_{bmc}
20	1.27 x 10⁻⁴	4.54 x 10⁻⁵	4.38 x 10⁻⁴
40	1.23 x 10⁻⁴	3.19 x 10⁻⁵	3.51 x 10⁻⁴
60	1.13 x 10⁻⁴	2.89 x 10⁻⁵	3.23 x 10⁻⁴
80	1.04 x 10⁻⁴	2.21 x 10⁻⁵	3.15 x 10⁻⁴
100	8.02 x 10⁻⁵	2.67 x 10⁻⁵	2.77 x 10⁻⁴

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Table 3. BMC with 100 kN transfer standard for

500 kN force calibrator

Force(kN)	w_{fcm}	w_{refv}	W_{bmc}
50	9.98×10^{-5}	1.67×10^{-5}	2.94×10^{-4}
80	1.25×10^{-4}	1.26×10^{-5}	3.42×10^{-4}
100	6.39×10^{-5}	1.29×10^{-5}	2.56×10^{-4}

Table 4. BMC with 500 kN transfer standard for

500 kN force calibrator

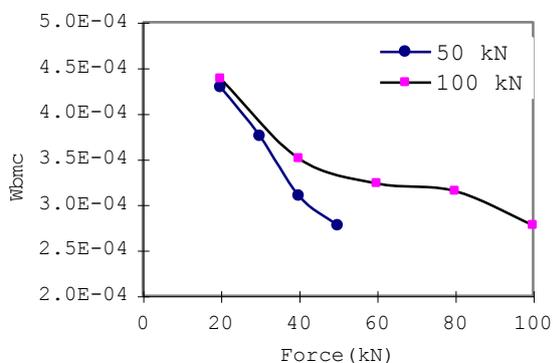| Force(kN)	w_{fcm}	w_{refv}	W_{bmc}
98.067	1.52×10^{-4}	1.95×10^{-5}	3.81×10^{-4}
196.133	1.12×10^{-4}	1.06×10^{-5}	3.16×10^{-4}
294.200	7.62×10^{-5}	1.02×10^{-5}	2.74×10^{-4}
392.266	6.20×10^{-5}	1.00×10^{-5}	2.61×10^{-4}
490.333	6.29×10^{-5}	2.40×10^{-5}	2.65×10^{-4}

Figure 4. BMC with different transfer standards for

100kN force calibrator

5. Conclusion

A high precision hydraulic force calibration

system with specially designed pressure

controller was developed, and BMC of the

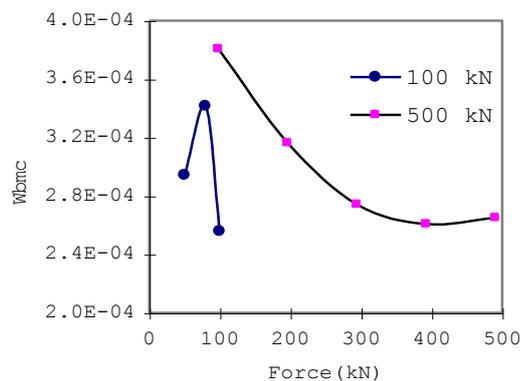system was evaluated as better than 0.05% of

the load.

Figure 5. BMC with different transfer

standards for 500kN force calibrator

6. References

[1]. Sawla A., *Guidance for the determination of the best measurement capability of force calibrators and uncertainty of calibration results of force measuring devices*, PTB-Mitteilungen 104 4/94

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