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PERFORMANCE OF A 50 N FORCE STANDARD MACHINE

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Abstract: The NRLM has therefore developed a force standard machine employing an electromagnetic force compensation sensor to extend the established 10 N to 20 MN force standards to forces of mN order. We are currently conducting research on achieving force standard measurement precision in this range of ± 0.02 % or less. In order to make comparative verification of force standard values established by deadweight-type force standard machines, the rated capacity of the electromagnetic force compensation sensor incorporated in this machine is 50 N at 0.1 mN resolution. However, by reducing the capacity of the electromagnetic force compensation sensor as necessary, the measurement range can be switched to suit the capacity of the force transducer. In this case, however, external vibrations have a major impact on the measurement result.

This report describes the structure of a force standard machine employing an electromagnetic force compensation sensor developed by the NRLM, test force control methods, and performance evaluation results obtained through comparison with a deadweight force standard machine.

Keywords: Force standards, Force transducer calibration, Electromagnetic force compensation sensor

1. INTRODUCTION

The National Research Laboratory of Metrology (NRLM) has established force standards of between 10 N and 20 MN with deadweight-type, lever-type, and hydraulic-type force standard machines using standard weights. These force standard machines are now being supplied to various industries in Japan. However, there is growing demand for calibration of force transducers that can measure extremely small forces of less than 10 N.

In line with the advances made in electronic and mechanical engineering technologies, as well as more energy-efficient assembly processes, electronic equipment increasingly uses component modules that can be easily replaced through mounting and demounting in sockets or slots. The force applied to these modules during mounting and demounting is one of the determinants of the long-term quality of the product, and demand for calibration of force transducers of less than 10 N to measure these forces is growing sharply. The magnitude of force to be measured may in some cases be as small as mN order.

With this as a background, the NRLM has proposed a force standard machine employing an electromagnetic force compensation sensor and is conducting research in order to extend the established 10 N to 20 MN force standards to forces of mN order. The expanded uncertainty of the target force standard setting in this range is ± 0.02 % or less. As the first step, we have developed a calibrating apparatus equipped with an electromagnetic force compensation sensor with a rated capacity of 5 kN.

This report describes the structure of a force standard machine employing an electromagnetic force compensation sensor developed by the NRLM, test force control methods, and performance evaluation results obtained through comparison with a deadweight force standard machine.

2. PRINCIPLE OF OPERATION AND STRUCTURE

2.1. Loading and control mechanism

This force standard machine has a structure and principle of operation similar to those of build-up force standard machines, which use a load cell as a reference standard. As shown in figure 1, the force transducer and the electromagnetic force compensation sensor are placed in vertical series inside the loading mechanism, which is actuated by high-precision ball screws so that a load is simultaneously applied to both the force transducer and electromagnetic force compensation sensor. The main body of a load cell-type uniaxial testing machine with 20 kN capacity, which maintains and controls the test force by servo controller, is used for the loading mechanism. Therefore, the magnitude of force generated in the loading device is feedback controlled during measurement so that the target value is maintained by the electromagnetic force compensation sensor instead of the force transducer.

Figure 1. Installation of the new machine

Figure 2 shows the control system of this force standard machine. As seen in the figure, based on the load output of the electromagnetic force compensation sensor that has already been span-calibrated with standard weights, the machine finely controls the position of the loading crosshead in the vertical direction and maintains the target test force. The loading crosshead is precisely positioned by measuring the number of rotations of the high-precision ball screws. A pulse-type servomotor is used for measuring and controlling the rotation of the high-precision ball screws, performing control so that the test force detected by the electromagnetic force compensation sensor does not exceed the set upper and lower limit values. This allows an accurate test force to be applied to the force transducer connected in series with the electromagnetic force compensation sensor in the loading device. The stroke control performance of the loading crosshead by pulse oscillation is 0.00002 mm/p.

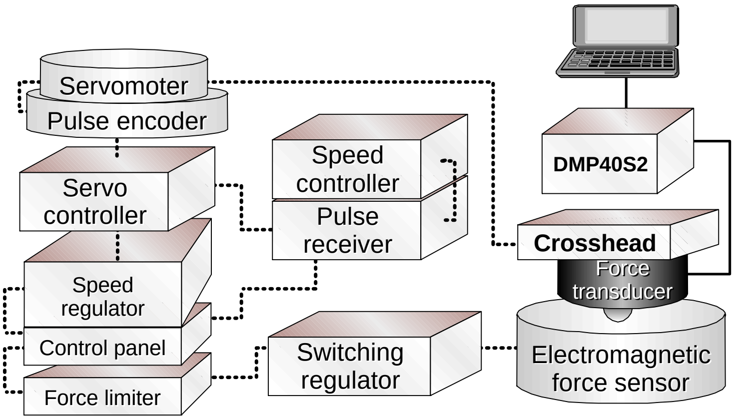

Figure 2. Block diagram of the control system

2.2. Electromagnetic force compensation sensor

The electromagnetic force compensation sensor is often used in precision balances because it has superior linearity, stability, and other desirable characteristics, and span calibration using standard weights is relatively easy. Moreover, its principal feature is that the load receiving section maintains a constant position regardless of the magnitude of the test force.

As shown in figure 3, the electromagnetic force compensation sensor consists of a permanent magnet, a compensating coil, an iron core integrated with the loading platform, a position sensor, an amplifier, and an analog-digital converter. Its principle of operation is as follows. First, the action of force on the loading platform causes the iron core to descend. At this time, the loading platform is made to ascend by inducing a current flow in the compensating coil so as to always maintain the platform in the same position, with the position sensor constantly monitoring the position of the bottom of the iron core. The mechanism employed is that the magnitude of the current at this time is proportional to the acting force.

In order to make a comparative verification with the force standard values already established by deadweight force standard machines, the rated capacity of the electromagnetic force compensation sensor incorporated in this machine is 50 N with a resolution of 0.1 mN. The advantage of this system is that the measurement range can be switched to suit the capacity of the force transducer by reducing the capacity of the electromagnetic force compensation sensor to be incorporated in the loading device as necessary. In this case, however, external vibrations may have a major impact on the measurement result.

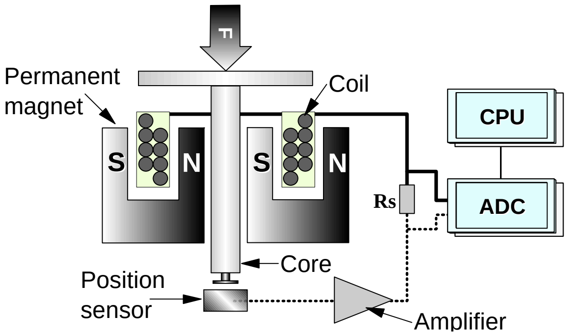

Figure 3. Cutout view of the electromagnetic force compensation sensor

3. STUDY ON ALIGNMENT OF AXIS OF FORCE

There are various structures and methods of installing force transducers for extremely small forces, according to the application. Consequently, adjusting the alignment of the axis of loading of the calibrating apparatus, comprising the axis of force of the force transducer and the axis of force of the electromagnetic force compensation sensor, is a decisive factor affecting the accuracy of calibration. Such alignment adjustment is impossible by means of visual observation or a level. This is because, in addition to the fact that the displacement of the force transducer is extremely small at 0.2 mm or less, the electromagnetic force compensation sensor which controls the generation of an accurate force must be conjoined face-to-face with the point of application of force of the force transducer.

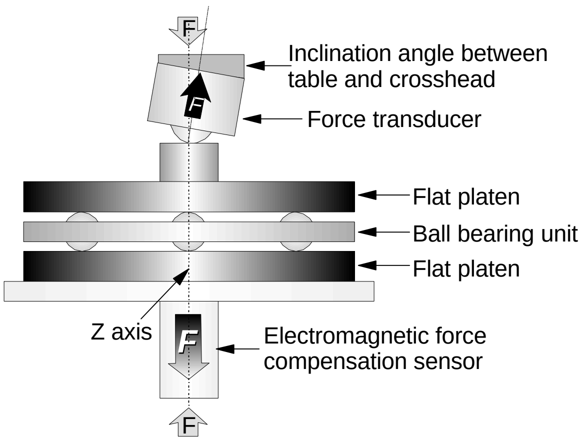

Figure 4. Strukture of the alignment adjusting bearing pad

Figure 4 shows a method of simplifying the alignment adjustment and reducing the effect of parasitic component forces occurring as a result of misalignment of the axis of loading. Moreover, a method of assisting the stroke control of the loading mechanism by creating a large overall displacement through insertion of a spring in the axis of loading has also been found to be effective, and was adopted in this experiment.

4. EXPERIMENTAL METHODOLOGY FOR PERFORMANCE EVALUATION

4.1. Configuration of experimental equipment

In order to verify the effectiveness of the force standard setting function of the newly developed force standard machine incorporating an electromagnetic force compensation sensor, a 500 N deadweight force standard machine providing force standards in 10 N steps was used for the reference standards. The expanded uncertainty of this deadweight force standard machine is within $\pm 2 \times 10^{-5}$.

For the transfer standards to make a comparative verification of the electromagnetic force compensation-type and deadweight-type force standard machines, three different types of load cells were used. These load cells had a rated capacity of 50 N, and all were for compression use. Load cells C1 and C2 had a spherical load button, while load cell C3 had a flat load button.

A digital static strain meter (DMP40-S2) and a personal computer were used for data recording and analysis. Software for force transducer calibration developed by the NRLM was installed in the computer.

4.2. Method of conducting comparative experiment

Comparative calibration was performed by the calibration method using a force transducer specified in JIS B 7728 in conformance with ISO 376.

Loading tests were performed in three directions at 120 degrees pitch. In principle, pre-loading should be implemented three times when installation of the transfer standards is changed. However, it was determined that pre-loading could be reduced to one time if the loading tests were performed successively in a short time frame of within 10 minutes. The loading tests were performed in 5 steps of 10 N intervals for increasing and decreasing test force, respectively, and this process was then repeated twice.

Including pre-loading, the standby time between each loading cycle was 180 sec, and the standby time from the time the target test force was reached until the start of measurement was 30 sec.

The transfer standards and measuring instrument were constantly energized from 24 hours before the experiment up to its completion. The temperature of each calibration room was 23 °C ± 1 °C.

5. PERFORMANCE EVALUATION

Figures 5 to 8 show the results of comparative verification of the newly developed force standard machine and the deadweight machine. Four systems were experimentally studied in this comparative verification: a system with no alignment adjustment mechanism, with a bearing pad inserted, with a spring inserted, and with both a bearing pad and a spring inserted between the electromagnetic force compensation sensor and a load cell.

5.1. System with no alignment adjustment mechanism

Figure 5 shows the verification results for the system in which no bearing pad or spring was used for alignment adjustment. Load cells C1 and C2, which had a spherical load button, exerted a large side-force effect at the lower limit of the test force, and the relative deviation was 2000 to 4000 ppm. As the test force increased, however, the relative deviation decreased to about 300 ppm. Moreover, a significant change in output due to installation change appeared at 1300 to 2700 ppm in the case of

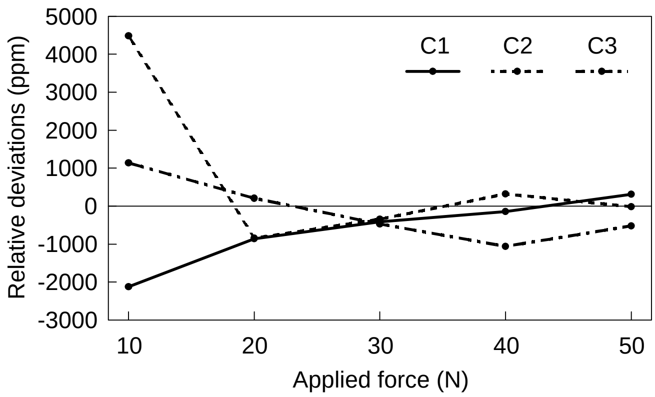

Figure 5. Comparison results of new machine cased of no alignment mechanism

C1 and at 1200 to 6000 ppm in the case of C2. Because alignment adjustment of the electromagnetic force compensation sensor and the load cell with respect to the loading axis was difficult.

On the other hand, in the case of load cell C3, which had a flat load button, alignment adjustment was insufficient, with the result that the relative deviation was 200 to 1000 ppm regardless of the magnitude of force. And the change in output due to installation change was 1500 to 5000 ppm.

5.2. System with bearing pad inserted

Figure 6 shows the comparative verification results for the system in which a bearing pad was used. Although a large comparative relative deviation of 2100 ppm was seen at the lower limit of C1, it was less than 500 ppm in the case of other test forces. A large change in output of 5200 ppm due to installation change was seen at the lower limit of C1, while in the case of other test forces it was 100 to 2000 ppm, thus demonstrating the effect of loading axis correction produced by insertion of the bearing pad.

On the other hand, in the case of C3, with a flat load button, no significant alignment adjustment effect was demonstrated even with the use of the bearing pad, and regardless of the magnitude of the test force. The relative deviation was around 1000 ppm while the change in output due to installation change was 1100 to 2500 ppm.

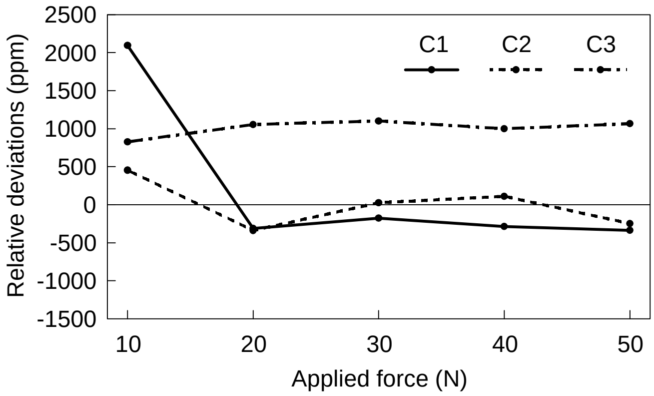

Figure 6. Comparison results of new machine cased of using bearing pad

5.3. System with spring inserted

Figure 7 shows the comparative verification results for the system in which a spring was used. The comparative relative deviation was within 130 ppm in the case of C1 and 210 to 430 ppm in the case of C2. The change in output due to installation change was 220 to 460 ppm in the case of C1 and 490 to 920 ppm in the case of C2, thus demonstrating the effect of loading axis correction produced by insertion of the spring.

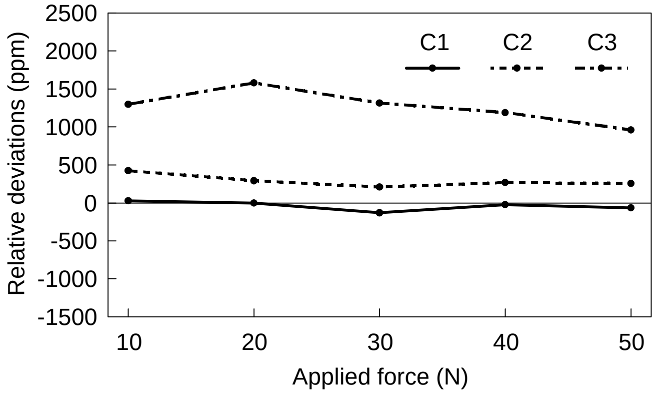

Figure 7. Comparison results of new machine cased of using spring pad

On the other hand, in the case of C3, no significant alignment adjustment effect was demonstrated even with the use of the spring, and regardless of the magnitude of the test force. The relative deviation was 960 to 1600 ppm while the change in output due to installation change was 2500 to 3500 ppm.

5.4. System with both bearing pad and spring inserted

Figure 8 shows the comparative verification results for the system in which both a bearing pad and a spring were used. The comparative relative deviation became relatively small at 113 to 300 ppm in the case of C1 and around 100 ppm in the case of C2. The change in output due to installation change was 50 to 180 ppm in the case of C1 and 100 to 700 ppm in the case of C2, thus demonstrating the significant effect of loading axis correction produced by insertion of both the spring and bearing pad.

In the case of C3 also, an effect of alignment adjustment due to the bearing pad and spring was seen. As the test force increased, the relative deviation decreased, declining from 750 ppm at the lower limit of the test force to 150 ppm. However, the change in output due to installation was 2040 to 5500 ppm, showing no decrease.

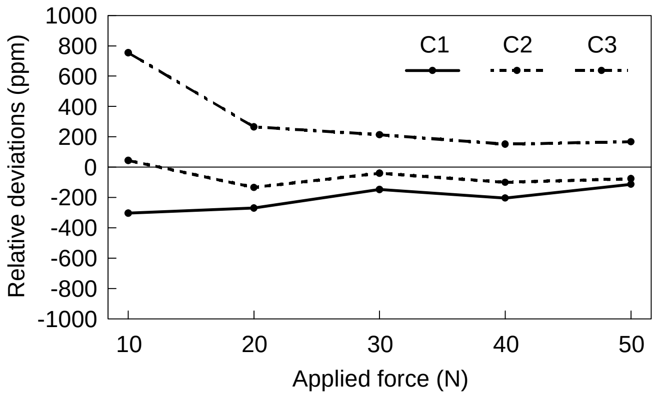

Figure 8. Comparison results of new machine cased using spring and bearing pad

6. CONCLUSION

Through the development of the force standard machine using the electromagnetic force compensation sensor, we have opened up the prospect of constructing a system for setting, maintaining, and supplying extremely small force standards of mN order which have been difficult to establish up to now. The devising and adoption of an alignment adjustment mechanism has paved the way for the enhancement of precision.

The expanded uncertainty of the current force standard setting performed by this force standard machine, which has been confirmed by comparative verification with a deadweight force standard machine, is ± 500 ppm or less.

Future research themes aimed at further enhancing the performance of this force standard machine are to reduce the control speed to ultraslow speed and achieve segmentation of the control displacement, to automate measuring and control operations that are currently carried out manually. Through the realization of these objectives, the development of ultra-small force standard setting equipment with an expanded uncertainty of ± 200 ppm or less can be expected.

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