The Compression Bar Timing Instrument for Testing Cycle Calibration of Rockwell Hardness Testing Machine

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Abstract. This paper presents the timing instrument for testing cycle calibration of Rockwell hardness testing machine, mainly the hardness machine that is not allowed for a calibration mode. It is developed and fabricated by hardness laboratory of National institute of metrology (Thailand, NIMT). It is designed for acquiring a test force signal under the regular hardness measurement. The concept of force detection is compression bar with a very low deformation structure. The force signals were plotted with 1 milliseconds sampling rate, then the testing cycle pattern was produced and calculated by PC. The operation of such force sensor effect on the depth measurement of hardness testing machine only 1.0 µm. The instrument can be used with testing force measurement range start from 1.961 N up to 1,471 N. The testing cycle verification results compared between fabricated instrument and NIMT’s primary hardness machine are less than ±0.10 seconds.

1. Introduction
The testing cycle patterned always change upon hardness value or increasing depth of indenter. Therefore, any deformation of support test block as well as timing instrument that influence depth caused the error of testing cycle. The international standard, i.e. ISO6508-2 [1] and ASTM E18 [2] required the measurement uncertainty of timing instrument lower than 0.2 s. Moreover, the verification and calibration results including uncertainty shall agree with the permissible limit. The first prototype of timing instrument was produced and described on 2017 [3], it is deformed only 2.2 µm under 1,471 N which less effect to increasing depth of indenter. A set of PZT actuator was used as force detection unit. From in the field test, one dropped was broken the PZT as well as the junction between PZT and pressure plate also was damaged. The PZT is very sensitive to amount of detecting force but also very fragile. As a result, the new designed of timing instrument with one piece pressure plate and sensing element structure is developed. As expected the damage from dropped instrument was less severe as the first prototype. The concept of force detection and high stiffness structure can be described as follows.

2. Design and concept of compression bar timing instrument
In this section we describe how to design the second model of timing instrument by using the compression bar type. In 2017 the prototype of high stiffness load cell for calibration of Rockwell hardness testing machine was introduced [4]. Its structure deformation is less than 0.020 mm at 1,471
N applied force. The compression bar type timing instrument was designed using the concept of a very low deformation load cell, since it has less effect on hardness measurement process. The sensing body was machined by using AISI440 stainless steel (Young’s modulus 200 GPa) with heat treatment process to increase the material hardness up to 60 HRC. There are four compression sensing bodies that bear the test force equally, dimensional size of 5.26 mm per area and 10.00 mm per length. It was designed to tolerate over 40,000 N compression forces, 10,520 N each sensing body. The strain under 1,471 N compression forces is only 0.000035 m/m with only 3.5 µm deformation. The drawing of compression bar type timing instrument is shown in figure 1.

The relationship of stress, strain and compression force can be calculated using equation (1) and (2)

\[
\sigma = \varepsilon \times E \quad (1)
\]

\[
\sigma = \frac{F}{A} \quad (2)
\]

Where

- \( \varepsilon \) is strain (m/m)
- \( \sigma \) is stress (N/m²)
- \( E \) is Young’s modulus of elasticity (N/m²)
- \( A \) is cross sectional area (m²)

Well known wheatstone bridge circuit is used to detect the amount of compression force. Four high gain strain gauges model: KSN-2-120-E4-11 manufactured by Kyowa Co., Ltd. are used in this circuit. The descriptions of the strain gauge are: 104 gauge factor, 2 mm gauge length and -0.23%/°C temperature coefficient. Hence, the electrical signal of this full bridge circuit at loaded force 1,471 N, 0.000 035 m/m strain would be 3.64 mV/V approximately.

3. Fabricated timing instrument

The fabricated timing instrument is shown in figure 2. Moreover, the timing instrument with full setup including data acquisition (DAQ) with software and laptop is shown in figure 3.
In figure 4 presents the block diagram of timing instrument. The strain signal was produced by applied force then the signal was amplified by bridge amplifier. The signal was collected using DAQ and then analyzed the testing cycle by PC program and reported in the form of graph. Additionally, the data acquisition module NI DAQPad-6015 and cDAQ-9237 from national instrument are used as bridge amplifier and data acquisition unit, respectively. The time based of DAQ including PC are calibrated using time standard (standard function generator), which the verification results are good within ±0.05 seconds including uncertainty.

To prevent the effect of using a timing instrument, the verification of machine hysteresis must be finished. Perform repeated Rockwell hardness tests using a blunt indenter acting directly onto the 65 HRC block over the timing instrument and the anvil (with and without the timing instrument). Test force 1,471 N (HRC scale) is used as a total test force in this experiment. The results in table 1 shown that the machine hysteresis between with and without using the timing instrument is less than 1.0 µm in deformation.

| Condition               | Deformed at 1,471 N (µm) | Machine hysteresis (µm) | Repeat of measurement (µm) |
|-------------------------|--------------------------|-------------------------|----------------------------|
| Without timing instrument | 22.95                    | 0.18                    | 0.04                       |
| With timing instrument  | 23.54                    | 0.19                    | 0.07                       |

Moreover, the stiffness of new timing instrument is described by the verification results of machine hysteresis and total deformation under 1,471 N compared between with and without timing instrument as shown in table 1. The deformation is 0.59 µm and the machine hysteresis is 0.01 µm. These results can confirm that the timing instrument has less effect on the hardness measurement process.

4. Verification results

In this section we describe how to verify the timing instrument according to standard requirements. Regarding to NIMT’s Rockwell primary machine (Akashi corporation, model: SHT-31), its testing cycle can be controlled and monitored precisely by PC. Such testing cycle can be monitored in term of indentation depth versus time during the entire hardness measurement process. Consequently, the testing cycle results from timing instrument can be verified using the results from the primary machine.

The hardness block 85 HRA, 30 HRBW and 45 HRC were used as artifacts for verification process. The equipment setup for testing cycle verification is shown in figure 5. The compression bar type timing instruments was placed instead of SHT-31’s anvil and the artifact block is placed on the top of the
compression bar type. Finally, the hardness block artifact is placed on the top of a timing instrument. The verification results using SHT-31 as time standard are presented in table 2.

![Figure 5. Experiment setup with NIMT’s Rockwell primary machine, Akashi SHT-31.](image)

![Figure 6. Experiment result compared between indentation depth data from SHT-31 and test force data from timing instrument](image)

In figure 6 presents the output signal from timing instruments (force versus time) compare with testing cycle data from SHT-31(indentation depth versus time). The result was obviously shown that the test force result from timing instrument was similar to each other. Moreover, the testing cycle verification results using hardness block scale 85 HRA, 30 HRB and 45 HRC designated that the deviations are less than ±0.05 s with measurement uncertainty ±0.1 s for three hardness ranges.

| Nominal (s) | 85 HRA | 30 HRB | 45 HRC |
|------------|--------|--------|--------|
|            | Deviation (s) | Ue (s) | Deviation (s) | Ue (s) | Deviation (s) | Ue (s) |
| t0         | -0.037  | 0.060  | -0.018  | 0.059  | -0.021  | 0.059  |
| t0-t1      | 0.031   | 0.063  | -0.025  | 0.059  | -0.001  | 0.060  |
| t1         | -0.042  | 0.098  | 0.018   | 0.073  | 0.002   | 0.060  |

5. Conclusion and future work

The design of fabricated instrument was proved by the very low machine hysteresis compare between with and without using the timing instrument. Additionally, the deformation of timing instrument is only 0.59 μm under 1,471 N. These results can confirm that the timing instrument has less effect on the hardness measurement process. Finally, the testing cycle verification results showed that the deviation between fabricated instrument and the SHT-31 was less than ±0.10 s. In the future, the timing instrument for testing cycle verification of Brinell hardness testing machine 29,420 N will be the next goal.

References

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