

IMEKO 2010 TC3, TC5 and TC22 Conferences  
 Metrology in Modern Context  
 November 22–25, 2010, Pattaya, Chonburi, Thailand

## VIBRATION EFFECT ON VICKERS HARDNESS MEASUREMENT

*Tassanai Sanponpute*<sup>1</sup>, *Apichaya Meesaplak*<sup>2</sup>

<sup>1</sup>National Institute of Metrology Thailand, Pathumthani, Thailand, [Tassanai@nimt.or.th](mailto:Tassanai@nimt.or.th)

<sup>2</sup>National Institute of Metrology Thailand, Pathumthani, Thailand, [Apichaya@nimt.or.th](mailto:Apichaya@nimt.or.th)

**Abstract** – The effect of environmental vibration on Vickers hardness machine is reported in this paper. Test force 9.807 N (HV1) and 98.07 N (HV10), representing low-force hardness test and normal hardness test, were selected for this experiment. Two machines with different loading mechanism made indentation under influence of single sinusoidal vibration with frequency ranging from 10 Hz to 100 Hz and amplitude ranging from 0.002 m/s<sup>2</sup> to 0.04 m/s<sup>2</sup>. Indentations were captured by CCD camera and diagonal lengths were measured automatically by software. Response to vibration for each loading mechanism, hardness level, and test force level is discussed in this paper. This experiment shows that the relative errors are higher than maximum permissible error in ISO 6507-2 when vibration amplitude higher than 0.005 m/s<sup>2</sup> or 0.0005 g<sub>n</sub>. Result from this paper can be used as a guideline to revise maximum allowable vibration acceleration and test force scale to which the limit should be applied.

**Keywords** : Vibration effect, Vickers hardness

### 1. INTRODUCTION

National Institute of Metrology Thailand had studied on vibration effect on Rockwell scale hardness measurement in 2009 [1,2]. The research emphasized the importance of setting the allowable vibration limit as a guideline for Rockwell hardness testing machine users. Although vibration limit according to ISO 6507-3[3] was applied, vibration still caused the error of Rockwell hardness measurement higher than the maximum permissible error. Vibration effect on Vickers was assumed to cause error higher than maximum permissible error as similar as in Rockwell hardness measurement. The maximum allowance acceleration identified in ISO 6507-3 is applied only to micro hardness testing only. Therefore, this research was aimed to investigate the effect of vibration on Vickers hardness measurement for vibration acceleration under maximum allowance applied to low-force and normal Vickers hardness test.

### 2. EXPERIMENTAL SETUP

In this experiment, the vibration signal was single sinusoidal wave. Accelerometer was used to confirm vibration frequencies and amplitudes and also to check that no other vibration noises reaching the machines during the

experiment. The Vickers hardness testing machines were placed on the vibration table. In this study, only indentation process was under vibration influence. No vibration effect involved in diagonal length measuring process.

To study the response-to-vibration behavior of different loading mechanism of Vickers hardness testing machine, two machines with two types of mechanism, which are the common types in Vickers hardness testing machine, were used in this experiment. First machine, machine A is capable of measure hardness scale HV0.01-HV1. Test force is generated directly from deadweight and transferred through weight axle, which slides in the Teflon coated bush.

Machine B composes of 2 loading devices. The first one is for hardness measurement scale HV0.01-HV2. Weight of indenter and deadweight is deducted by internal counter weight, so the initial force starts at 10 gf for scale HV0.01. Indenter moves vertically in ball bearing slot. This is called as Machine B-I.

The second loading device of machine B is used for hardness scale HV0.1 to HV10. This loading device has similar main structure as loading device I, but weight of indenter and indenter rod was designed to generate initial force at 100 gf. Therefore, counter weight is not needed for the smallest scale, HV0.1. Machine B with loading device II is called as B-II.

To eliminate the effect of diagonal length measurement, the same microscope was used to measure all indentations in this experiment. Indentations were captured by 12-Megapixel CCD camera. Then, diagonal lengths were directly measured by software with reproducibility 0.05% for 300 μm and 1% for 50 μm.

Machine A, machine B-I and machine B-II were under the experiment respectively. First, machines were verified by calibration procedure according to ISO 6507-2. Then, the experiment started from hardness measurement at free from vibration condition at nominal 200 HV1 and 900 HV1 for machine A, 200 HV1, 600 HV1, 900 HV1 for machine B-I, and 200 HV10, 600 HV10, 900 HV10 for machine B-II. This measurement values were used as reference for error calculation. Then, peak of error were found under vibration at amplitude of 0.002, 0.005, 0.01, 0.02, and 0.04 m/s<sup>2</sup>. For each amplitude, frequencies were set depending on the error trend to ensure that the error peak was found. However all frequencies used in this research are between 5 Hz to 100 Hz.

The result analysis includes the behavioral response to vibration of each structure type, hardness level, and test force level.

### 3. RESULTS AND DISCUSSION

#### 3.1 Machine Calibration Result

Both machines passed direct and indirect verification according to ISO 6507-2:2005. However, during the test force verification, some of observation was made as follows.

- Repeatability of test force of machine A is larger than one of machine B. During the 30-second loading time, creep of test force on precision balance shows the instability of test force. This could be the result from friction between the bush and the indenter rod.

- Test force verification result of machine B shows good repeatability. No creep occurred during calibration indicates only slightly friction remaining in the system. However, indenter rod can loosely move horizontally due to gap between bearing and indenter rod.

#### 3.2 Vibration model

The hardness testing machine under vibration effect experiment can be modeled as base excitation problem as shown in figure 2. It is assumed that base is Vickers hardness testing machine, which moves as the vibration input in (1), and mass  $m$  is deadweight and indenter, which moves according to base excitation through linear spring,  $k$ , parallel with viscous damper,  $c$ .

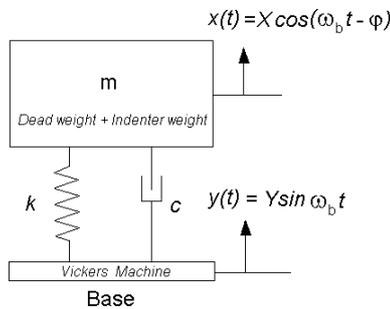


Fig.2 Base excitation models the motion of deadweight and Indenter weight on the vibration table.

$$y(t) = Y \sin \omega_b t \tag{1}$$

Where  $Y$  represents amplitude of the base motion and  $\omega_b$  is frequency of base excitation. The solution of  $x(t)$  is solved and shown in the simple form as in (2).

$$x(t) = X \sin(\omega_b t - \varphi) \tag{2}$$

Where

$$X = Y \left[ \frac{1 + (2\xi r)^2}{(1 - r^2)^2 + (2\xi r)^2} \right]^{1/2}$$

$$r = \omega_b / \omega_n, \quad \xi = \frac{c}{2\sqrt{km}}, \quad \text{and} \quad \omega_n = \sqrt{k/m}$$

$X$  denotes to magnitude of the solution and  $\varphi$  is phrase shift of mass oscillation.  $r$  is frequency ratio and  $\xi$  is damping ratio. The ratio of maximum response magnitude to the input displacement magnitude, displacement transmissibility, is used to describe how motion is transmitted from the base to the mass as a function of frequency ratio, as shown in figure 3.

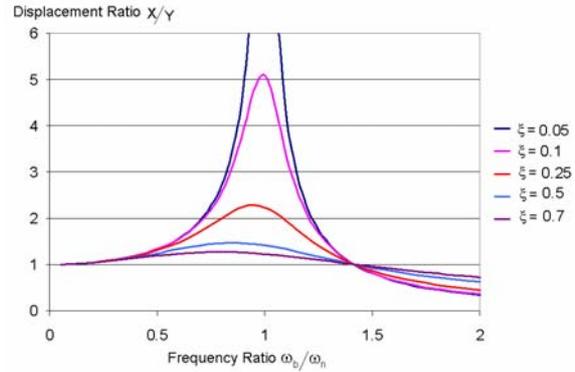


Fig. 3 Displacement transmissibility as a function of frequency ratio of base excitation model.

This plot shows that when frequency ratio is 1 (base excitation frequency is equal to natural frequency of the system), or resonance, the maximum amount of base motion is transferred to displacement of the mass, and the magnitude of displacement of mass depends on damping ratio. However, when damping ratio increase, the maximum displacement ratio does not occur at  $r = 1$ . Frequency ratio for maximum displacement ratio was calculated in a function of damping ratio and plotted in figure 4. The graph shows that when damping ratio increases, resonance occurs at frequency ratio lower than 1 (base excitation frequency is lower than natural frequency). This will be used to explain the different frequency between machine A and machine B.

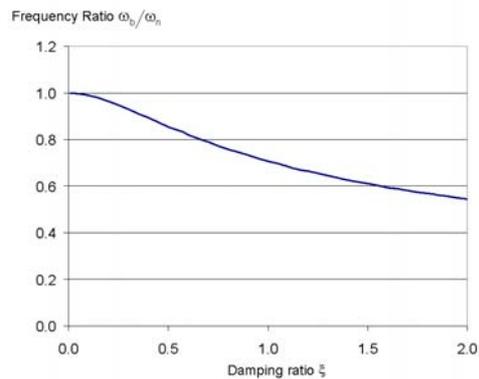


Fig. 4 Frequency ratio of resonance as a function of damping ratio.

#### 3.3 Absolute Error by Machines

To compare absolute error by machine, result of HV1 measurement from machine A and machine B-I at 200 HV1 and 900 HV1 are illustrated in figure 5(a) and 1(b).

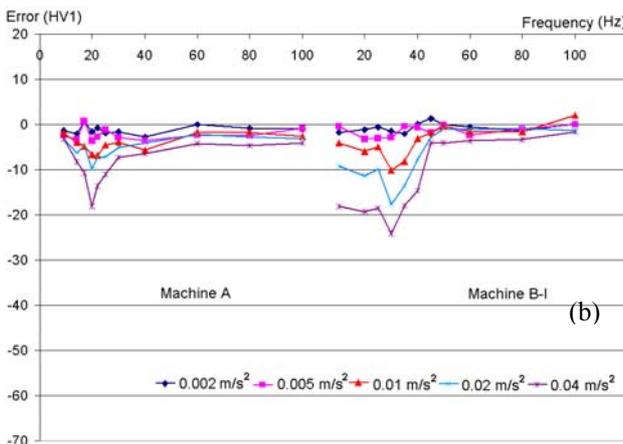
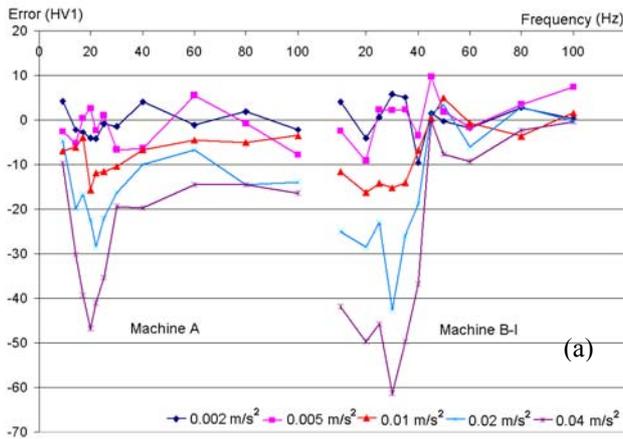


Fig 5. Absolute error in HV1 of machine A and machine B-I for (a) 200HV1 and (b) 900 HV1.

Overall, both machines responded to vibration in similar way. Error is direct proportional to magnitude of vibration amplitude. The error peak is highest at one frequency, but both machines are different in terms of frequency of error peak and magnitude of error.

- Frequency of error peak

Machine A is response to vibration at 20 Hz while Machine B-I is response at 30 Hz. This could be the result from higher friction in indenter guide slot in machine A than one in machine B-I, as observations during test force calibration. This friction, acting as damping in the system, causes damping ratio to be larger. As shown in figure 4, therefore, the base excitation frequency causing resonance of machine A is lower than one of machine B-I when both machine assumed to have same natural frequency.

- Magnitude of error

Friction does not result only in frequency, but also in magnitude of error. As in figure 3, when damping ratio increases, the displacement ratio is lower. Thus the magnitude of error of machine A is lower than one of machine B-I with the same input.

### 3.3 Absolute Error by Hardness Level

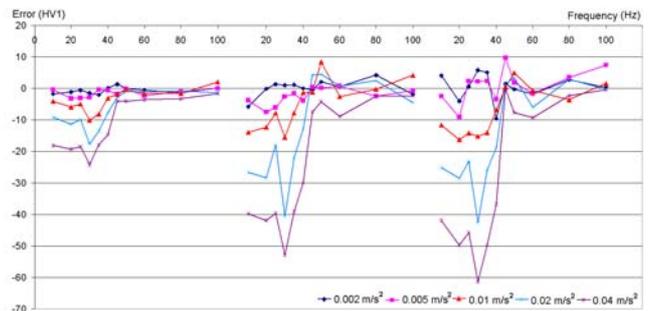


Fig. 6 Absolute error in HV1 of machine B-I

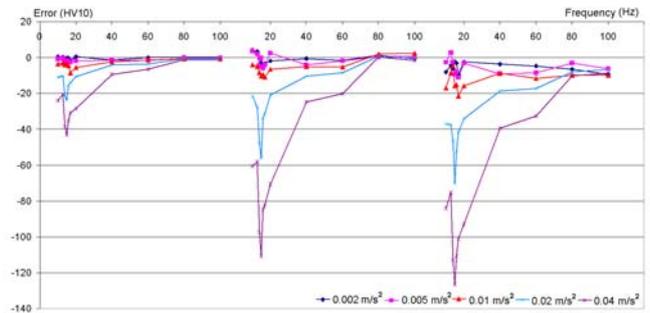


Fig. 7 Absolute error in HV10 of machine B-II

Figure 6 and 7 show error of hardness measurement from machine B-I and B-II in terms of absolute error. Error in HV directly varies to hardness level whereas error of Rockwell scale C varies indirectly as shown in figure 8. This inconsistency is discussed as follows.

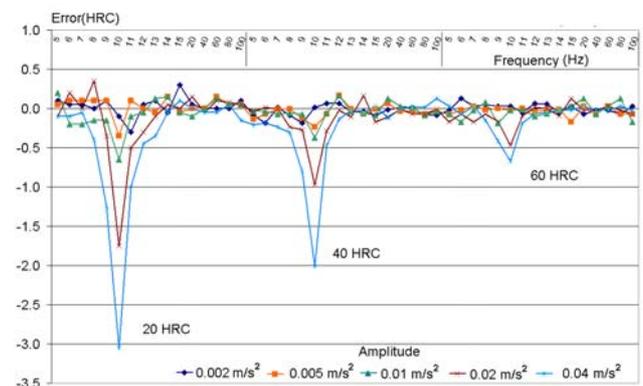


Fig. 8 Absolute error in HRC of Rockwell testing machine

To be comparable, errors in term of indentation depth of Vickers HV10 were calculated and compared with depth error of Rockwell under vibration amplitude 0.02 and 0.04 m/s<sup>2</sup> as illustrated in figure 9.

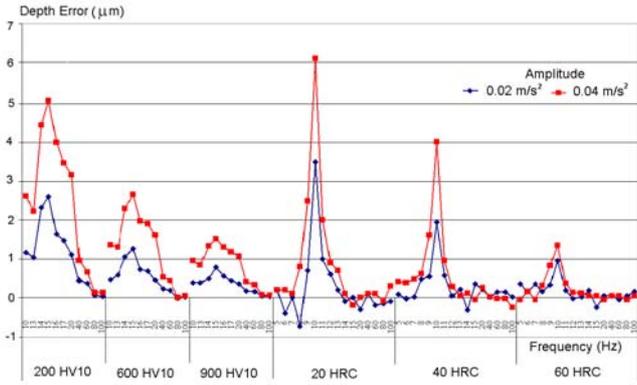


Fig.9 Comparison of error of indentation depth between HV10 and HRC

The graph clearly shows that in terms of depth error, indentations of all hardness level of both scale behaved similarly under vibration. The lower hardness specimen is less resistant to impact force than the harder specimen, so indentations are deeper. Moreover, it can be found that, at the frequency of error peak of each scale, relationship between depth error and hardness level is linear of both scales as in figure 10.

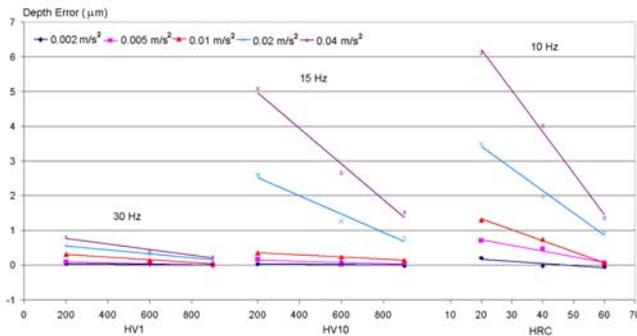


Fig.10 Error of indentation depth of HV1, HV10, and HRC measurement at the frequency of error peak

Even behavior in terms of depth is similar to both scales as mentioned, behavior in terms of absolute error is different because of the different definition of both hardness scales as in (3) and (4).

$$HRC = 100 - \frac{h}{0.002} = f(-h) \tag{3}$$

$$HV = 0.102 \frac{F \sin \frac{136^\circ}{2}}{d^2} = 0.102 \frac{F \sin \frac{136^\circ}{2}}{(h\sqrt{2} \tan \frac{136^\circ}{2})^2} = 0.102 \frac{F \sin \frac{136^\circ}{2}}{8h^2 \tan^2 \frac{136^\circ}{2}} = f\left(\frac{1}{h^2}\right) \tag{4}$$

Where

- $F$  Test force in Newtons (N)
- $d$  Mean of diagonal lengths in millimeters (mm)
- $h$  Indentation depth in millimeters (mm)

From (3), Rockwell hardness value is function of depth, so absolute hardness error is in linear correlation with hardness value as same as the depth error. For Vickers hardness, on the other hand, HV is inversely proportional to square of depth, as in (4). Figure 11 illustrates correlation between absolute error of HV10 and HRC and hardness value under vibration acceleration of 0.04 m/s<sup>2</sup> at peak of error and frequency and nearby frequencies.

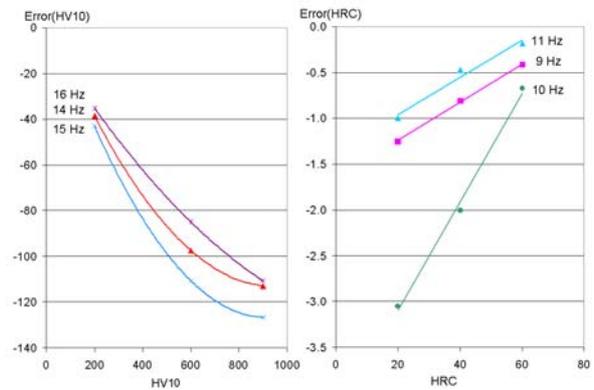


Fig.11 Absolute error of HV10 and HRC under vibration acceleration of 0.04 m/s<sup>2</sup> at peak of error and frequency and nearby frequencies

### 3.4 Relative Error

Graph of absolute error of HV10 in figure 11 shows that the slope of graph is high in low hardness level and lower in high hardness level, while the slope of HRC is constant. With this characteristic, relative error of HV as (4) behaves similarly to slope of absolute error graph.

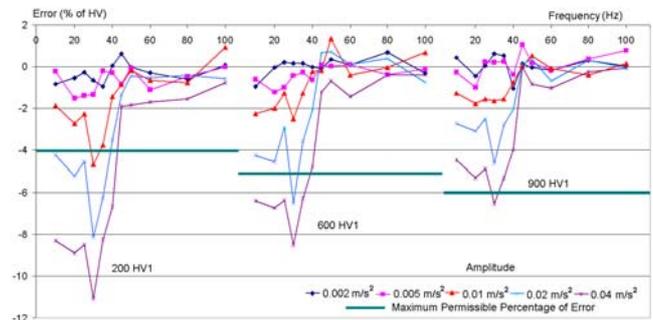


Fig.12 Relative error in percentage of HV1 machine B-I

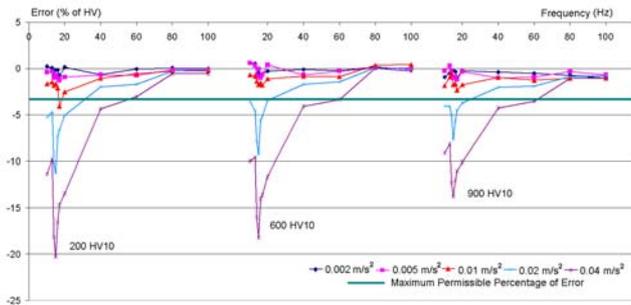


Fig. 13 Relative error in percentage of HV10 machine B-II

Relative error responds to vibration amplitude, test force, and hardness level. Relative error is direct proportional to vibration amplitude and test force, but varies inversely to hardness level. The relative error results disagree with the maximum permissible error (MPE) according to ISO 6507-2, which is set to be indirect proportional to test force and direct proportional to hardness level. From experiment at 200 HV, 600 HV, 900 HV at test force 1 kgf and 10 kgf, indentations under vibration amplitude over  $0.005 \text{ m/s}^2$  have relative error higher than permissible error especially for low hardness level, but indentations under vibration amplitude less than  $0.005 \text{ m/s}^2$  or  $g_n$ , all hardness errors of all hardness level and test forces are under 2%, which is under the limit of maximum permissible error specified in 6508-2.

### 3.3 Irregular indentations

One difference between Vickers and Rockwell hardness testing is indentation measurement. In Rockwell hardness, indentation depth is measured during the indentation process, but in Vickers, diagonal measurement process is done after indentation process. Thus Vickers hardness users could be able to inspect the indentations if abnormality happens. From the experiment, besides causing indentation larger, vibration also creates marking inside indentation or at the end of diagonals. Figure 14 illustrates the comparisons between non-vibration influenced diagonal and influenced one from machine B-I and machine B-II. The marking, especially at the end of diagonal, compounds the difficulty in estimating where the diagonal tip ends, and might create appreciable error in diagonal measurement. However this marking cannot be observed for all vibration influenced indentations. There are still some indentations exceeding maximum permissible error that cannot be detected.

Indentations with or without effect from vibration of machine A are not different as shown in figure 15. This could be the result from different loading mechanism between the two machines. Indenter rod of machine B can loosely move horizontally due to gap between bearing and indenter rod; thus causing the marking on indentations of machine B.

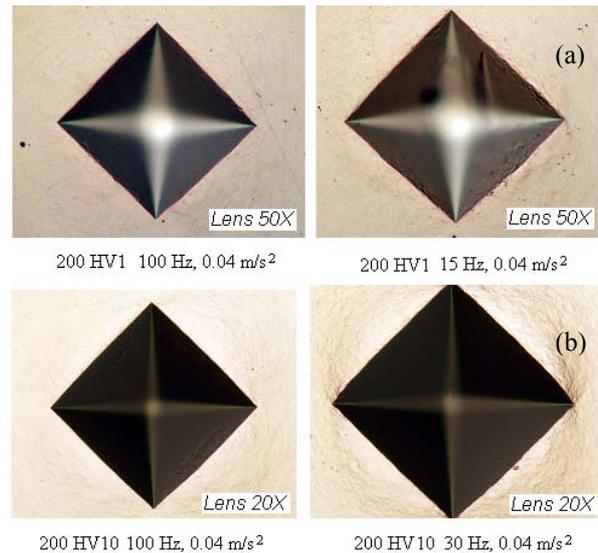


Fig.14 Comparison between indentations with and without effect from vibration of machine (a) B-I and (b) B-II

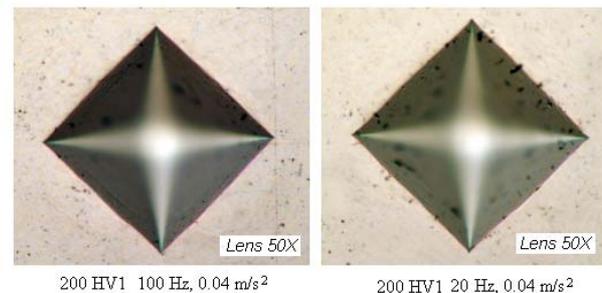


Fig. 15 Comparison between indentations with and without effect from vibration of machine A

## 4. CONCLUSIONS

Result from this experiment confirms that Vickers hardness measurement is affected by vibration as in Rockwell hardness measurement. Relative errors are direct proportional to magnitude of test force and vibration amplitude for frequency less than 100 Hz, but it is indirect proportional to hardness level. The relative errors are higher than maximum permissible error in ISO 6507-2 when vibration amplitude higher than  $0.005 \text{ m/s}^2$ .

This paper suggests that maximum allowable vibration acceleration limit reaching Vickers hardness testing machine in ISO 6507-2 should be lower than  $0.0005 g_n$  and the limit in ISO 6507-3 should be revised to include higher test force or all test force up to 50 kgf.

## REFERENCES

- [1] T. Sanponpute, A. Meesaplak, "Vibration Effect on Rockwell scale C hardness measurement", *XIX IMEKO World Congress*, Lisbon, Sept 2009.
- [2] T. Sanponpute, A. Meesaplak, "Vibration Effect on hardness measurement", *Measurement* 43 (2010) 631–636
- [3] ISO 6507 International Standard of Metallic Material-Vickers Hardness Test, 2005