XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6−11, 2009, Lisbon, Portugal

VIBRATION EFFECT ON ROCKWELL SCALE C HARDNESS MEASUREMENT

Tassanai Sanponpute [1], *Apichaya Meesaplak* [2]

[1] National Institute of Metrology Thailand (NIMT), Patumthani, Thailand, tassanai@nimt.or.th
[2] National Institute of Metrology Thailand (NIMT), Patumthani, Thailand, apichaya@nimt.or.th

Abstract − Three ranges of Rockwell scale C reference hardness blocks: 20, 40, and 60 HRC were measured by deadweight-lever system hardness testing machine with two types of display: analog and digital. The testing machines were placed on the vibration table, whose frequency and amplitude of vibration can be controlled. Piezoelectric probe and vibration meter were used to confirm both amplitude and frequency of vibration. The hardness value at free from vibration is used as a reference to calculate the error of each hardness measurement at certain frequency and amplitude. Both machines give the same tendency. At vibration frequency higher than 15 Hz, there is no significant error of measurement in any vibration amplitude lower than 0.04 m/s^2 for all three hardness ranges. However, below 15 Hz vibration frequency, the negative error of both digital and analog displayed machine appears significantly higher and increases as the amplitude of vibration increases. Moreover, the softer range of hardness is more affected by the vibration**.** . Therefore, the result from this paper can be used as guideline for laboratory to control environmental vibration amplitude to be less than 0.01 m/s^2 for frequency (10±5) Hz and 0.05 m/s^2 for other in Rockwell scale C hardness measurement.

Keywords: Vibration effect, Rockwell scale C

1. INTRODUCTION

The principle of Rockwell hardness test is applying force according to the scale to test piece through a specified shape size and material indenter, measuring the indentation depth, and then calculating the depth into Rockwell hardness scale [1]. The difference depth of each HRC is only two microns, so only a small change in environmental conditions could affect the measurement result. Thus, the environment must be controlled during the measurement to achieve higher accuracy. The environmental condition such as temperature during measurement, vibration as well as cleanliness of test piece and indenter can add up error to the measurement [2]. In this paper, only vibration effect will be studied. In metrology field, the example of ground vibration limit requirement to be met for mass calibration laboratory is shown in the table 1[3].

Table 1. Vibration requirements to be met by the mass calibration laboratory.

Acceleration (mm/s^2)	Classification				
	E_1	E_2	F_1	F_2	M_1
< 3 Hz	5×10^{-4}	1.5×10^{-3}	5×10^{-3}	1.5×10^{-2}	5×10^{-2}
3 Hz-30 Hz	5×10^{-3}	1.5×10^{-2}	5×10^{-2}	0.15	0.5
> 30 Hz	1.5×10^{-2}	5×10^{-2}	0.15	0.5	1.5

The requirement clearly specifies vibration acceleration for each frequency range. At frequency less than 3 Hz, the smallest amplitude limit is given. This implies that low vibration frequency will affect more on mass measuring system than high vibration frequency does.

In hardness measurement field, the example of given allowable vibration is shown in Vickers hardness standard procedure, ISO 6507-3:2005[3]. The standard states that the maximum allowable vibration acceleration reaching the calibration machine shall be 0.005 g_n (or 0.05 m/s^2) for micro hardness testing. However, in Rockwell test standard, there is no identified vibration frequency or acceleration limit. It only warns the user to avoid making measurements when the machine is subjected to shock or vibration. In hardness measurement, vibration during the measurement can cause the softer value than the actual value. Especially with deadweight machines, the vibration in deadweight will add up the actual indenting force [4]. Even though it is known that vibration can lead to softer value, the magnitude of error and vibration limit have never been discussed. The result from this paper can help identifying the maximum allowable vibration frequency and acceleration for Rockwell scale C hardness measurement.

2. EXPERINMENTAL SETUP

The vibration table used in this experiment is floated by pneumatic so that it is free to vibrate. Sinusoidal wave signal is generated by function generator, then amplified by power amplifier, and transmitted to 4 actuators, which directly transfer the motion to the table platform. The vibration signal is monitored by piezoelectric probe connected to vibration meter. Amplitude and frequency of signal will be adjusted at function generator as required. The schematic of vibration table is shown in figure 1.

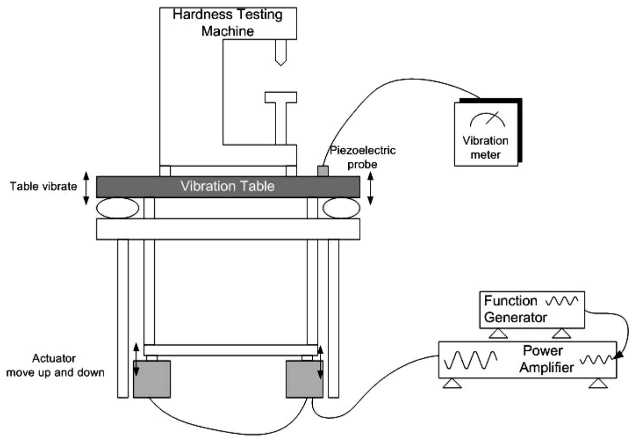

Fig. 1. Schematic of vibration Table.

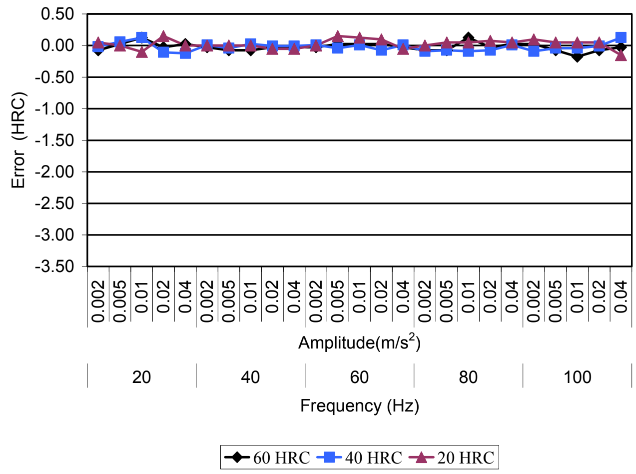

Fig. 2. Errors of hardness measurement at frequency 20 to 100 Hz with varied amplitude from 0.002 to 0.04 m/s^2 of analog-displayed hardness tester.

The hardness testing machines used in the experiment are analog-displayed and digital-displayed hardness tester. Both of them are deadweight type and force applied through lever mass system.

The experiment started by measuring the hardness of hardness standard blocks at free from vibration state on the solid table. The hardness result at this state will be used as a reference to calculate the error for other measurements on vibration table. Then, vibration was applied with varied frequency from 100, 80, 60, 40, 20, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, and 5 Hz respectively and amplitude of vibration was set up at five levels: 0.002, 0.005, 0.01, 0.02, and 0.04 m/s^2 rms at each frequency. The reason vibration is ranging from frequency 20 Hz to 100 Hz increasing with 20 Hz step and the frequency from 16 Hz to 19 Hz are omitted because the NIMT preliminary research shows insignificant error in any frequency higher than 15 Hz. The results will be discussed in two parts: Analog hardness tester and digital hardness tester.

3. RESULTS AND DISCUSSION

The hardness measurement was done at frequency ranging from 5 to 100 Hz, which is categorized into two groups: high and low frequency vibration in discussion section. At high frequency, the frequency starts at 20 Hz to 100 Hz with 20 Hz incremental. For low frequency, the data was collected from 5 to 15 Hz with 1 Hz increasing step.

3.1. Analog-displayed hardness tester

At high frequency vibration, figure 2 shows all error for each frequency and each amplitude of three hardness ranges. The result shows that the range of error is within 0.4 HRC as shown in figure 2. Those small errors are assumed to be non-uniformity of the reference blocks. Thus, in this frequency range, there is no significant effect from vibration with any amplitude used in this experiment (lower than 0.04 m/s^2).

For low frequency vibration, the data were collected at smaller incremental of frequency in order to see the effect by frequency. The results are shown in figure 3a) to figure 3c) by each hardness value. The error of 20 HRC measurement is shown in figure 3a) varied by each vibration amplitude. The measurement error is higher than the maximum permissible error when the amplitude rises up to 0.005 m/s^2 and increases as the vibration amplitude increases. The error is as high as –3 HRC at 10 Hz and 0.04 m/s^2 vibration. The peak of the error of each vibration amplitude is at 10 Hz and the error line declines as the frequency away from 10 Hz. The error of 40 HRC and 60 HRC in figure 3b) and 3c) also show the same behavior as in 20 HRC. However, the measurement starts to be affected higher amplitude than one of 20 HRC. The errors are noticeable at vibration amplitude of 0.01 m/s^2 and 0.02 m/s^2 for 40 HRC and 60 HRC respectively. Moreover, for each vibration amplitude, all the error shows the same trend that the vibration has more effect on softer hardness range than the harder one.

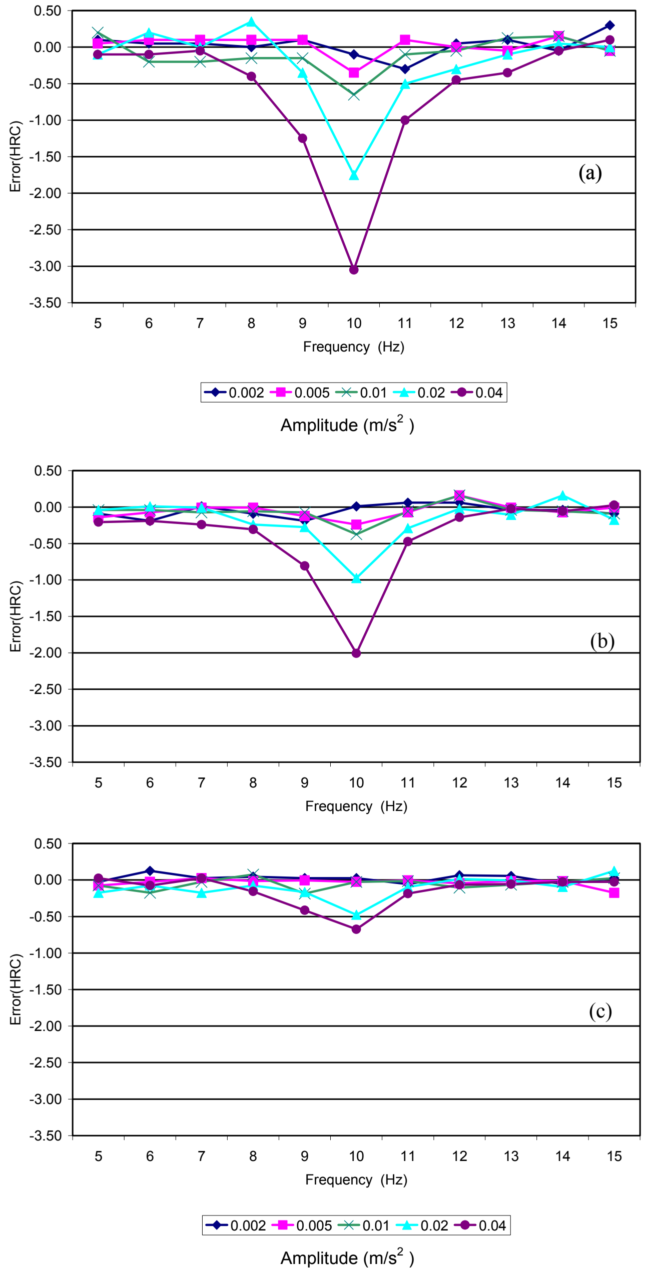

Fig. 3. Errors of hardness measurement at frequency 5 to 15 Hz for hardness value (a) 20 HRC (b) 40 HRC (c) 60 HRC of analog-displayed hardness tester.

The error at the most affected frequency, 10 Hz, was plotted by varied vibration amplitude as in figure 4. The relationship between the error and vibration amplitude can be fitted as a linear curve, which can be used to predict the effect of vibration for known vibration characteristic. However this linear relation can predict at the most impacted frequency only. At other frequencies, no obvious linear curve shows up.

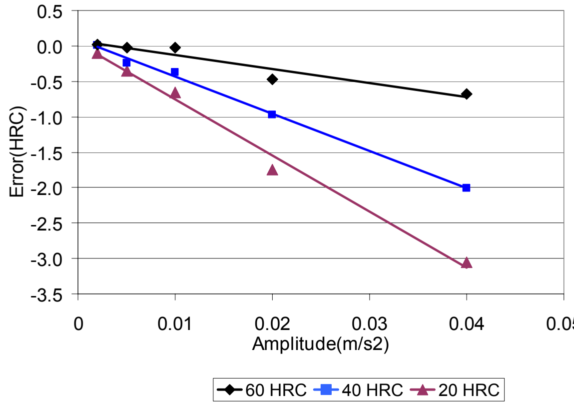

Fig. 4. Errors of hardness measurement with varied amplitude from 0.002 to 0.04 m/s^2 at frequency 10 Hz of analog-displayed hardness tester.

3.2. Digital-displayed hardness tester

The error of hardness measurement by digital-displayed hardness tester shows the same tendency as in analog-displayed one. At high frequency, no significant error shows on any amplitude of vibration as shown in figure 5. The range of all error is only 0.3 HRC which is smaller than maximum permissible of non-uniformity.

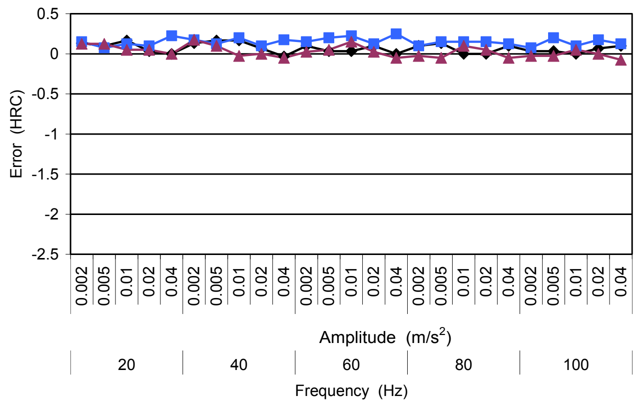

Fig. 5. Errors of hardness measurement at frequency 20 to 100 Hz with varied amplitude from 0.002 to 0.04 m/s^2 of digital-displayed hardness tester.

For low frequency, the behavior of error as the increasing amplitude is same as that of analog-displayed tester. Also, vibration affects on softer range of hardness block. However, the maximum peak shifts from 10 Hz to 9 Hz, and there is also another peak occurring at 7 Hz at 0.02 m/s^2 and 0.04 m/s^2 amplitude as shown in figure 6. Two error peaks could be the result from hardness testing machine under forced vibration acting as multiple-degree-of-freedom system. This causes the system to have more than one natural frequency.

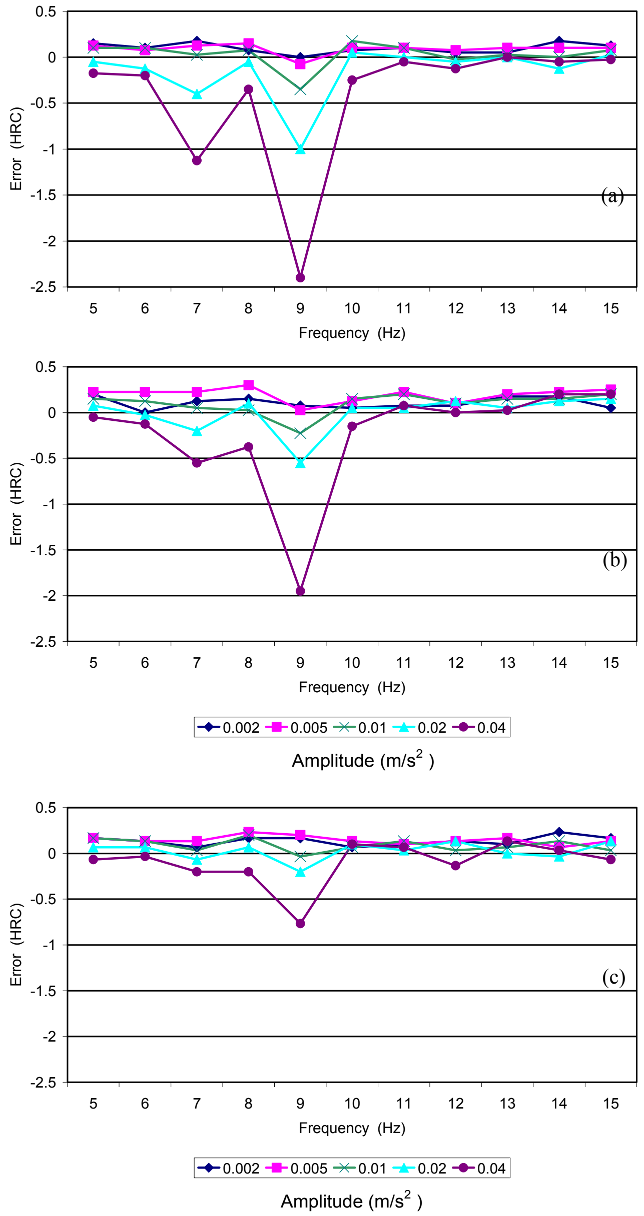

Fig. 6. Errors of hardness measurement at frequency 5 to 15 Hz at hardness value ((a) 20 HRC (b) 40 HRC (c) 60 HRC of digital-displayed hardness tester.

In digital-displayed machine, the frequencies giving the peak of error are at 7 and 9 Hz. The relationship between error and vibration amplitude was plotted and curve-fitted linear graph can be used to predict the error as shown in figure 7. This result also support the result from analog-displayed tester that the interpolation can be applied to only the data point at the most impacted frequency, where in this case, linear curve at 9 Hz represents the error better than that at 7 Hz.

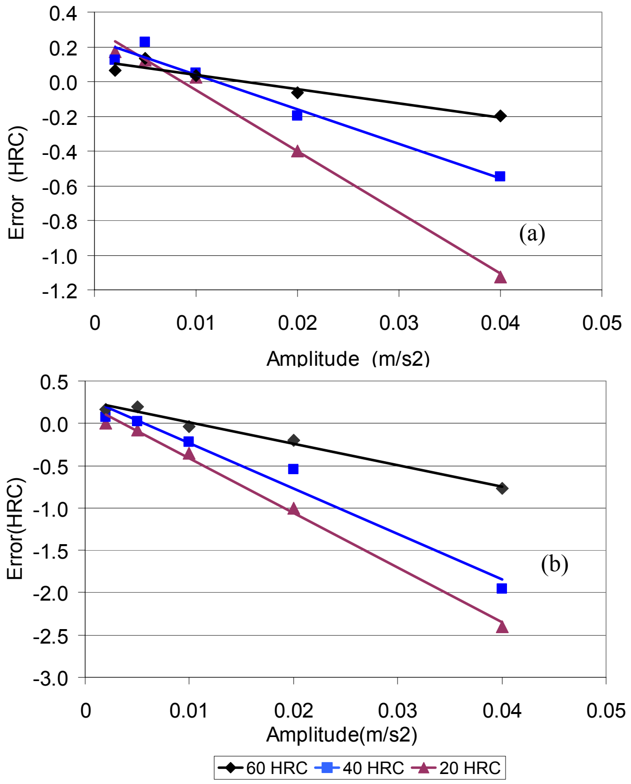

Fig. 7. Errors of hardness measurement with varied amplitude from 0.002 to 0.04 m/s^2 of analog-displayed hardness tester a) at frequency 7 Hz b) at frequency 9 Hz.

As shown in the result in both deadweight-typed machine, vibration at frequency 10±5 Hz leads to the lower hardness value compared to one measured without vibration excitation. This might be the result from vibration causing the deadweight of total test force to bounce, so the actual total test force is increased. As the sensitivity coefficient of total force, the measured hardness value will be lower than actual value. Besides, the degree of error for 20 HRC, 40 HRC, and 60 HRC agrees to the sensitivity coefficients of total force at each hardness level.

4. CONCLUSION

In this paper, an experiment set up for determination of maximum allowable vibration acceleration and frequency for Rockwell scale C hardness measurement has been done. The effect of vibration on hardness measurement can be observed in lower range of frequency for both hardness testing machine which are different in manufacturer, size and weight. All the errors found are in negative, or in the another word, the hardness tester under vibration condition gives the softer than expected result. The error obviously occurs at 10±5 Hz frequency with vibration amplitude only at 0.01 m/s^2 or 0.001 g_n. For high frequency range, 20-100 Hz, at all vibration amplitude lower than 0.04 m/s^2, there is no observation of significant error. Moreover, the different hardness range causes the different magnitude of error. The softer range block will be more influenced by vibration than harder range one.

This experiment shows that even though allowable vibration acceleration, 0.005 gn (or 0.05 m/s^2) as in Vickers hardness measurement ISO 6507: 2005 is applied to Rockwell scale C, measured value might still be deviated more than the specified tolerance as in ISO6508: 2005. Thus, it is insufficient to specify only acceleration as a vibration limit, but the frequency could be included. From this paper, the recommendation for Rockwell hardness measurement is to avoid vibration amplitude over 0.01 m/s^2 for frequency lower than 15 Hz and 0.05 m/s^2 (as in Vickers hardness measurement) for other frequency.

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