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THE UNCERTAINTY OF PITCH AND YAW RE-EVALUATED FOR PRIMARY ROCKWELL HARDNESS STANDARD SYSTEM IN CMS

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Abstract – The Primary Rockwell Hardness Standard System was set up in the Center for Measurement Standards since July 1996 till June 1997. During the time, a laser interferometer, HP10737R 3-axis compact interferometer system was used to measure the effect of pitch and yaw of the Rockwell Hardness machine .

As the laser interferometer was performed the measurement of the pitch and yaw of the indenter when the hardness was measured; then we evaluated the uncertainty caused from the Abbe's error through pitch and yaw measurements. In this paper, we will compare the results to the results of 2003 and to evaluate the aging effect of the indenter axis during seven years' used.

Keywords: **Rockwell hardness, 3-axis compact interferometer, indenter axis**

1. INTRODUCTION

The Rockwell hardness number is calculated from the difference in the penetration depths before and after application of the total maintaining force. For scales that use a proper diamond indenter, the Rockwell hardness number is determined by [1-3]:

$$HRC = K_1 - (h_1 - h_0)/K_2 \quad (1)$$

where
HRC: Rockwell hardness unit;
h_0: penetration depth of preloading in mm;
h_1: penetration depth of total loading in mm;
K_1 = 100 mm: for diamond cone indenter;
K_2 = 0,002 mm: for Rockwell hardness.

The depths h_0 and h_1 are determined by the average of the optical paths X_1, X_2 and X_3 measured by the 3-axis compact interferometer. The measurement principle can be shown in Fig. 1.

The definition of pitch and yaw were calculated by these measurements: X_1, X_2, X_3, L and d.

$$Pitch = \vartheta_y = \frac{(X_2 + X_3)/2 - X_1}{d} \quad (2)$$

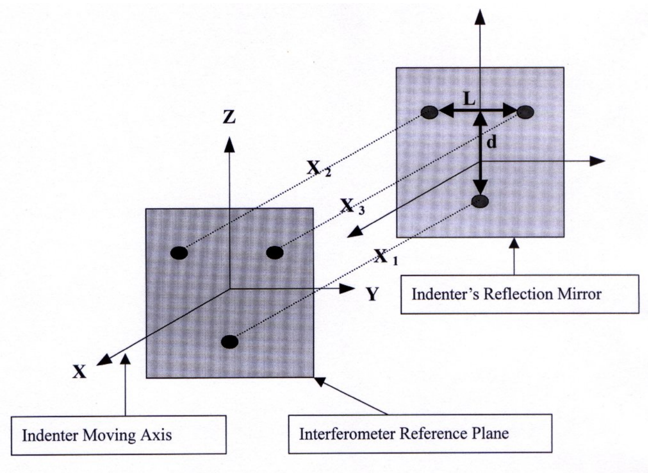

Fig. 1. The optical paths of 3-axis compact interferometer

$$Yaw = \vartheta_x = \frac{X_2 - X_3}{L} \quad (3)$$

where L and d are equal to 14,38 mm [4].

While the standard uncertainty of the hardness measurement due to the Abbe's error, u_{Abbe} , can be determined by the sum of the yaw multiplied by its own Abbe's offset and the pitch multiplied by its own Abbe's offset, divided by K_2:

$$u_{Abbe} = \frac{|\Delta X_{Abbe}| + |\Delta Y_{Abbe}|}{K_2} \quad (4)$$

with

$$\Delta X_{Abbe} = Yaw \times \Delta X = \vartheta_x \times \Delta X \quad (5)$$

$$\Delta Y_{Abbe} = Pitch \times \Delta Y = \theta_y \times \Delta Y \quad (6)$$

and
ΔX_{Abbe}: Abbe's error in yaw-direction;
ΔY_{Abbe}: Abbe's error in pitch-direction;
ΔX : Abbe's offset in yaw-direction;
ΔY : Abbe's offset in pitch-direction.

2. EXPERIMENT SETUP

The primary Rockwell hardness standard system WAS modified the grating length measurement instrument by the interferometer system was shown in Fig. 2. The interferometer system, which was calibrated, includes the laser head 3-axis compact interferometer and the optical signal receivers. The indenter, test block plate and the loading weights are below the interferometer system. The control system was in the right size that can control the loading time by dialling the panel switches.

Fig. 2. Primary Rockwell Hardness Standard System in CMS.

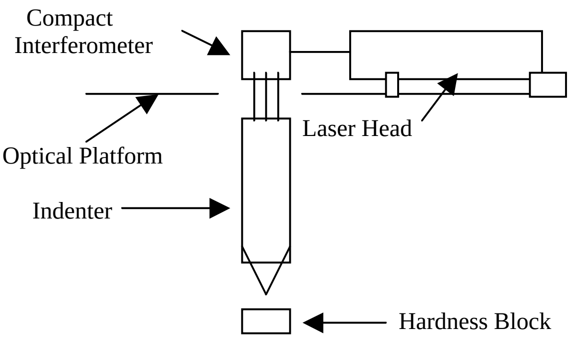

Fig. 3. Setup for the depth measurement

The corresponding optical path was shown in Fig. 3. Flatness of the optical table was measured, and these results caused an effect on the evaluation of cosine's uncertainty. The 3-axis compact interferometer was used to measure the depth and the pitch and yaw when the indenter was moving. The signals of the depths were measured and transferred to a PC by optical receivers and all of the data were calculated automatically. The typical three depths (X_1, X_2 and X_3), as shown in Fig. 4, were recorded during the hardness measurement. Substituting these values to (2) and (3) we can calculate the values of the pitch and yaw.

3. RESULTS

The pitch and yaw for individual HRA, HRB and HRC were measured during the hardness measurement. Each measurement includes eighteen to twenty-five datum. The maximum of each pitch and yaw in one hardness measurement. These results of the pitch and yaw are plotted in Fig. 4, Fig. 5 and Fig. 6. In these figures, the diamond and square dots lines are the pitch and yaw of HR in 2003, the cross dots lines are the pitch of HR and the triangle dots lines are the pitch and yaw of HR in 2010.

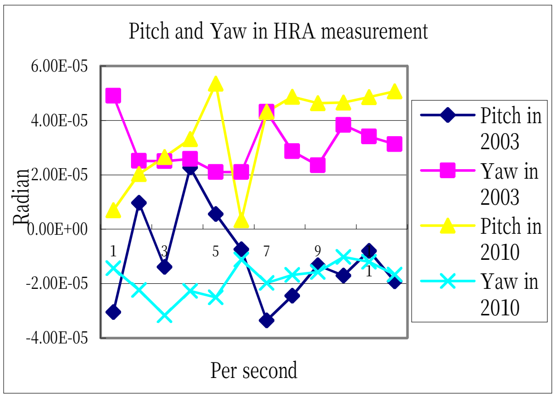

Fig. 4. Pitch and Yaws of HRA in 2003 and 2010.

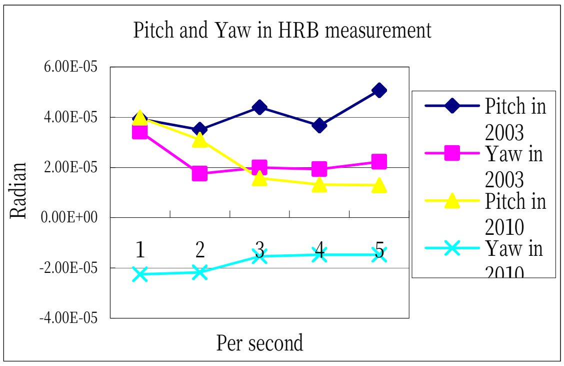

Fig. 5. Pitch and Yaws of HRB in 2003 and 2010.

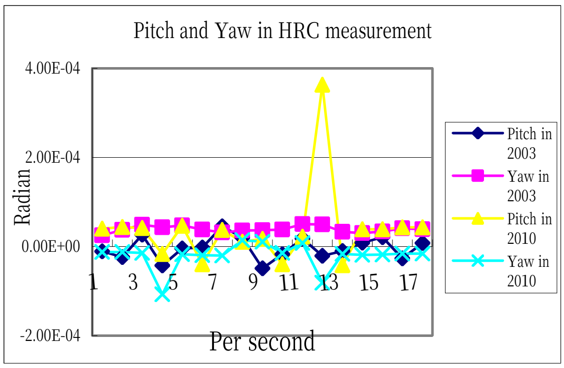

Fig. 6. Pitch and Yaws of HRC in 2003 and 2010.

TABLE I. The results of the pitch and yaw for HRA

Year		2003		2010	
Nominal value	Count	Pitch	Yaw	Pitch	Yaw
HRA 87	1	-3,05E-5	4,91E-5	7,04E-6	-1,43E-5
	2	9,70E-6	2,51E-5	2,03E-5	-2,23E-5
	3	-1,39E-5	2,50E-5	2,66E-5	-3,16E-5
	4	2,27E-5	2,58E-5	3,31E-5	-2,27E-5
	5	5,55E-6	2,1E-5	5,35E-5	-2,50E-5
	6	-7,4E-6	2,1E-5	3,30E-6	-1,12E-5
HRA 76	1	-3,35E-5	4,32E-5	4,31E-5	-1,97E-5
	2	-2,45E-5	2,87E-5	4,87E-5	-1,68E-5
	3	-1,33E-5	2,35E-5	4,63E-5	-1,57E-5
	4	-1,70E-5	3,83E-5	4,66E-5	-1.02E-5
	5	-8,0E-6	3,41E-5	4,86E-5	-1,20E-5
	6	-1,92E-5	3,13E-5	5,07E-5	-1,67E-5
Max. value		-3,05E-5	4,91E-5	5,35E-5	-3,16E-5

TABLE II. The results of the pitch and yaw for HRB

Year		2003		2010	
Nominal value	Count	Pitch	Yaw	Pitch	Yaw
HRB 90	1	3,93E-5	3,42E-5	3,99 E-5	-2,25E-5
	2	3,50E-5	1,75E-5	3,10 E-5	-2,17 E-5
	3	4,39E-5	2,00E-5	1,58 E-5	-1,54 E-5
	4	3,66E-5	1,93E-5	1,32 E-5	-1,47 E-5
	5	5,07E-5	2,22E-5	1,29 E-5	-1,47 E-5
Max. value		5,07E-5	3,42E-5	3,99 E-5	-2,25E-5

TABLE III. The results of the pitch and yaw for HRC

Year		2003		2010	
Nominal value	Count	Pitch	Yaw	Pitch	Yaw
HRC 65	1	-1,06E-5	2,54E-5	4,02E-5	-1,20E-5
	2	-2,34E-5	3,72E-5	4,40E-5	-1,20E-5
	3	2,67E-5	4,86E-5	4,20E-5	-1,41E-5
	4	-4,26E-5	4,30E-5	-1,66E-5	-1,07E-4
	5	-4,26E-6	4,72E-5	4,65E-5	-1,73E-5
HRC 46	1	-2,13E-6	3,80E-5	-3,97E-5	-1,94E-5
	2	4,50E-5	3,15E-5	3,77E-5	-2,01E-5
	3	2,05E-5	3,63E-5	1,11E-5	1,43E-5
	4	-4,91E-5	3,65E-5	1,71E-5	1,10E-5
	5	-1,70E-5	3,83E-5	-3,95E-5	-1,41E-5
	6	1,80E-5	5,02E-5	2,23E-5	8,00E-6
HRC 20	1	-2,11E-5	5,00E-5	3,63E-4	-8,10E-5
	2	-1,00E-5	3,33E-5	-4,19E-5	-1,68E-5
	3	8,83E-6	3,03E-5	3,91E-5	-1,84E-5
	4	2,08E-5	3,36E-5	3,92E-5	-1,81E-5
	5	-2,67E-5	4,11E-5	4,32E-5	-1,57E-5
	6	8,1E-6	3,86E-5	4,32E-5	-1,58E-5
Max. value		-4,91E-5	5,02E-5	3,63E-4	-1,94E-5

The data number of the pitch and yaw of the hardness measurement for HRA, HRB and HRC are twelve, five and seventeen respectively. The results of the pitch and yaw for the nominal values HRA 87 and HRA 76 are listed in TABLE I, and the maximum values of the pitch and yaw pairs are ($-3{,}05 \times 10^{-5}$, $4{,}91 \times 10^{-5}$) radian in 2003 and $5{,}35 \times 10^{-5}$, $-3{,}16 \times 10^{-5}$) radian in 2010 respectively. The results of the pitch and yaw for the nominal value HRB 90 are listed in TABLE II, and the maximum values of the pitch and yaw pairs are ($5{,}07 \times 10^{-5}$, $3{,}42 \times 10^{-5}$) radian in 2003 and ($1{,}32 \times 10^{-5}$,$-1{,}47 \times 10^{-5}$) radian in 2010 respectively. The results of the pitch and yaw for the nominal values HRC 65, HRC 46 and HRC 20 are listed in TABLE III, and the maximum values of the pitch and yaw pairs are ($-4{,}91 \times 10^{-5}$, $5{,}02 \times 10^{-5}$) radian in 2003 and ($3{,}63 \times 10^{-5}$, $-1{,}94 \times 10^{-5}$) radian in 2010 respectively. These maximum values can be combined with the Abbe's offset [6] to calculate the Abbe's uncertainty. Then the uncertainties can be determined for the related HRA, HRB and HRC units. The following is evaluated the standard uncertainty due to Abbe's error of the hardness measurement for HRA:

$$(Pitch_{Max})_{HRA2003} = -3{,}05 \times 10^{-5};$$

$$(Yaw_{Max})_{HRA2003} = 4{,}91 \times 10^{-5}$$

$$\Delta X_{Max} = 0{,}6 \text{ mm}; \Delta Y_{Max} = 0{,}3 \text{ mm}$$

$$(u_{Abbe})_{HRA2003} = \frac{\Delta X_{Abbe} + \Delta Y_{Abbe}}{K_2}$$

$$= \frac{|(Yaw_{Max})_{HRA} \times \Delta X_{Max}| + |(Pitch_{Max})_{HRA} \times \Delta Y_{Max}|}{K_2}$$

$$= 0{,}020 \text{ HRA}$$

and

$$(Pitch_{Max})_{HRA2010} = 5{,}35 \times 10^{-5};$$

$$(Yaw_{Max})_{HRA2010} = 3{,}16 \times 10^{-5}$$

$$\Delta X_{Max} = 0.6 \text{ mm}; \Delta Y_{Max} = 0.3 \text{ mm}$$

$$(u_{Abbe})_{HRA2010} = \frac{\Delta X_{Abbe} + \Delta Y_{Abbe}}{K_2}$$

$$= \frac{|(Yaw_{Max})_{HRA} \times \Delta X_{Max}| + |(Pitch_{Max})_{HRA} \times \Delta Y_{Max}|}{K_2}$$

$$= 0{,}052 \text{ HRA}$$

where

$(Pitch_{Max})_{HRA}$: the maximum value of the pitch for HRA;

$(Yaw_{Max})_{HRA}$: the maximum value of the yaw for HRA;

ΔX_{Max} : the maximum value of the Abbe's offset in yaw-direction;

ΔY_{Max} : the maximum value of the Abbe's offset in pitch-direction;

$(u_{Abbe})_{HRA}$: standard uncertainty caused by the Abbe's error for HRA.

The effects of pitch and yaw on the hardness were listed on the TABLE IV.

TABLE III. The effects of the pitch and yaw on Hardness

Year and HR	HRA	HRB	HRC
2003	0.020	0.018	0.023
2010	0.052	0.014	0.120

4. RESULT AND OUTLOOKS

Using the 3-axis compact interferometer system, we got an easy method to evaluate the uncertainty of the hardness measurement due to the Abbe's uncertainty. During the procedure, we had got a maximum pair pitch and yaw when we took the first measurements from HRC20. This effect maybe caused by the system after sequentially seventeen HRC measured. Another effect is the first measurement of HRC was not contact with the platform perfectly. After these measurement, we claim the uncertainty from optical measurement 0.1 HR to 0.2 HR. There are more aging effect on HRC measurement than HRB and HRC measurement according these information. After this work, we will trace and measure this effect and get more complete information of the primary Rockwell hardness standard system.

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