XX IMEKO World Congress
Metrology for Green Growth
September 9–14, 2012, Busan, Republic of Korea

DEVELOPMENT OF METHOD FOR DETERMINATION OF PRESSURE BALANCE PISTON FALL RATE

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Abstract: This paper describes internal method for determination of pressure balance piston fall rate using simple camera-based optical system with laboratory developed software. Measurements were carried out on three standard piston/cylinder units in Croatian National Pressure Laboratory (LPM) using gas and oil as transmitting medium.

Measurement equipment, procedure and fall rate results for three set of measurements are given as well as evaluation of measurement uncertainty. Results were compared with other relevant measurements.

Keywords: pressure balance, fall rate measurement, Sobel filter

1. INTRODUCTION

Determination of pressure balance piston fall rate is important due to several reasons. As internal measure for quality insurance it can indicate some deformation or changes in effective area, and in the "cross-float" calibration of other pressure balances where the fall-rate obtained when the two balances are connected is compared with the natural fall-rate. If the fall-rates differ, small masses can be added to or subtracted from one of the pressure balance, and the measurements should be repeated until the fall-rates agree. [2].

For periodical determination of LPM standard units fall-rates it was necessary to develop simple, efficient, repeatable and precise enough method.

Since there is no standard procedure for this measurements, there was no limitation in selection of equipment. Piston rate of fall is usually determined with laser sensors or expensive optic.

Equipment that was taken into consideration in this work were eddy current sensors and different cameras.

Analyzing measurement possibilities regarding accuracy, accessibility and price, simple camera was chosen.

2. MEASUREMENT METHOD AND CALCULATION PROCEDURE

Measurements were performed with amateur camera equipped with appropriate lenses. Plan parallel gauge block with 1,5 mm thickness was used to connect relative motion into real displacement in millimeters. Before measurement, while piston was in stand-up position, snap of standard gauge block was taken.

Pictures were analyzed using Matlab software which has inbuilt and predefined functions for various filters. In this measurement Sobel filter was used. This filter is often used for edge detection. Utilization of edge detection enable following of relative movement of pressure balance edges through continuous pictures.

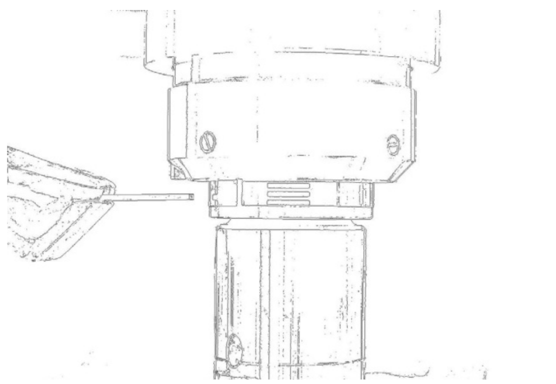

Figure 1. Photography of pressure balance and plan parallel gauge block with applied Sobel filter

After implementation of Sobel filter, simple method for transforming real thickness into pixel thickness was applied. Number of pixels for movement between pictures can be calculated and converted into millimeters.

Two different results were obtained. For two measurements, thickness of standard gauge block was 16 pixels and for one it was 15 pixels. That shows that achieved resolution of described equipment was at least 0,1 mm.

Taking pictures interval was a little bit longer than one minute, so that adequate number of pictures can be acquired to achieve good accuracy. For the analysis of each measurement, pictures with 3 seconds interval between them were used, which means there were 20 measurement points in one minute.

The initial concept was to take 60 measurement points in a minute to precisely follow the movement of pressure balance piston. Due to computer and camera limitations, 3 seconds interval between pictures, the highest possible with used equipment, was achieved. To avoid any contact with camera, all adjusting parameters and beginning of the photographing process was done via computer which was connected to camera all the time.

Every setting was adjusted by appropriate software that allowed camera control via cable. This way fixed position of camera, which was critical for the applied method of measurement, was assured. After all the photographs were taken and treated using Sobel filter we had 20 continuous pictures for each measurement with relative movement in pixels. To avoid accidental movement of camera or imperfections of edges visible on pictures, x axis was kept constant. That way, possible distortions on photographs would be constant through whole y axis movement in order to avoid errors. Relative motion in pixels on y axis was calculated to mm for every two consecutive pictures.

Measurements were performed on three different piston/cylinder effective areas including oil and gas pressure balances. Oil pressure balance was designed by Budenberg with double piston for 600 bar and 60 bar loads. Gas pressure balance that was used in this work was DHI PG7601 with 3 bar load. DHI standard pressure balance is equipped with internal fall rate measuring sensor so we had an opportunity to compare results obtained with proposed method with those obtained from DHI pressure balance. Fall rate on oil unit was compared with last calibration certificates from PTB institute.

3. FALL RATE RESULTS AND MEASUREMENT UNCERTAINTY EVALUATION

In this paragraph results for three standard piston/cylinder units are presented as well as measurement uncertainty evaluation.

Fall rate measurement uncertainty, u_F, was evaluated as Type B uncertainty [3] taking into account gauge block uncertainty, camera resolution and time measurements as main influence quantities.

$$u_F = \sqrt{u_g^2 + u_r^2 + u_t^2} \qquad (1)$$

Where:

u_g -is uncertainty of planparalel gauge block
u_f -is uncertainty due to resolution
u_t -uncertainty due to time measurement

3.1. Oil operated system up to 600 bar

Measurements performed on Budenberg standard pressure balance with 600 bar load has high rate of fall, as expected. It was clearly visible without any equipment. Results can be compared with results given in calibration certificate given from Physikalisch-Technische Bundesanstalt Institut (PTB Institute). These results were 3±0,5 mm/min. Results from LPM first unit are given in the following Table.

Table 1. Determination of oil piston fall rate at 600 bar load

Sec	Measurement 1			Measurement 2			Measurement 3		
	x	y	Δy [mm]	x	y	Δy [mm]	x	y	Δy [mm]
0	760	352	0,00	760	349	0,00	760	353	0,00
3	760	354	0,19	760	350	0,09	760	355	0,19
6	760	357	0,47	760	353	0,38	760	358	0,47
9	760	359	0,66	760	355	0,56	760	360	0,66
12	760	361	0,84	760	357	0,75	760	362	0,84
15	760	363	1,03	760	359	0,94	760	364	1,03
18	760	365	1,22	760	361	1,13	760	366	1,22
21	760	367	1,41	760	363	1,31	760	369	1,50
24	760	370	1,69	760	365	1,50	760	370	1,59
27	760	372	1,88	760	367	1,69	760	373	1,88
30	760	374	2,06	760	369	1,88	760	375	2,06
33	760	376	2,25	760	371	2,06	760	377	2,25
36	760	378	2,44	760	373	2,25	760	378	2,34
39	760	379	2,53	760	375	2,44	760	380	2,53
42	760	381	2,72	760	377	2,63	760	382	2,72
45	760	383	2,91	760	379	2,81	760	384	2,91
48	760	385	3,09	760	381	3,00	760	386	3,09
51	760	387	3,28	760	383	3,19	760	387	3,19
54	760	388	3,38	760	385	3,38	760	390	3,47
57	760	390	3,56	760	386	3,47	760	392	3,66
60	760	393	**3,84**	760	389	**3,75**	760	394	**3,84**

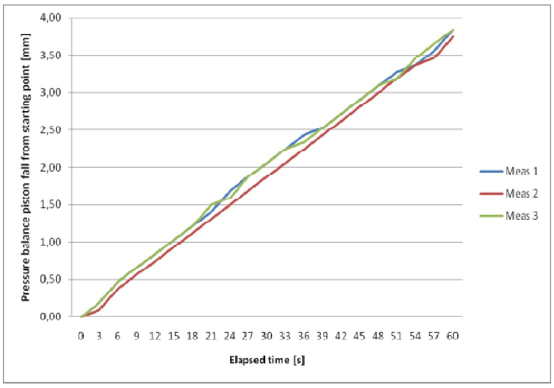

Figure 2. Determination of oil piston fall rate at 600 bar load

From the result it can be seen that fall rate is too big for pressure balance classified into accuracy class of 0,02. Maximum piston fall rate defined in [1] is 1,5 mm/min.

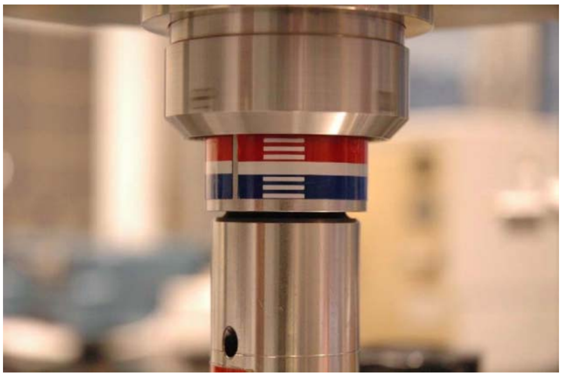

Figure 3. Start of measurement (first photograph) of Budenberg pressure balance with 600 bar load

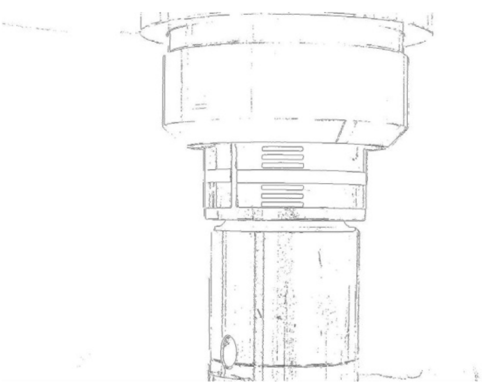

Figure 4. Start of measurement (first photograph) of Budenberg pressure balance with 600 bar load – Sobel filter applied

Uncertainty estimation is given in Table 2 only for first piston/cylinder unit although is calculated for each unit separately with different sensitivity coefficient for measurement of time.

Table 2. Fall rate uncertainty evaluation

Influence quantity	Uncertainty of the influence quantity	Factor	Sensitivity coefficient	Contribution to the standard uncertainty
Planparalel gauge block	0,1 µm	$\sqrt{3}$	1	0,06 µm
Resolution	0,1 mm	$\sqrt{3}$	1	57,8 µm
Time	0,5 s	$\sqrt{3}$	0,06 mm/s	17,3 µm
	Fall rate uncertainty		u_F	60 µm
	Expanded fall rate measurement uncertainty (k=2)		$U_F=2\cdot u_F$	0,12 mm

3.2 Oil operated system up to 60 bar

Second measurement is performed on the same Budenberg oil unit but using low pressure range up to 60 bar maximum load. PTB results for this unit were 0,26 ± 0,1 mm/min. Results assigned after pictures analysis are shown in the following table.

Table 3. Determination of oil piston fall rate at 60 bar load

Sec	Measurement 1			Measurement 2			Measurement 3		
	x	y	Δy [mm]	x	y	Δy [mm]	x	y	Δy [mm]
0	760	492	0,00	760	487	0,00	760	487	0,00
3	760	492	0,00	760	488	0,10	760	487	0,00
6	760	492	0,00	760	488	0,10	760	487	0,00
9	760	492	0,00	760	488	0,10	760	487	0,00
12	760	492	0,00	760	488	0,10	760	487	0,00
15	760	493	0,10	760	488	0,10	760	487	0,00
18	760	493	0,10	760	488	0,10	760	488	0,10
21	760	493	0,10	760	488	0,10	760	488	0,10
24	760	493	0,10	760	488	0,10	760	488	0,10
27	760	493	0,10	760	488	0,10	760	488	0,10
30	760	493	0,10	760	489	0,20	760	488	0,10
33	760	493	0,10	760	489	0,20	760	488	0,10
36	760	494	0,20	760	489	0,20	760	488	0,10
39	760	494	0,20	760	489	0,20	760	488	0,10
42	760	494	0,20	760	489	0,20	760	489	0,20
45	760	494	0,20	760	489	0,20	760	489	0,20
48	760	494	0,20	760	489	0,20	760	489	0,20
51	760	494	0,20	760	489	0,20	760	489	0,20
54	760	494	0,20	760	489	0,20	760	489	0,20
57	760	494	0,20	760	490	0,30	760	489	0,20
60	760	495	**0,30**	760	490	**0,30**	760	490	**0,30**

Good agreement between PTB and LPM results can be seen in this case.

3.3 Gas operated standard system up to 3 bar

Third set of measurements were performed on gas operated DHI pressure balance with maximum load of 3 bar. This unit is equipped with internal fall rate sensor and all the results were directly compared. Results assigned after pictures analysis are shown in the following table.

Table 4. Determination of DHI PG7601 gas piston fall rate at 3 bar load

Sec	Measurement 1			Measurement 2			Measurement 3		
	x	y	Δy [mm]	x	y	Δy [mm]	x	y	Δy [mm]
0	760	495	0,00	760	496	0,00	760	495	0,00
3	760	495	0,00	760	496	0,00	760	496	0,09
6	760	495	0,00	760	496	0,00	760	496	0,09
9	760	496	0,09	760	496	0,00	760	496	0,09
12	760	496	0,09	760	497	0,09	760	496	0,09
15	760	496	0,09	760	497	0,09	760	497	0,19
18	760	497	0,19	760	497	0,09	760	497	0,19
21	760	497	0,19	760	497	0,09	760	497	0,19
24	760	497	0,19	760	498	0,19	760	498	0,28
27	760	498	0,28	760	498	0,19	760	498	0,28
30	760	498	0,28	760	498	0,19	760	498	0,28
33	760	498	0,28	760	499	0,28	760	499	0,38
36	760	499	0,38	760	499	0,28	760	499	0,38
39	760	499	0,38	760	499	0,28	760	499	0,38
42	760	499	0,38	760	500	0,38	760	500	0,47
45	760	500	0,47	760	500	0,38	760	500	0,47
48	760	500	0,47	760	500	0,38	760	500	0,47
51	760	500	0,47	760	501	0,47	760	500	0,47
54	760	501	0,56	760	501	0,47	760	501	0,56
57	760	501	0,56	760	501	0,47	760	501	0,56
60	760	501	**0,56**	760	502	**0,56**	760	501	**0,56**

In this measurement relative movement was 0,094 mm for one pixel, and internal fall rate sensor has precision of 0,1 mm. This prevented direct comparison. As it can be seen from the results in table, pressure balance fall rate is 0,56 mm/min, and internal fall rate sensor started changing it's value from 0,5 to 0,6 mm after one minute and three seconds.

Maximum piston fall rate for gas operated systems according to OIML document is 1 mm/min.

Comparing the results in all three cases with results from the calibration certificates, as well as from comparison with internal fall rate sensor in DHI pressure balance, it can be seen that new method is precisely enough for further development.

4. CONCLUSIONS

Internal laboratory method for determination of fall rate with target uncertainty of 0,1 mm/min using camera based optical system is developed in LPM.
The advantages of the proposed method are in simple and cheap measurement equipment.

Measurement results obtained with proposed method are showing good agreement with other relevant measurements.

Disadvantages are found in choice of lenses and further development of method related to automatization of measurements can be done.

5. REFERENCES

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[3] ISO Guide to the Expression of Uncertainty in Measurement, Geneva: ISO, 1995.