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Development of a method for the determination of the pressure balance piston fall rate

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ABSTRACT
This paper describes a laboratory method for the determination of the pressure balance piston fall rate using a simple camera-based optical system with internally developed software. Measurements were carried out on three standard piston/cylinder units in the Croatian National Pressure Laboratory (LPM) using gas and oil as transmitting medium.
Measurement equipment, procedure and fall rate results for three sets of measurements are given, as well as an evaluation of the measurement uncertainty. Results were compared with other relevant measurements.

Section: RESEARCH PAPER

Keywords: Pressure balance; Fall rate measurement; Sobel filter

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1. INTRODUCTION

The determination of the pressure balance piston fall rate is important for to several reasons. As an internal measure for quality assurance it indicates some deformation or changes in effective area [1], and in the "cross-float" calibration of other pressure balances where the fall rate is obtained when the two balances are connected and 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 the LPM standard unit fall rates and for internal quality assurance it was necessary to develop a simple, efficient, repeatable and precise enough method.

Since there is no standard procedure for this measurement, there was no limitation in selecting equipment. Piston rate of fall is usually determined with laser sensors or expensive optic. Further equipment that was also taken into consideration in this work comprises eddy current sensors and different cameras.

A simple camera has been chosen for analysing measurement possibilities regarding accuracy, accessibility and price.

2. MEASUREMENT METHOD AND CALCULATION PROCEDURE

Measurements were performed with an amateur camera (Nikon Digital Camera) equipped with appropriate lenses. A plane parallel gauge block with 1.5 mm thickness was used to relate relative motion to real displacement in millimetres. Before the measurement, while the piston was in stand-up position, a snap of the standard gauge block was taken.

Pictures were analysed using Matlab software which has inbuilt and predefined functions for various filters. In this measurement a Sobel filter was used. This filter is often used for edge detection. Edge detection enables to follow the relative movement of the pressure balance edges through continuous pictures.

After implementation of the Sobel filter, a simple method for transforming real thickness into pixel numbers was applied. From the number of pixels the movement between pictures can be calculated and converted into millimetres.

Two different results were obtained. For two consecutive measurements on the same gauge, the thickness of the standard gauge block was found to be 16 pixels and 15 pixels,

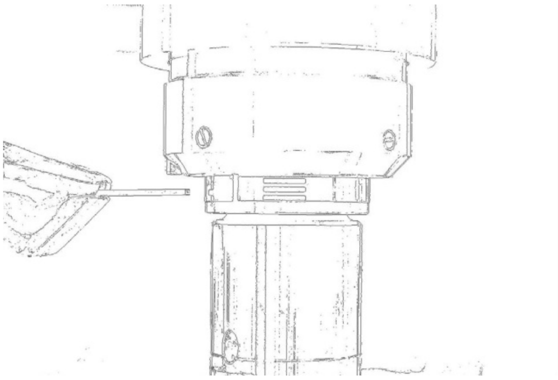

Figure 1. Computer image of the pressure balance and the plane parallel gauge block with applied Sobel filter.

respectively. This shows that a resolution of the described equipment of at least 0.1 mm was achieved.

The interval between two consecutive pictures was somewhat longer than one minute, so an adequate number of pictures can be acquired to achieve good accuracy. For the analysis of each measurement result, picture intervals of 3 seconds were used, which means 20 measurement points per minute.

The initial concept was to take 60 measurement points in a minute to precisely follow the movement of the pressure balance piston. Due to computer and camera limitations, the smallest possible interval between pictures with this equipment was 3 seconds. To avoid any contact with the camera, all adjusting parameters and the start of the photographing process were controlled by a computer connected to the camera.

Every setting was adjusted by appropriate software that allowed camera control via a cable. In this way a fixed position of the camera was assured, which is critical for the applied measurement method. After all the photographs were taken and have passed the Sobel filter (Figure 1), a series of 20 pictures for each measurement was obtained with information about the relative movement in pixels. To avoid accidental movement of the camera or imperfections of edges visible on the pictures, the *x*-axis was kept constant. In this way, possible distortions of the pictures are constant over the whole *y*-axis movement, avoiding errors. The relative motion in pixels on the *y*-axis was converted into mm for every two consecutive pictures.

Measurements were performed on three different effective areas of the piston/cylinder, including oil and gas pressure

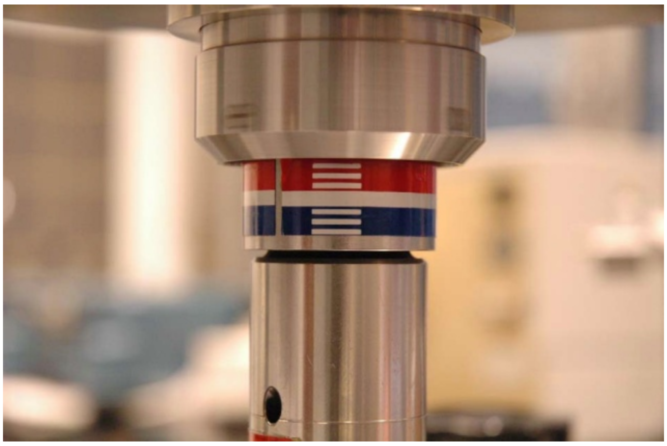

Figure 3. Start of measurement (first photograph) of the Budenberg pressure balance with 600 bar load.

balances (Figure 2). The oil pressure balance was designed by Budenberg with a double piston for 600 bar and 60 bar loads (Figure 3 and Figure 4). The gas pressure balance that was used in this work was a DHI PG7601 with 3 bar load. The DHI standard pressure balance is equipped with an internal fall rate sensor so we had an opportunity to compare results obtained between the proposed method and those obtained from the DHI pressure balance. The fall rate of the oil unit was compared with the last calibration certificates from the Physikalisch-Technische Bundesanstalt (PTB).

3. FALL RATE RESULTS AND MEASUREMENT UNCERTAINTY EVALUATION

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

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

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

where:

u_g - uncertainty of the plane parallel gauge block
u_r - uncertainty due to resolution
u_t -uncertainty due to the time measurement

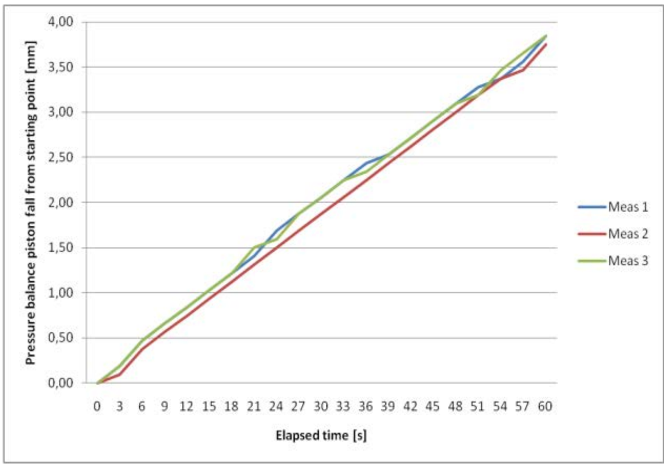

Figure 2. Determination of oil piston fall rate at 600 bar load.

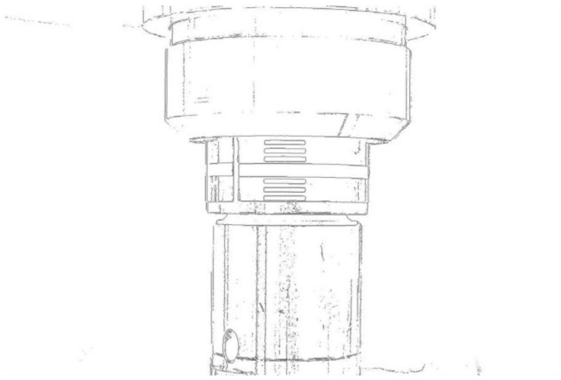

Figure 4. Start of the measurement (computer image) of the Budenberg pressure balance with 600 bar load after application of the Sobel filter.

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

s	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**

3.1. Oil operated system up to 600 bar

Measurements performed on the Budenberg standard pressure balance with 600 bar load has a high rate of fall, as expected. This was clearly visible without any equipment. Results can be compared with results given in the calibration certificate obtained from the PTB. These results were (3.0 ± 0.5) mm/min. Results from the LPM first unit are given in Table 1.

From this result it can be seen that the fall rate is too large for a pressure balance classified in the accuracy class of 0.02. The maximum piston fall rate defined in [1] is 1.5 mm/min.

The uncertainty estimation is given in Table 2, only for the first piston/cylinder unit, although it is calculated for each unit separately with different sensitivity coefficient for the time measurement.

Table 2. Fall rate uncertainty evaluation.

Influence quantity	Uncertainty of the influence quantity	Factor	Sensitivity coefficient	Contribution to the standard uncertainty
Plane parallel 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

The second measurement is performed on the same Budenberg oil unit but using a low pressure range up to 60 bar maximum load. Results from the PTB for this unit were (0.26 ± 0.10) mm/min. Results obtained from the picture analysis are shown in Table 3.

Good agreement between the results of PTB and LPM can be observed.

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

s	Measurement 1			Measurement 2			Measurement 3		
	x	y	Δy [mm]	x	y	Δy [mm]	x	y	Δy [mm]
0	760	492	0.0	760	487	0.0	760	487	0.0
3	760	492	0.0	760	488	0.1	760	487	0.0
6	760	492	0.0	760	488	0.1	760	487	0.0
9	760	492	0.0	760	488	0.1	760	487	0.0
12	760	492	0.0	760	488	0.1	760	487	0.0
15	760	493	0.1	760	488	0.1	760	487	0.0
18	760	493	0.1	760	488	0.1	760	488	0.1
21	760	493	0.1	760	488	0.1	760	488	0.1
24	760	493	0.1	760	488	0.1	760	488	0.1
27	760	493	0.1	760	488	0.1	760	488	0.1
30	760	493	0.1	760	489	0.2	760	488	0.1
33	760	493	0.1	760	489	0.2	760	488	0.1
36	760	494	0.2	760	489	0.2	760	488	0.1
39	760	494	0.2	760	489	0.2	760	488	0.1
42	760	494	0.2	760	489	0.2	760	489	0.2
45	760	494	0.2	760	489	0.2	760	489	0.2
48	760	494	0.2	760	489	0.2	760	489	0.2
51	760	494	0.2	760	489	0.2	760	489	0.2
54	760	494	0.2	760	489	0.2	760	489	0.2
57	760	494	0.2	760	490	0.3	760	489	0.2
60	760	495	**0.3**	760	490	**0.3**	760	490	**0.3**

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

s	Measurement 1			Measurement 2			Measurement 3		
	x	y	Δy [mm]	x	y	Δy [mm]	x	y	Δy [mm]
0	670	495	0.00	670	496	0.00	670	495	0.00
3	670	495	0.00	670	496	0.00	670	496	0.09
6	670	495	0.00	670	496	0.00	670	496	0.09
9	670	496	0.09	670	496	0.00	670	496	0.09
12	670	496	0.09	670	497	0.09	670	496	0.09
15	670	496	0.09	670	497	0.09	670	497	0.19
18	670	497	0.19	670	497	0.09	670	497	0.19
21	670	497	0.19	670	497	0.09	670	497	0.19
24	670	497	0.19	670	498	0.19	670	498	0.28
27	670	498	0.28	670	498	0.19	670	498	0.28
30	670	498	0.28	670	498	0.19	670	498	0.28
33	670	498	0.28	670	499	0.28	670	499	0.38
36	670	499	0.38	670	499	0.28	670	499	0.38
39	670	499	0.38	670	499	0.28	670	499	0.38
42	670	499	0.38	670	500	0.38	670	500	0.47
45	670	500	0.47	670	500	0.38	670	500	0.47
48	670	500	0.47	670	500	0.38	670	500	0.47
51	670	500	0.47	670	501	0.47	670	500	0.47
54	670	501	0.56	670	501	0.47	670	501	0.56
57	670	501	0.56	670	501	0.47	670	501	0.56
60	670	501	**0.56**	670	502	**0.56**	670	501	**0.56**

3.3. Gas operated standard system up to 3 bar

Third set of measurements was performed on the gas operated DHI pressure balance with a maximum load of 3 bar. This unit is equipped with an internal fall rate sensor and all the results were directly compared. Results obtained after pictures analyses are shown in Table 4.

In this measurement, the relative movement was 0.094 mm for one pixel, and the internal fall rate sensor has a precision of 0.1 mm. This prevented direct comparison. As it can be seen from the results in Table 3, the pressure balance fall rate is 0.56 mm/min, and the internal fall rate sensor started changing its value from 0.5 mm to 0.6 mm after one minute and three seconds.

The maximum piston fall rate for gas operated systems according to the 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 the internal fall rate sensor in the DHI pressure balance, it can be concluded that new method is sufficiently accurate for further development.

4. CONCLUSIONS

An internal laboratory method for the determination of the fall rate was developed in the LPM, with a target uncertainty of 0.1 mm/min, using a camera based optical system.

The advantages of the proposed method are a simple and cheap measurement equipment.

Measurement results obtained with the proposed method show good agreement with other relevant measurements.

Disadvantages are found in the choice of lenses. Further development of the method focuses on the automation of the measurements.

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