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VOLUME MEASUREMENT OF PISTON PROVER CYLINDER BY GRAVIMETRIC METHOD FOR VALIDATION OF WATER FLOW RATE TRACEABILITY AT METROLOGY LIPI

Jalu A. Prakosa, Nur Tjahyo Eka D, Bernardus H.S, Hafid

Research Center for Metrology - Indonesian Institute of Sciences (LIPI)
Kawasan PUSPIPTEK Serpong, Banten 15314, Indonesia
jalu001@lipi.go.id, nc_eka@kim.lipi.go.id, bernadushs@yahoo.com, hafid@kim.lipi.go.id

ABSTRACT

One way to validate the volume measurement of the piston prover cylinder is using gravimetric method called water draw. The purpose of this study is to measure the volume of piston prover cylinder with gravimetric method for validation of its water flow rate measurement value and also to achieve the uncertainty target. The measurement results of piston prover cylinder volume are 92.43 litre and expanded uncertainty of 0.09 litre or 0.09% in relative. The largest contribution comes from the water mass measurement repeatability because of the possibility of evaporation and error measurement in using three-way valve as diverter. The Data collecting methods should be improved in the future.

Keywords: cylinder volume, piston prover, gravimetric, water flow rate, traceability.

INTRODUCTION

Piston prover is one type of standard that is used for water flow rate quantity measurement. This system is worked based on the principle of positive displacement, when a volume of fluid that is located inside the cylinder, is moved by a piston. Flow rate is measured by volumetric method that the piston displacement is proportional to the volume that has been moved per unit time or it's flow [1]. The displacement of piston at Metrology LIPI as Indonesian National Metrology Institute, the brand of "Flow Technology Incorporated", is measured by linear encoder so flow rate can be calculated from the data of encoder pulses[2] and collecting time as shown in Fig. 1 and 2. Frequency from linear encoder is also proportional to flow rate. This standard can calibrate many kinds of flow meter such as turbine, water meter, variable area, ultrasonic, electromagnetic flowmeters, etc [3].

Piston prover is the standard of volume flow rate quantity so it derive the quantity from volume and time. This paper will discuss about how to validate the measurement and traceability of cylinder volume of piston prover. There are some methods to measure volume of piston prover cylinder : volumetric dimentional method, gravimetric method and using flow meter. In this study, gravimetric method in water draw would be used to determine the cylinder volume of piston prover [4]. To measure water mass that moved from piston cylinder, we use electronic balance "sartorius F150S*D2" with capacity of 151 kg and 1 g resolution in Fig.3 [5]. This balance was calibrated to weights E2 that have been traceable to SI units through mass laboratory of Metrology LIPI. That water draw of piston prover can build traceability chain of water flow rate measurement in Metrology LIPI to SI units.

Piston prover facilities at Flow Laboratory of Metrology LIPI has done peer review by KRISS expert in November 2011 then the results are the measurement range of 4 ~ 1300 L/min with uncertainty of 0.12% [6]. To achieve this uncertainty target, the uncertainty measurement of each components at mathematical model also should be achieved to minimum specific value. The purpose of this study is to measure the volume of piston prover cylinder with gravimetric method for validation of its water flow rate measurement value and also to achieve the uncertainty target.

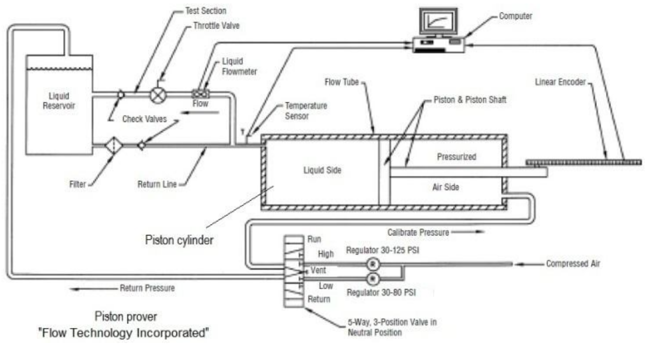

Figure. 1 Piston prover schema [1]

Figure. 2 Piston prover in Metrology LIPI

Figure. 3 Electronic balance[5]

THEORY OF WATER VOLUME FLOW RATE MEASUREMENT USING PISTON PROVER

Piston prover is a system that serves to calibrate flow meter as flowmeter calibrator. This system also works on the principle of positive displacement, where the calibrated volume of fluid located in the cylinder, is moved by a piston. To drive the piston,then used compressed air from the compressor. Piston displacement are correlated with the fluid volume that has been moved. Therefore, this system is also called piston prover [1]. In Flow Laboratory of Metrology LIPI, water has been used as fluid. See again in fig.2 for the piston prover picture.

This system used linear encoder to measure piston displacement. The number of pulses from linear encoder is proportional to the distance of the piston displacement that recorded in the data acquisition of computer. To convert pulses into volume quantity of fluid, it can use K-factor value that has unit of pulses per volume unit. The number of encoder pulses per unit time or frequency of encoder is also proportional to the volume flow rate that generated on the piston prover systems.

The volume flow rate define as volume unit per time unit so the mathematical model of water volume flow rate measurement using piston prover can be derived as this following :

$$Q_V = \frac{\Delta V}{\Delta t} = \frac{f_E .60}{\mathrm{K}} \tag{1}$$

There are effect of temperature and pressure as correction factor to the equation (2) below.

$$Q_V = \frac{f_E .60}{K_{20,0}} \cdot \frac{[1-\alpha_g(t_E-20)]}{[1-\beta_S(t_S-20)].[1-E_a.P_a].\left[1-\frac{r_S.P_S}{d_S.E_S}\right]} \tag{2}$$

Information :

- Q_V = Water volume flow rate.
- ΔV = Water volume changes.
- Δt = Travelling time.
- $K_{20,0}$= K-factor value corresponding to 20 °C dan 0 Mpa.
- αg = Linear thermal expansion coefficient of encoder.
- t_E = Encoder temperature when do calibration.
- βs = Volumetric thermal expansion coefficient of piston cylinder.
- ts = Piston cylinder temperature when do calibration.
- Ea = Water compressibility coefficient.
- Pa = Water pressure when do calibration.
- rs = Radius of piston cylinder.
- ds = Width of piston cylinder.
- Es = Constant of elasticity modulus for piston cylinder.
- Ps = Pressure at piston cylinder when do calibration.
- f_E = Frequency of linear encoder

MEASUREMENT METHOD

The volume of piston cylinder is equal to the volume of displaced water from it. The displaced water volume can be calculated from its meaures mass and density. Apply pressure about 0.14 Mpa to the piston so it will push the water to flow out to weighing tank for mass measurement. [7] Collection data of water mass measurement will be done by 23 times repeatability.

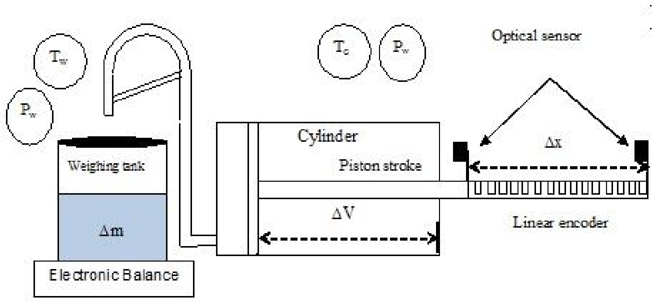

Figure. 4 Water draw diagram

Figure.5 Pipe connection between piston and tank

To control when start and stop for collecting data of water mass as diverter, three-way valve is used in Fig. 6

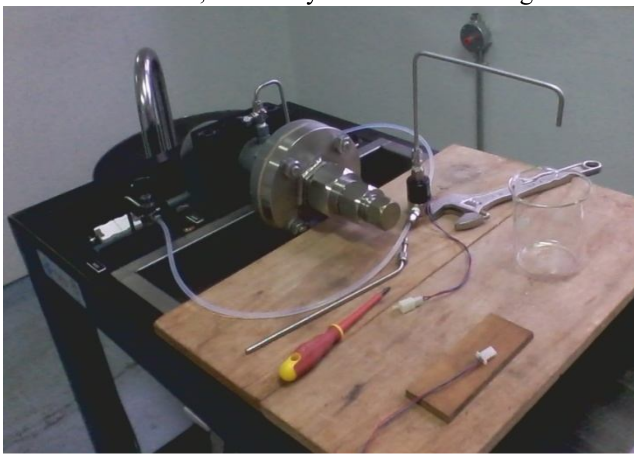

Figure. 6 Three-way valve as water flow diverter

Cylinder volume of piston prover can be calculated as this following (3) :

$$V_c = \frac{m_w}{\rho_w} \tag{3}$$

There are air buoyancy corection, so the formula should be as in (4)

$$V_c = \frac{m_w}{\rho_e} \cdot \left(\frac{\rho_e - \rho_a}{\rho_w - \rho_a} \right) \tag{4}$$

We also calculate expansion of cylinder according to temperature and pressure and water compressibility in the cylinder so the mathematical model would be as in (5).

$$V_{c,20} = \frac{m_w}{\rho_e} \cdot \left(\frac{\rho_e - \rho_a}{\rho_w - \rho_a} \right) .(1 - \beta_c .(T_c - 20)) .(1 - X_c .P_c).(1 - Z_w .P_w) \tag{5}$$

Information :
V_c = Cylinder volume of piston prover.
$V_{c,20}$ = Cylinder volume of piston prover corresponding to temperature of 20 °C.
m_w = Water mass that displaced from piston.
ρ_e = Density of E2weight standard.
ρ_w = Water density.
ρ_a = Air density.
β_c = Volumetric thermal expansion coefficient.
T_c = Temperature of cylinder.
X_c = Constant of elasticity modulus for piston cylinder.
P_c = Pressure in the cylinder.
Z_w = Water compressibility coefficient.
P_w = Water temperature.

RESULTS AND DISCUSSION

Water draw is done at Flow Laboratory of Metrology LIPI in November 2013 with room temperature of (22±2)°C and room humidity of (44±3)%RH also room pressure of (1003±5) hPa. The results is in (7)

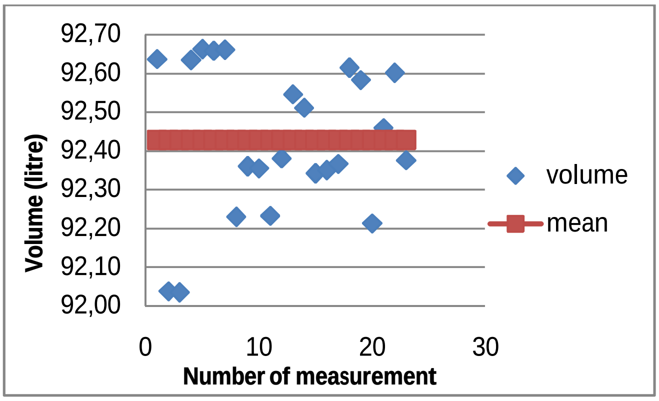

Figure. 7 Cylinder volume of piston

The uncertainty budget and data analysis[8] for cylinder volume of piston prover measurement results are desribed as in Table.1

Table. 1 Uncertainty budget for cylinder volume of piston prover

Components of uncertainty	ci.u(xi)/xi (%)	$(ci.u(xi)/uc)^2$ (%)
Water mass, m_w	0.04	93.8

Density of E2 weight, ρ_e	0.00	0.2
Water density, ρ_w	0.01	5.9
Air density, ρ_a	0.00	0.0
Temperature of cylinder, T_c	0.00	0.1
Pressure of cylinder, P_c	0.00	0.0
Water pressure, P_w	0.00	0.0
Combined uncertainty, u_c	0.04	
Expanded uncertainty(k=2), U	0.09	

This is the contribution of uncertainty diagram that consist of squared value of standard uncertainty multiplied by sensitivity coefficient(ui.ci) in relative for each component that form the mathematical model as shown in Fig. 8.

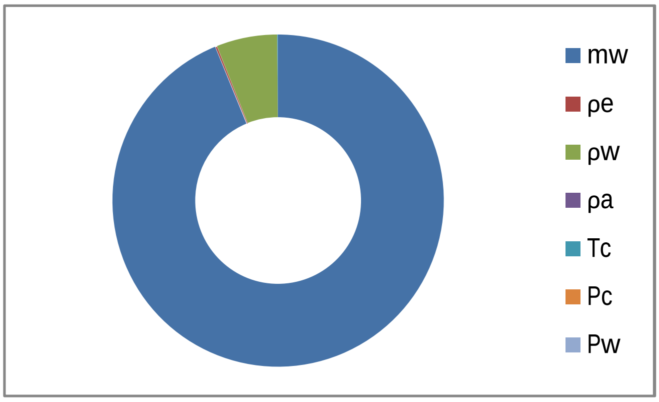

Figure. 8 Uncertainty contribution

From the table 1 and fig. 8, shown that the largest contribution came from repeatability of water mass collection data about 93.8% and the second came from repeatability of water density collection data about 5.9%. The uncertainty from electronics balance traceablity is very small that only have 2 gram or 22 ppm relative because its is calibrated to excellent standard of E2 weight. The other contributor components is neglected because their contribution is below 0.5%.

The cylinder volume of piston prover are measured and calculated at 92.43 litre and expanded uncertainty of 0.09 litre so its relative uncertainty is 0.09%. This result are out of factory specification that they claim the uncertainty of 0.05% for their product. In November 2011, Dr Jong Seung Paik from KRISS Korea suggest flow laboratory of Metrology LIPI to re-estimation our uncertainty for volume flow rate then the value of 0.12 % considered appropriate.

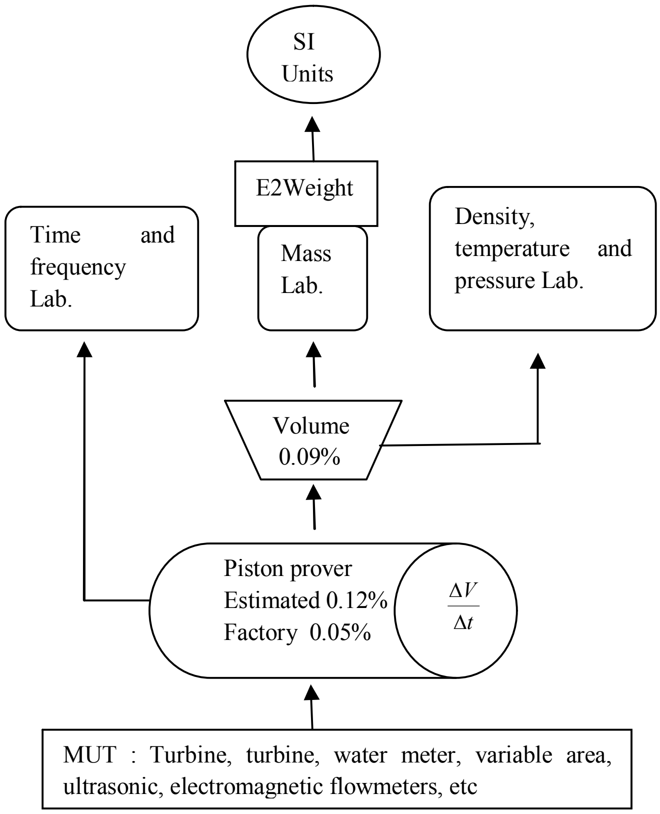

Figure. 9 Traceability chart for water flow rate in Metrology LIPI

Although the uncertainty measurement value of the cylinder volume is large enough but it has been traceable to SI units as shown in Fig. 9

There are some reason that maybe cause the repeatability of water mass collection data is large enough. As shown in Fig.2, the window is exposed directly to the sunlight and in Fig.5, the weighing tank is freely open to the atmosphere so the effect of water evaporation should be considered [9]. The use of three-way valve in Fig.6 to control when start and stop to collect data also possibility cause measurement error [10].

CONCLUSIONS

Flow Laboratory of Metrology LIPI has successfully validate the measurement traceability for cylinder volume of piston prover as standard of water flow rate to SI units. From the results of measurement as much as 23 times repeatability and the data analysis obtained that volume of piston prover cylinder are (92.43±0.09) litre. The expanded uncertainty is 0.09% in relative that has out of factory specification of 0.05%. The largest contribution of 93.8% comes from the uncertainty of mass measurement repeatability of water displaced from the piston cylinder. The some possibility cause the large repeatability of water mass collection data are :

1) The window position that exposed directly to the sunlight and the weighing tank is freely open to the atmosphere so the water evaporation may be occurred.

2) The use of three-way valve to control when start and stop to collect data as diverter also possibility cause measurement error.

Data collecting methods of water draw needs to be improved so the target of water flow rate measurement uncertainty can be better in the future.

ACKNOWLEDGMENTS

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