

## **“Prover-by-prover”: CALIBRATION OF PROVERS USING COMPACT PROVER AS MASTER METER**

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**Abstract:** The article describes the calibration of petroleum products provers with a compact prover as reference (master prover), using the same fluid in the same conditions as used in the process line.

**Keywords:** Prover, Proving Systems, Calibration, Metering Systems

### **1. Introduction**

The “Brazilian Technical Regulation for Measurement of Petroleum and Natural Gas” is in use since June 2000, and companies that transfer fluids through ducts must have their metering systems periodically calibrated according to the rules of this Technical Regulation. In the case of transfer of large quantities of expensive fluids, the reference metering system in the petroleum and petrochemical is usually a prover, either ball or compact, which is installed and aligned with a totalizing flow meter, the custody transfer meter.

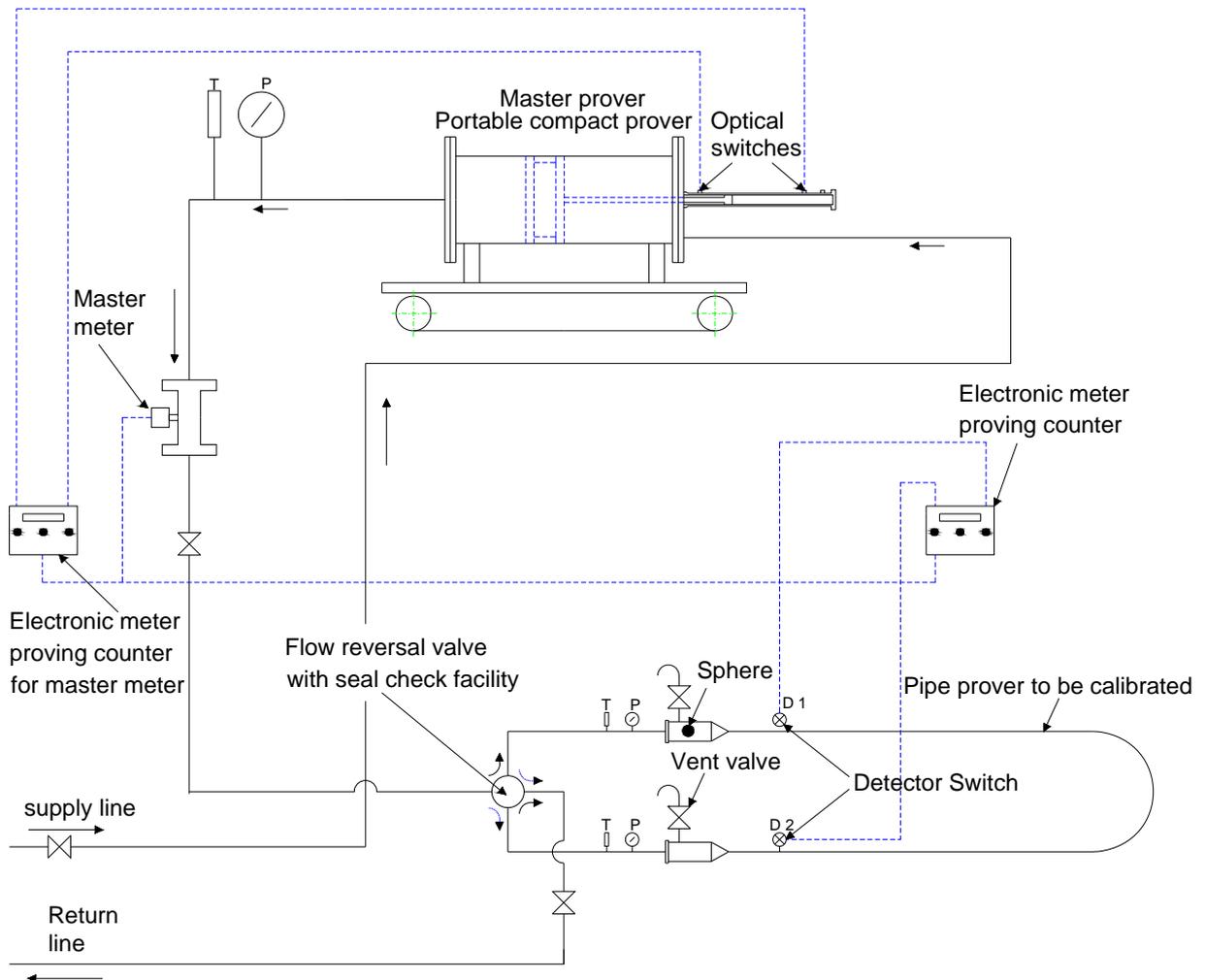
The prover calibration method described in the *API – MPMS - Chapter 12.2 –Part 4 – Calculation of Base Prover Volumes by the water Draw Method*, is the water draw, which determines its volume either by using a standard test measure or by the gravimetric method (weighing device), using water as calibrating fluid.

To use this method is necessary to disconnect the prover from the metering station, normally isolating the prover from the system by means of a blind plate. The system must be then be decontaminated, i.e., all the working fluid must be drained, and washed. After that, it is necessary to assemble a bench composed by re-circulation pumps, a reservoir with enough potable water to fulfill the test line and a standard test measure or a weighing tank. This requires significant time and work, which implies that this kind of test is quite expensive.

To overcome these difficulties, an alternative calibration methodology was used, allowing the calibration to be performed with the same fluid that flows through the piping, with the advantage to save time and money in the process, generating at the end an acceptable global uncertainty, within the limits of the regulations.

### **2. Methodology of Calibration**

The calibration of provers using the "prover-by-prover" method consists basically in the determination of the base prover volume using another calibrated prover as standard, and an intermediate meter between both provers, to be calibrated by both provers and then extrapolating the global uncertainty. This meter will be the responsible for the transference of the volume values, as it is mentioned in the *OIML R 119 - Pipe provers for testing measuring systems for liquids other than water*.

**Figure 1 – Calibration set-up lay-out, in the field.**

In the tests conducted at the facilities of a petroleum refinery, a conventional ball prover with 3600 litres (*prover under calibration*) was calibrated with a compact prover of 94 litres (*master prover*), using a 6 inches turbine meter as the transfer standard.

The mobile prover was assembled in series with the measurement station which contains the prover to be calibrated, with all secondary instruments installed, composed of the following items:

- Flowmeter, which was a turbine meter;
- Static pressure transmitter installed near the turbine meter;
- Temperature transmitter, sensor installed in the turbine meter.

These instruments were connected to the flow computer of the master prover (the compact prover). These outputs are usually installed on the flow computer assembled in the measurement station.

Once the mobile prover is installed, the calibration system will function as a measurement station composed of the two provers and a turbine meter.

The calibration of the turbine (master meter) installed on the measurement station should then take place, using both provers in each run.

The meter calibration consists on the meter factor (MF) determination and its calculation is presented below.

Combining the volume equations of the turbine meter and prover, the mathematical model which is used for the determination of the MF is obtained. This model is obtained from both provers, the master prover (*mp*) and the prover under calibration (*puc*). The index p refers to any of the provers, the index m refers to the turbine meter.

$$MF = \frac{V_{p15}}{V_{m15}}$$

$$V_{p15} = V_{Basep15} \cdot CTS_p \cdot CPS_p \cdot CTL_p \cdot CPL_p$$

$$V_{m15} = \frac{N_p}{K_n} \cdot CTL_m \cdot CPL_m$$

$$MF = \frac{V_{Basep15} \cdot CTS_p \cdot CPS_p \cdot CTL_p \cdot CPL_p}{\frac{N_p}{K_n} \cdot CTL_m \cdot CPL_m}$$

on which:

MF : meter factor of the turbine meter.

$V_{Basep15}$ : prover volume at 15°C.

$V_{m15}$  : total volume indicated at the turbine meter, corrected to the reference condition of 15°C.

$N_p$  : number of pulses generated by the turbine meter.

$K_n$  : nominal k factor of the turbine meter (n° of pulsos/m<sup>3</sup>).

$CTL_m$  : correction factor that corrects the volume according to fluid thermal expansion or contraction due to differences in operating and reference (15°C) temperatures in the meter.

$CPL_m$  : correction factor that corrects the volume that flows by the meter due to fluid compressibility in operating pressure, in relation to the reference pressure (zero).

$CTS_p$  : correction factor that corrects the prover volume according to thermal expansion or contraction, due to differences in operating and reference (15°C) temperatures.

$CPS_p$  : correction factor that corrects the prover volume according to elastic deformation of the materials of the prover, caused by the operating pressure of the prover.

$CTL_p$  : correction factor that corrects the volume due to the fluid thermal expansion or contraction caused by the difference between operating and reference temperatures in the prover chamber.

$CPL_p$  : correction factor which corrects the prover volume due to fluid compressibility or expansion caused by the operating pressure inside the prover chamber when compared to the reference pressure (zero).

The “prover-by-prover” calibration method made the comparison between the results obtained in the calibrations of the meter installed on the measurement station realized with both provers, in the same operating conditions, and it is therefore important that the information contained on the flow computers of both systems, be correctly configured with the same fluid specification, fluid density, correction tables for the calculation of CTL and CPL, since these calculations are implemented through the flow computers algorithms.

The turbine meter was calibrated realizing 5 runs for each flow rate. Two different flow rates were used: operating flow rate and another at least 25% below this value.

The calibration of the turbine meter used as reference must take place simultaneously with both provers installed in series. Once the meter has been calibrated and the calibration reports from both flow computers obtained, with all corrections made, it is possible to calculate the new volume for the prover that is being calibrated, using the volume of the master prover as reference.

### 3 Calculation of the new volume for the prover under calibration.

As explained, it was used a turbine meter to transfer the values of the master prover volume (compact prover used as reference) to the volume of the prover under calibration.

The method should fulfill the following requirements:

The MF of the turbine meter obtained using the prover under calibration must equal the MF obtained with the master prover used as reference.

$$MF_{15 \text{ Masterprover}} = MF_{15 \text{ New MFprover under calibration}} \quad (\text{I}) \quad \text{and}$$

$$\frac{MF_{15 \text{ Masterprover}}}{MF_{15 \text{ actual MFprover under calibration}}} = FC \quad \text{or}$$

$$MF_{15 \text{ New MF prover under calibration}} = FC \cdot MF_{15 \text{ actual MFprover under calibration}} \quad (\text{II})$$

And:

FC = Correction factor to new MF

$MF_{15 \text{ Master prover}}$  = Turbine meter factor obtained from the compact prover used as reference corrected to the condition of 15°C.

$MF_{15 \text{ actual MF prover under calibration}}$  = Turbine meter factor obtained from the actual volume (“actual” in this case means the volume in the template of the prover) of the prover under calibration corrected to the condition of 15°C.

$MF_{15 \text{ New MF prover under calibration}}$  = Turbine meter factor obtained from the actual MF prover under calibration corrected by the MF to the condition of 15°C.

Substituting (I) in (II)

$$MF_{15 \text{ New MF prover under calibration}} = MF_{15 \text{ actual MF prover under calibration}} \cdot FC \quad (\text{III})$$

$$MF_{15 \text{ New MF prover under calibration}} = \frac{V_{15 \text{ New volume prover under calibration}}}{V_{15m}} \quad (\text{IV})$$

$$MF_{15 \text{ actual MF prover under calibration}} = \frac{V_{15 \text{ actual volume prover under calibration}}}{V_{15m}} \quad (\text{V})$$

Substituting (IV and V) in (III)

$$\frac{V_{15 \text{ New volume prover under calibration}}}{V_{15m}} = \frac{V_{15 \text{ actual volume prover under calibration}}}{V_{15m}} \cdot FC$$

Then:

$$V_{15 \text{ New volume prover under calibration}} = V_{15 \text{ actual volume prover under calibration}} \cdot FC$$

So:

$V_{15 \text{ New volume prover under calibration}}$  = new volume for the Ball prover determined on the calibration.

$V_{15 \text{ actual volume prover under calibration}}$  = volume of the ball prover used in the calibration.

#### 4. UNCERTAINTY BUDGET

The model for the calculation is:

$$MF_{15 \text{ Masterprover}} = \frac{V_{\text{Basep15}} \cdot CTS_p \cdot CPS_p \cdot CTL_p \cdot CPL_p}{\frac{N_p}{K_n} \cdot CTL_m \cdot CPL_m}$$

$$\frac{MF_{15 \text{ Masterprover}}}{MF_{15 \text{ actual MF prover under calibration}}} = FC$$

$$V_{15 \text{ New volume prover under calibration}} = V_{15 \text{ actual volume prover under calibration}} \cdot FC$$

**UNCERTAINTY BUDGET - PROVER UNDER CALIBRATION**

UNCERTAINTY SOURCE, Xi	SIMB.	ESTIMATE, xi	STANDARD UNCERTAINTY u(xi)	u (xi) VALUE	DEGREES OF FREEDOM	PROBABILITY DISTRIBUTION	SENSITIVITY COEFFICIENT , ci	ci . u[Xi]	[ ci . u (Xi)] <sup>2</sup>	CONTRIBUTION (%)
Prover volume at 15°C ( <b>V<sub>basep15</sub></b> ), in liters	Vbasep15	0,0945868	u(Vbasep15)	4,7E-06	infinity	Normal	10,63224	5,03E-05	2,53E-09	20,43%
Corr. for the effect of temp. on steel in a prover ( <b>CTS<sub>p</sub></b> )	CTSp	1,0007	u(CTSp)	6,80E-05	5,885E+08	Normal	1,00493	6,83E-05	4,67E-09	37,71%
Corr. for the effect of pressure on steel prover ( <b>CPS<sub>p</sub></b> )	CPSp	1,0000	u(CPSp)	1,57E-06	1,282E+14	Normal	1,00562	1,58E-06	2,49E-12	0,02%
Corr. for compressibility of fluid in a prover ( <b>CTL<sub>p</sub></b> )	CTLp	0,9830	u(CTLp)	4,51E-05	2260481	Normal	1,02301	4,62E-05	2,13E-09	17,22%
Corr. For compressibility of fluid in prover ( <b>CPL<sub>p</sub></b> )	CPLp	1,0008	u(CPLp)	2,48E-06	1,066E+10	Normal	1,00489	2,49E-06	6,21E-12	0,05%
Pulses number ( <b>N<sub>p</sub></b> )	Np	534,6404	u(Np)	0,1691	2	Normal	0,00018	2,99E-05	8,96E-10	7,24%
K factor, pulses per unit volume ( <b>K<sub>n</sub></b> )	Kn	5680,000	u(Kn)	0	infinity	rectangular	-0,00188	0,00E+00	0	0%
Corr. for the effect of temp. on a liquid in the meter ( <b>CTL<sub>m</sub></b> )	CTLm	0,98305	u(CTLm)	4,51E-05	1,357E+06	Normal	-1,02301	-4,62E-05	2,13E-09	17,23%
Corr. for compressibility of liquid in meter ( <b>CPL<sub>m</sub></b> )	CPLm	1,0008	u(CPLm)	3,41E-06	450	Normal	-1,00489	-3,43E-06	1,18E-11	0,10%
Meter factor	MF	1,0057			381	Normal			0,00011	100%

Meter factor	MF	1,0057	u(type B)	1,11E-04	381	Normal	1,00000	1,11E-04	0,000000012	9,58%
Average meter factor	MF	1,00532	standard deviation(MF)	3,42E-04	5,000E+00	Normal	1,00000	3,42E-04	0,000000117	90,42%
					6				0,00036	100%

Coverage factor K =	2,52
Expanded uncertainty (MF) =	0,00090
Expanded uncertainty (%) =	0,09%

**Meter factor = 1,00532 ± 0,00090**

## 5. RESULTS

Three different ball provers were calibrated using the method, each one with a different fluid: Diesel oil, propane and LPG-liquefied petroleum gas, using the same compact prover as master meter.

The results presented refer to the temperature of 15°C, and 101325 Pa. Thermal volumetric expansion coefficient of the prover's tube (mild carbon)  $G_c = 3,35E-05/oC$ . Modulus of elasticity of the prover's tube material (mild carbon steel)  $E = 206800000$  kPa.

Table 1 – Results obtained in the calibration of the ball prover using Diesel oil

Run N <sup>o</sup>	Flow rate	Prover Volume at 15°C original	Prover Volume at 15°C new	Deviation from the original volume
	(m <sup>3</sup> /h)	(Liters)	(Liters)	(%)
1	311	3603.42407	3613,57	0,28
2	309	3603.42407	3614,24	0,30
3	216	3603.42407	3613,99	0,29
	Average		3613,93	
	Maximum deviation		0,019 %	

The expanded uncertainty associated to the average volume is of 3,25 Liters or 0,09%

Note: The expanded uncertainty shown is based in a combined standard uncertainty multiplied by a coverage factor  $k = 2,52$ , which gives an approximated 95% confidence level.

Table 2 – Results obtained in the calibration of the ball prover using propane

Run N <sup>o</sup>	Flow rate	Prover Volume at 15°C original	Prover Volume at 15°C new	Deviation from the original volume
	(m <sup>3</sup> /h)	(Liters)	(Liters)	(%)
1	27	396,2086	395,79	-0,11
2	27	396,2086	395,79	-0,10
3	20	396,2086	395,79	-0,10
	Average		395,79	
	Maximum deviation		0,001 %	

The expanded uncertainty associated to the average volume is of 0,36 Liters or 0,09%

Table 3 – Results obtained in the calibration of ball prover using LPG

Run N <sup>o</sup>	Flow rate (m <sup>3</sup> /h)	Prover's Volume at 15°C original (Liters)	Prover's Volume at 15°C new (Liters)	Deviation from the original volume (%)
1	247	1888,2	1888,40	0,01
2	244	1888,2	1888,37	0,01
3	224	1888,2	1888,41	0,01
4	179	1888,2	1888,89	0,04
5	179	1888,2	1888,88	0,04
	Average		1888,59	
	Maximum deviation		0,028 %	

The expanded uncertainty associated to the average volume is of 1,70 Liters or 0,09%

## 6. CONCLUSION

This paper shows the possibility of applying this calibration method, and that its uncertainty is in accordance with the exactitude levels demanded by Brazilian law. It is, though, possible to achieve better uncertainty levels as the methodology is used and improved.

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