SELF-REFERRING CALIBRATION FOR BETACAP60-3G

Test procedure – Introduction

Testing gas dividers do require flow measurements :

Dilution ratio = input span gas flow / total output gas flow.

What is particular here is that **absolute (or traceable) references are not required,** because the calculated value of dilution ratio don’t change when the two measured flows are multiplied by the same value, wichever it is.

The base of this “self-referring calibration procedure” is assuming correct the flow measuring through one of the capillaries included in the gas divider and measuring all the other elements (flows through capillaries groups) with reference to the internal “reference capillary”

Doing that , the “Measuring” term is wrong : we are just interested to flows comparison and we may forget any ralation with the external world, including “measuring range, measuring unit and so on”. Just to have a commom language with the reader we will continue to use those terms.

In the procedure we want to present the test is divided into 5 phases completely independent each other : errors calculated in the previous phases are used in next phases calculation, but before doing that they are re-scaled to the actual phase conditions. I think this is a very important point.

In fact, the independence of many parameters (pressure applied to capillaries, sensitivity of the flow measure-ments, etc.) add quality to the results, because many kinds of errors (non linearity, measuring drifts, unaccuracy of flow measuring are not transferred to the quality of the result.

Just one point is till required : the two or three measurements performed in each test phase must be repeatable (testing conditions as applied pressure and measuring sensitivity must be stable during each testing phase).

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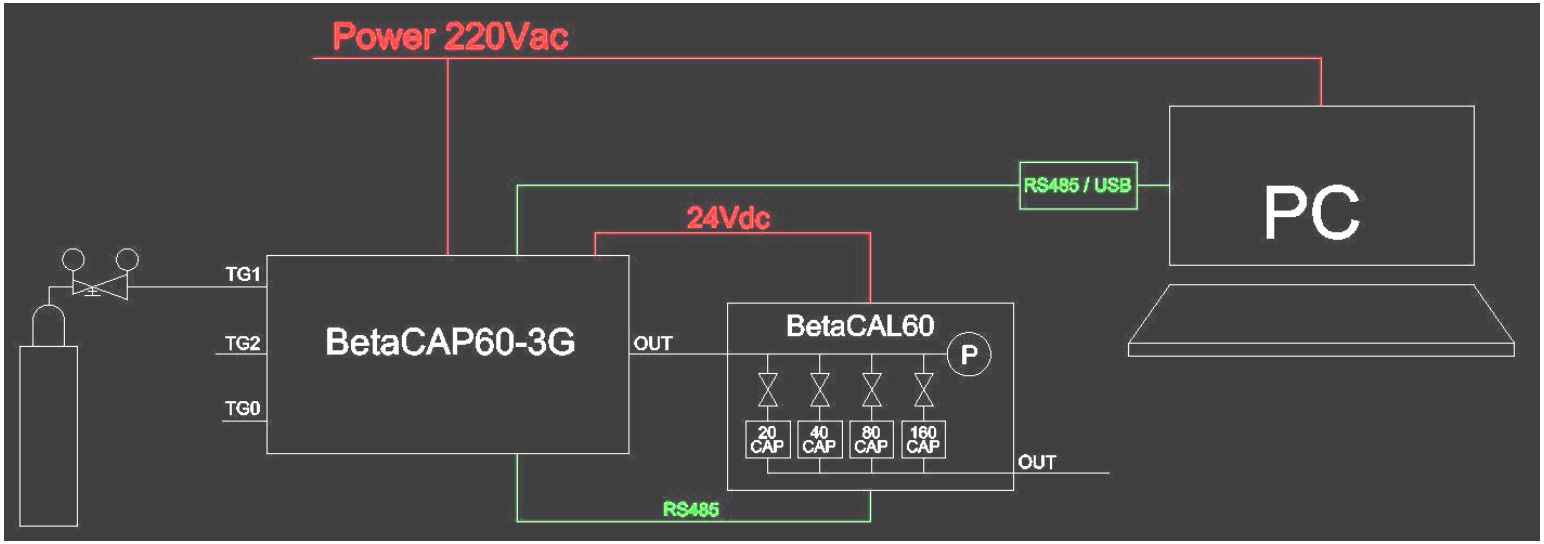
Test procedure – The testing bench



The gas divider BetaCAP60-3G is connected through different serial ports at a Windows PC (which manages the test) and at a five ranges flow meter based on laminating flow elements and relative (differential) pressure.

A pressurised gas (whichever) is supplied at TG1 port at 2.5 Bar ± 1 Bar (flow meter discharge is vented out).

According to the program CAL60, the PC drives the gas divider which drives the flow meter, receiving back the flow measuring values, which are transferred to PC upon request.

In the different test phases the flows to be measured are in a very wide range : the flow measuring unit is driven to adapt his measuring range to the flows requirement in a way to operate always with the best resolution.

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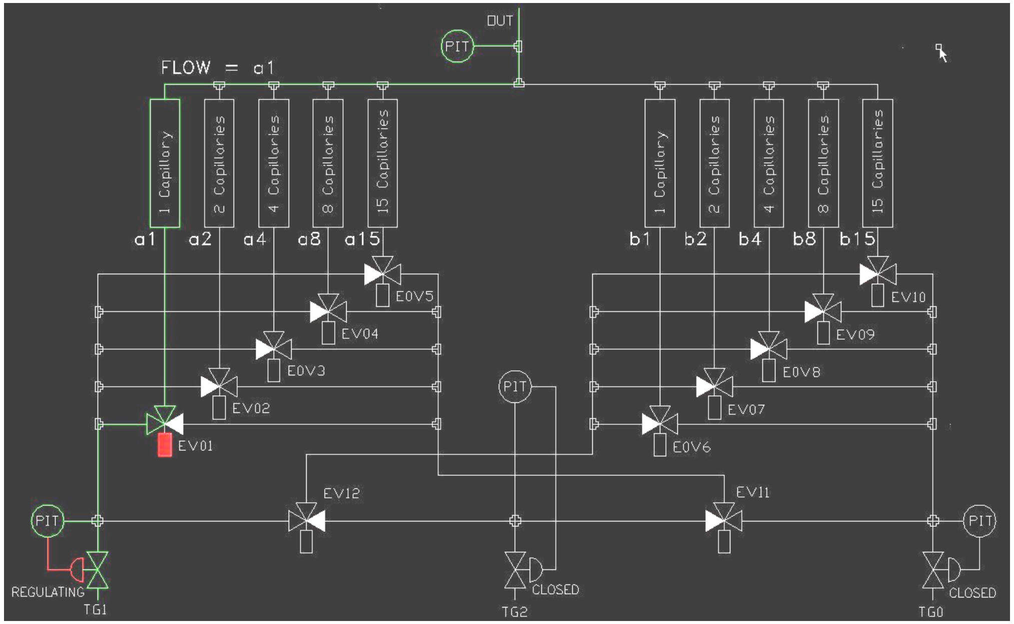
Test procedure – The symbols used

The gas divider BetaCAP60-3G is built with two modules each made by 30 capillaries grouped according to the 2^N progression : 1 capillary, 2 capillaries, 4 capillaries, 8 capillaries and 15 capillaries (small exception).

We will name A and B the two modules and a1, a2, a4, a8, a15 and b1, b2, b4, b8, b15 the capillaries groups.

Same name of capillaries groups are given to the flow measured through the corresponding group.



The sum of the flows through equal composition groups a1 and b1, a2 and b2…a15 and b15 will be named a1b1, a2b2, … a15b15

The relative errors (relative flows deviation between measured value and theoretical value) are called ε_{ij} where i = a or b and j = 1, 2, 4, 8, 15 depending on which capillaries group is involved.

Note : theoretical values are K, 2K, 4K, 8K, 15K both for a1t … a15t and for b1t … b15t (measuring unit is optional)

where K = a1, because εa1 = 0 (we did select this capillary as internal reference)

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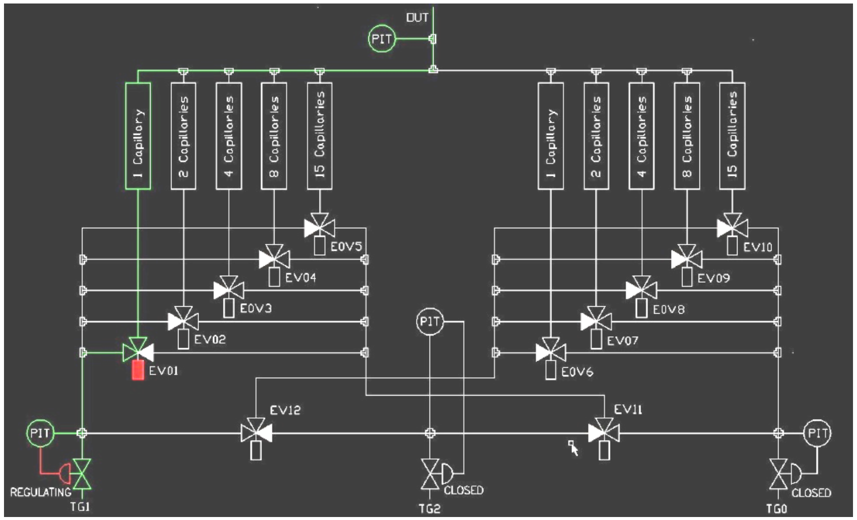
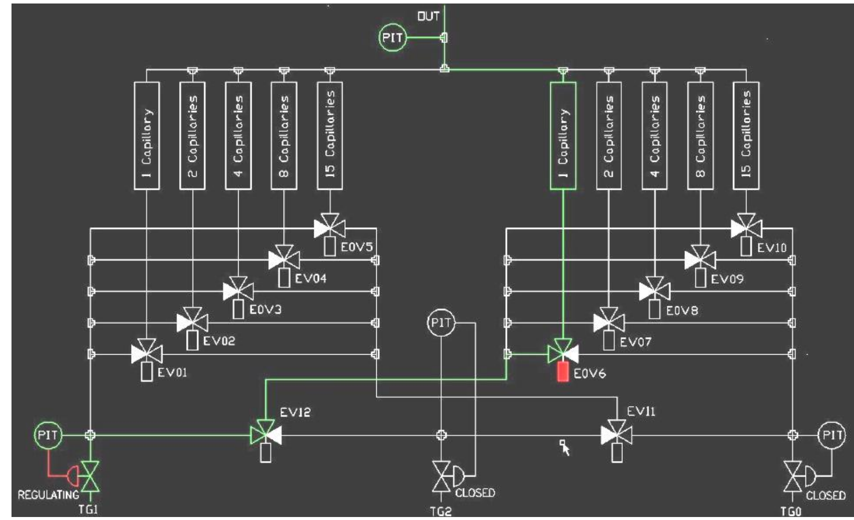
Test procedure – phase 1



Step 1 to measure a1



Step 2 to measure b1

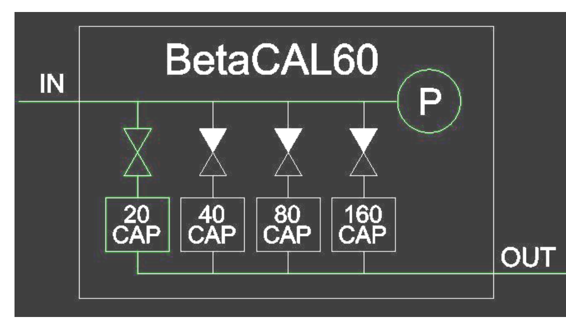
The flow through 1 capillary groups a1 and b1 are measured in sequence

a1 is the selected internal reference capillary ($\varepsilon(a1) = 0$)

The theoretical flows through a1 and b1 must be equal (a1t = b1t), then the measured flows deducted by the relevant errors must be equal :

$a1 - \varepsilon(a1) \times a1 = b1 - \varepsilon(b1) \times b1$ $\quad\quad$ $a1 - zero = b1 - \varepsilon(b1) \times b1$

$\varepsilon(b1) = (b1 - a1) / b1$ $\quad\quad$ for next use it's also calculated $R1 = a1 / b1$



Flows measuring unit (set for 1 capillary flow)

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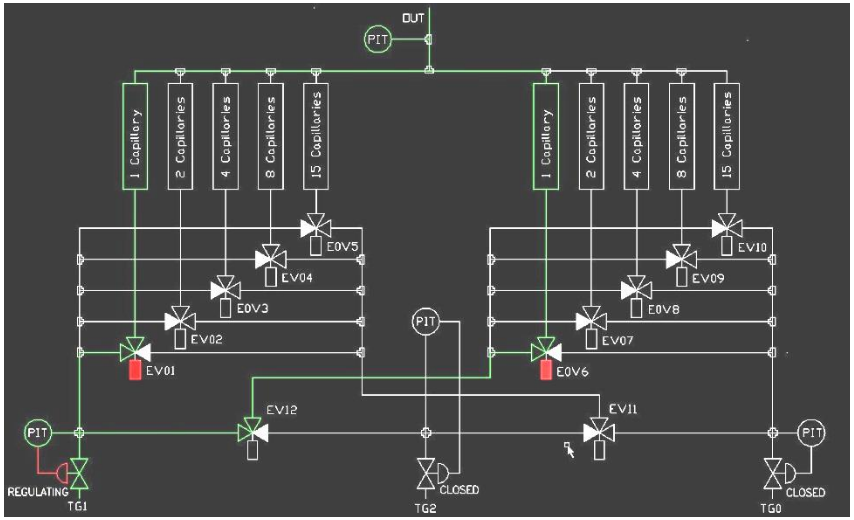
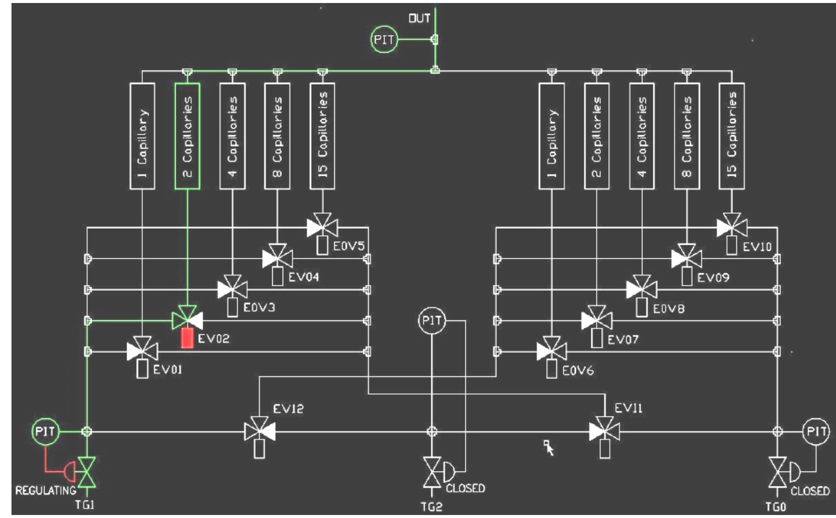
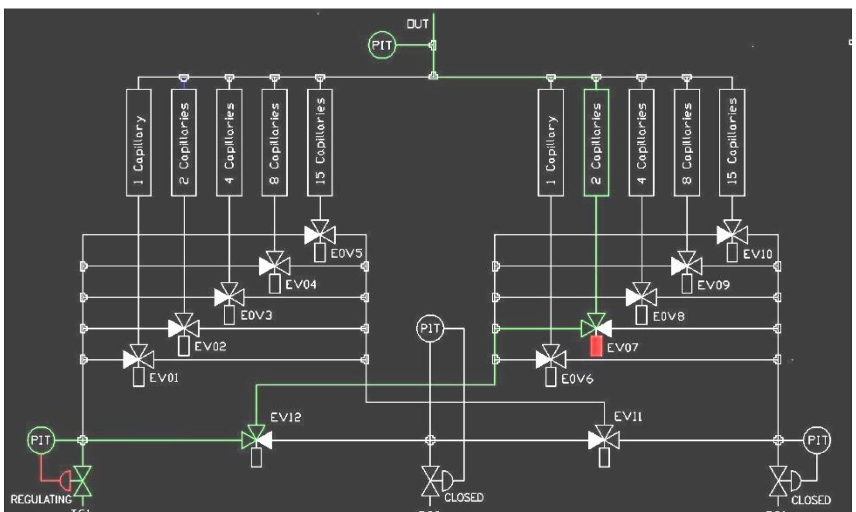
Test procedure – phase 2



Step 1 to measure a1 and b1 in parallel (name a1b1)



Step 2 to measure a2

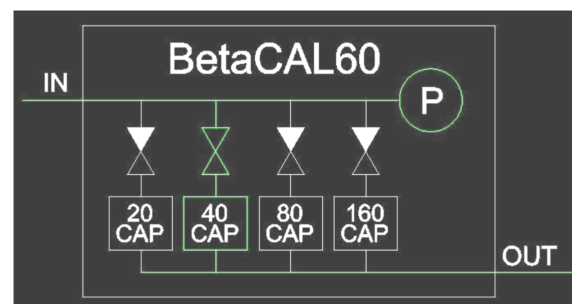


Step 3 to measure b2

The flow through 2 capillaries groups a1b1, a2 and b2 are measured in sequence :

a1b1 – ε(b1) * a1b1 / (1+R1) = a2 – ε(a2) * a2 = b2 – ε(b2) * b2

For next use also is calculated R2 = a2/b2



Flows measuring unit (set for 2 capillaries flow)

SELF-REFERRING CALIBRATION FOR BETACAP60-3G

Test procedure – Calculations explaination

May be the double equation

$a1b1 - \varepsilon(b1) * a1b1 / (1+R1) = a2 - \varepsilon(a2) * a2 = b2 - \varepsilon(b2) * b2$

must be clarified : it comes from the theoretical (wanted) equality of all the capillaries in the groups.

Theoretical flows comparison is made comparing the measured real flows deducted by the absolute errors which in the left term are calculated from previous results and in the right terms are unknown (to be calculated).

The errors calculated before (left term) are of "relative type" and must be converted to absolute (multiplying them by the relevant actual flows).

We just know the flow a1b1 (the sum of a1 and b1) and the ratio R1=a1/b1 but calculating a1 and b1 is not difficult (note that the values a1 and b1 are not the same a1 and b1 calculated in the previous phase, but they keep the same relative error and the same ratio) :

$a1b1 = a1 + b1 = a1 + a1/R1$, then $a1 = R1 \times a1b1 /(1+R1)$ and $b1 = a1b1 / (1+R1)$

Note that relative errors and flows ratio may be used in a measuring system different from the measuring system that was used to calculate their values. Doing that the measuring sensitivity may be adapted to the different measured flows to get always the best measuring resolution

Note : talking about errors we mean the relative deviation from the correct proportion of the flows to the numbers of involved capillaries

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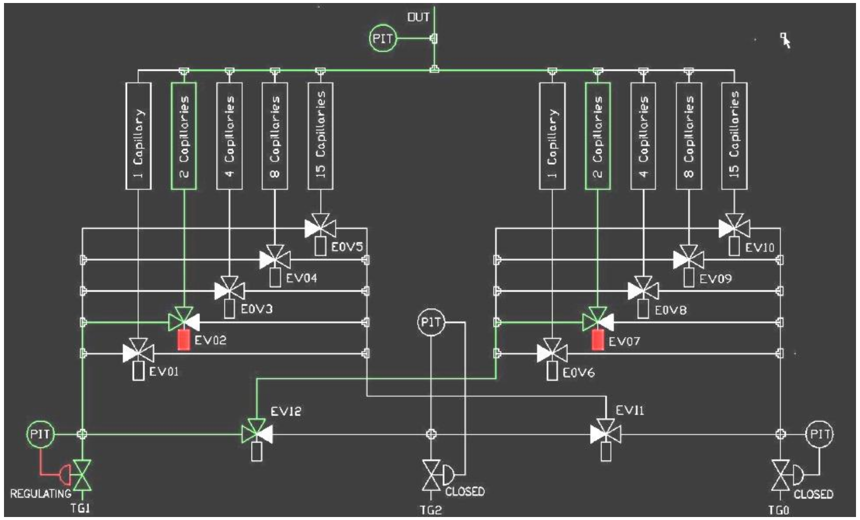
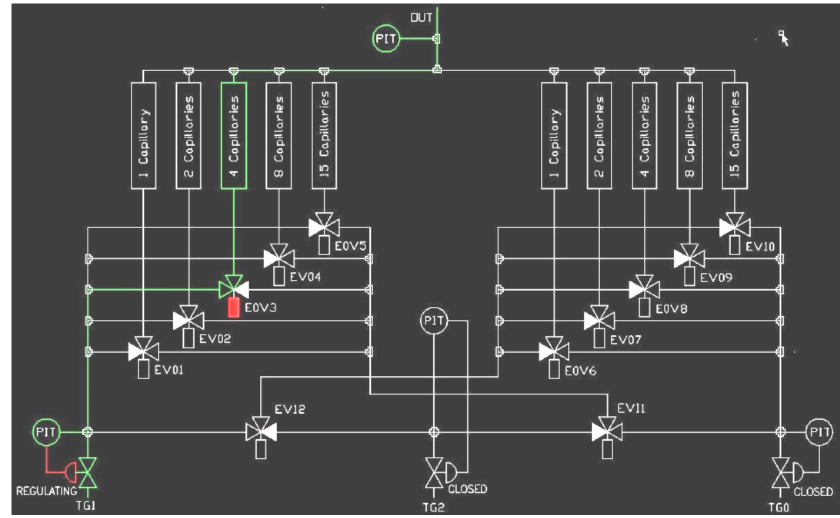
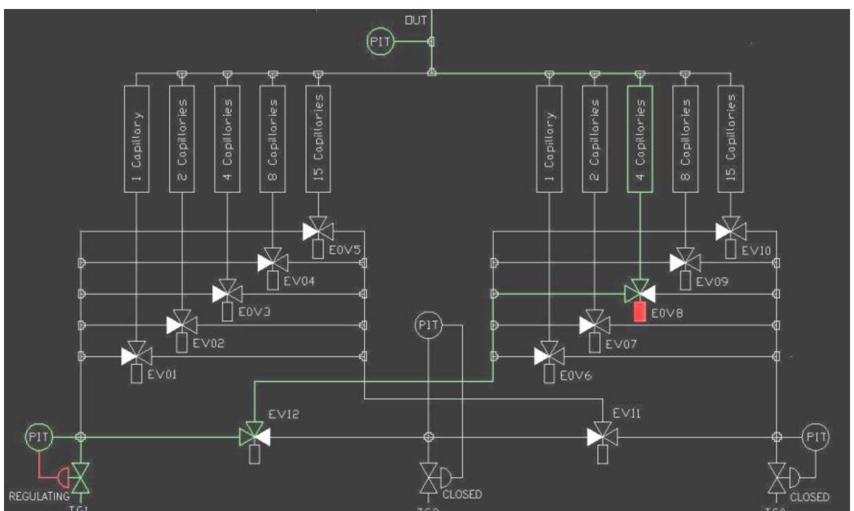
Test procedure – phase 3



Step 1 to measure a2 and b2 in parallel (name a2b2)



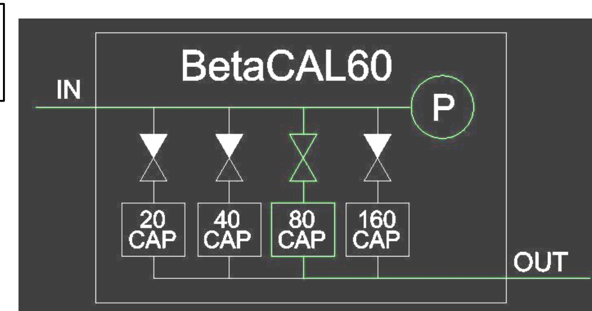
Step 2 to measure a4



Step 3 to measure b4

The flow through 4 capillaries groups a2b2, a4 and b4 are measured in sequence :
$a2b2 - \varepsilon a2 * R2 * a2b2 / (1+R2) - \varepsilon b2 * a2b2 / (1+R2) = a4 - \varepsilon a4 * a4 = b4 - \varepsilon b4 * b4$

For next use also is calculated R4 = a4/b4



Flows measuring unit (set for 4 capillaries flow)

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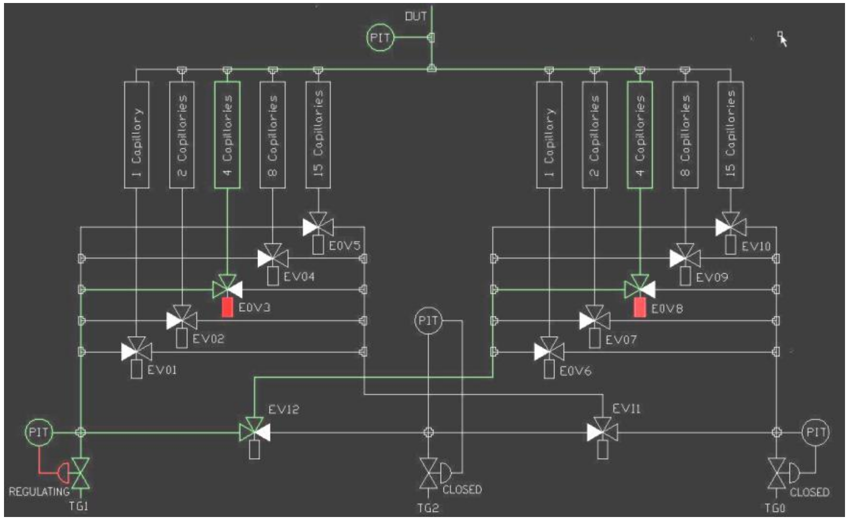
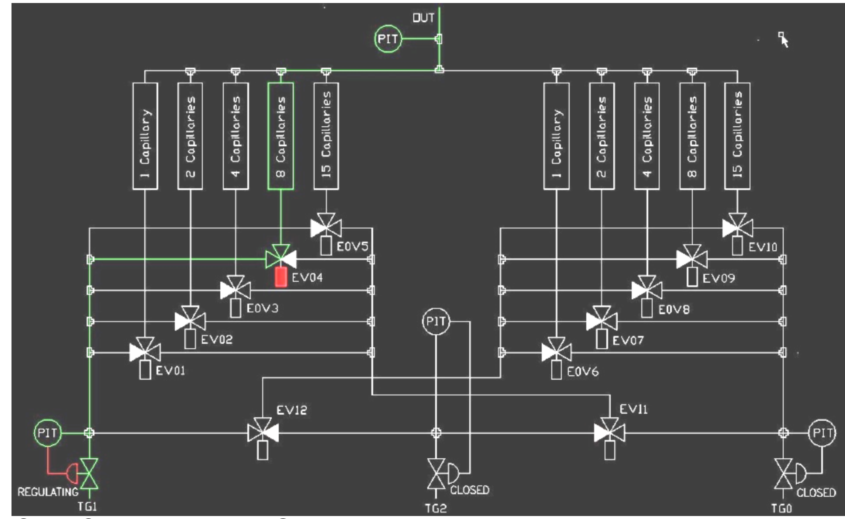
SELF-REFERRING CALIBRATION FOR BETACAP60-3G

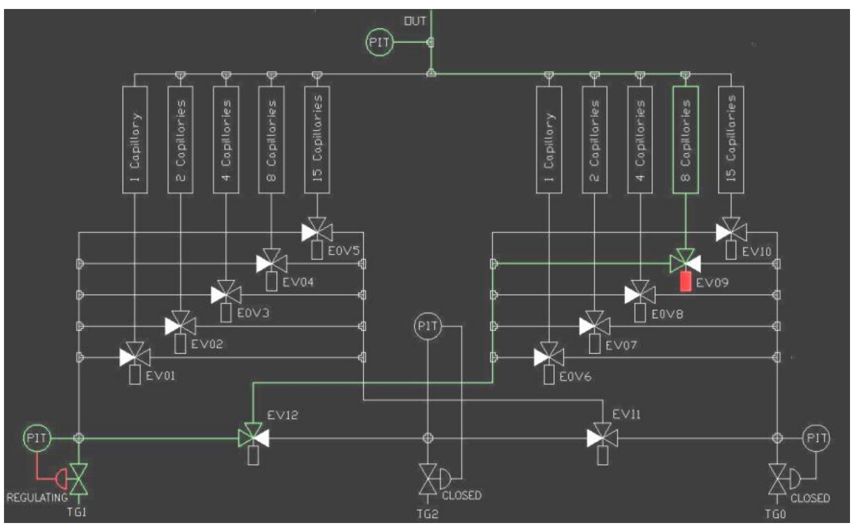
Test procedure – phase 4



Step 1 to measure a4 and b4 in parallel (name a4b4)



Step 2 to measure a8

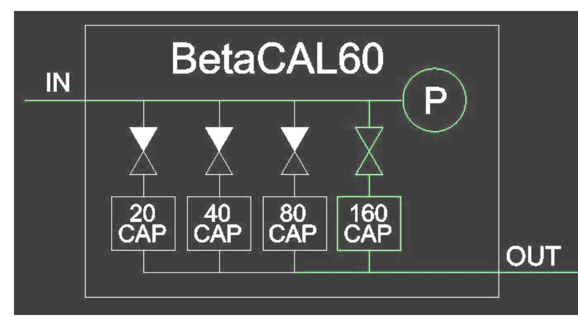


Step 3 to measure b8

The flow through 8 capillaries groups a4b4, a8 and b8 are measured in sequence :

$a4b4 - \varepsilon a4 * R4 * a4b4 / (1+R4) - \varepsilon b4 * a4b4 / (1+R4) = a8 - \varepsilon a8 * a8 = b8 - \varepsilon b8 * b8$

For next use also is calculated R8 = a8/b8



Flows measuring unit (set for 8 capillaries flow)

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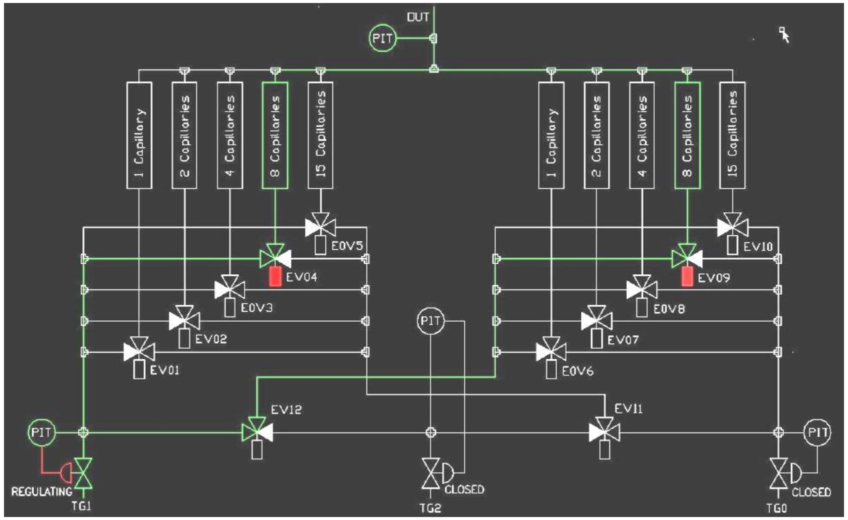
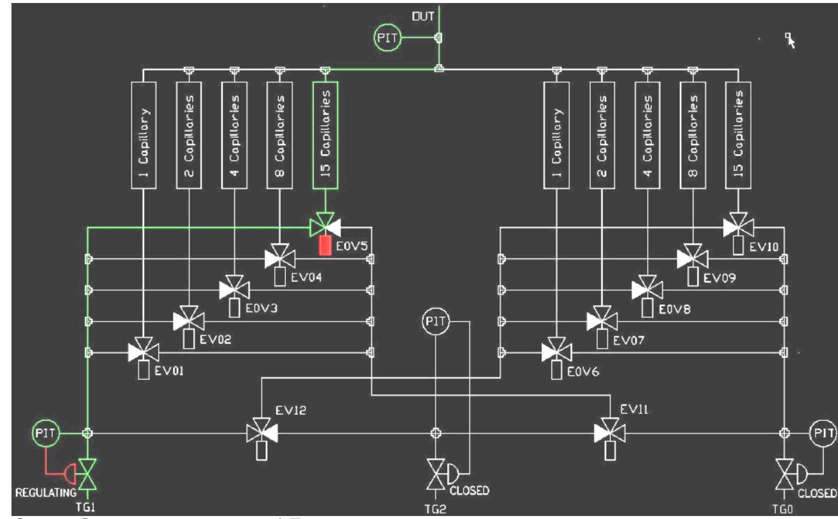
SELF-REFERRING CALIBRATION FOR BETACAP60-3G

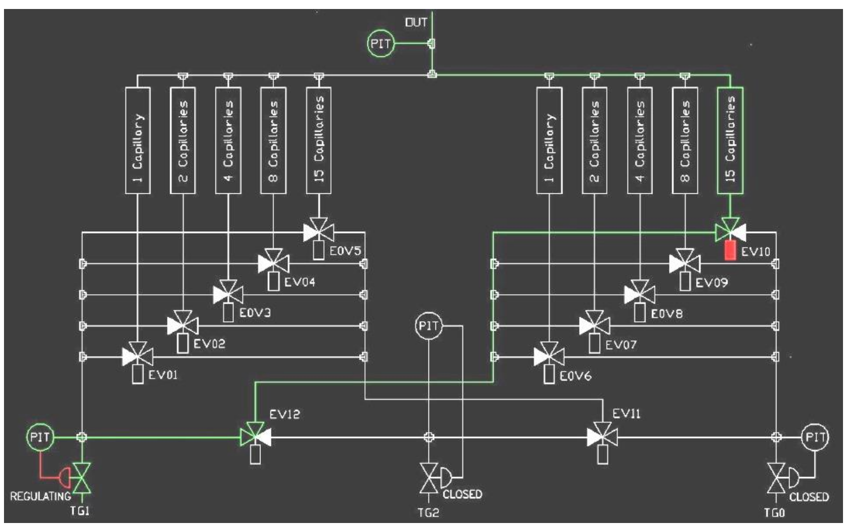
Test procedure – phase 5



Step 1 to measure a8 and b8 in parallel (name a8b8)



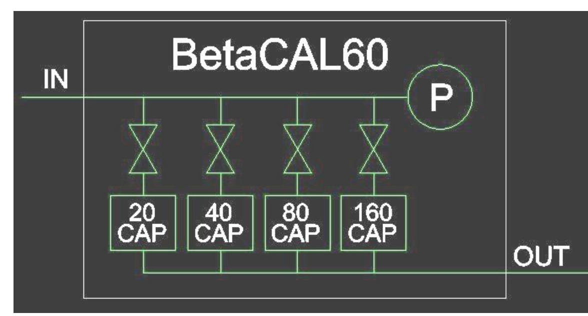
Step 2 to measure a15



Step 3 to measure b15

The flow through 15 or 16 capillaries groups a8b8, a15 and b15 are measured in sequence :
[a8b8 - εa8 * R8 * a8b8 / (1+R8) - εa8 * a8b8 / (1+R8)] *15/16 = a15 - εa15 * a15 = b15 - εb15 * b15

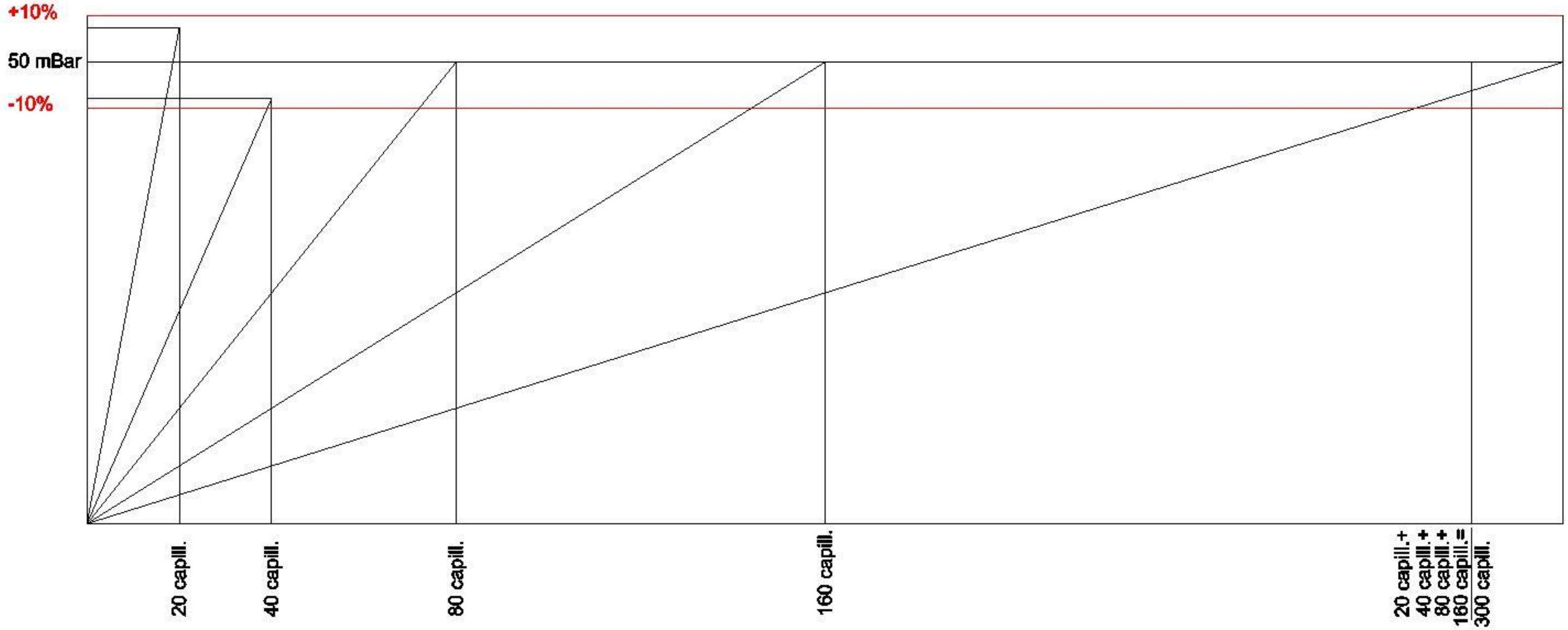
Note : in this phase, step 1 measures 16 capillaries and steps 2 and 3 measure just 15 ! The multiplier 15/16 is used to proportion a8b8 to 15 capillaries flow



Flows measuring unit (set for 15 or 16 capillaries flow)

SELF-REFERRING CALIBRATION FOR BETACAP60-3G

Notes about the flow meter BetaCAL60



Here are imaged the 5 measuring ranges of the flow meter BetaCAL60 supposing that the two lower ranges (with 20 e 40 capillaries)are not linearly scaled : this error is not influent on the calibration process quality, where each phase is not related to the others.

In fact the values used in the next phase: $\varepsilon\ a(i-1)$, $\varepsilon\ b(i-1)$ and $R = a(i-1) / b(i-1)$
are not depending on the flow meter sensitivity (two relative errors and a flows ratio).
The purpose of different ranges is just to have all the flow measurements reading in the higher side of the measuring range for getting the best relative resolution.

SELF-REFERRING CALIBRATION FOR BETACAP60-3G

Test procedure – Errors correction

All the errors depending on not perfect “scaling” of capillaries groups are then calculated : they are the most important contribution to the dilution uncertainty. Knowing them it’s possible to neutralize their effects.

Each dilution ratio (in BetaCAP60-3G we have two dilution ratios : one for TG1 and one for TG2) is given by a known combination of the flows through capillaries groups at numerator and denominator of the dilution ratio.

It’s then possible to include in the dilution ratio the actual errors contribution summing each error to the corresponding flow (through each capillaries group).

Depending on how TG1, TG2 and TG0 are distributed (by EV11 and EV12) through the two dilution modules (A and B), it’s possible to express the dilution ratios

Kdil 1 as function of P(TG1) / P(TG0)

Kdil 2 as function of P(TG2) / P(TG0)

And then it’s possible to calculate the value of each above pressure ratio, which could generate an error equal and opposite to the calculated errors affecting the gas divider

Considering that P(TG1), P(TG2), P(TG0) are the pressures across the involved capillaries, electronically controlled each with a calculated pressure set point, it’s evident that the best way to apply the calibration is acting on pressures ratios, and that’s done with results confirming the theory.