Infrastructure Commission (INFCOM)

Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)

Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration of Precipitation Instruments

Part-3: Calibration Examples (1)

Holger Doerschel (DWD)
Zafer Turgay Dag (TSMS)

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- Introduction to this unit and historical information
- Concepts and definitions

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- Methods of measurement
- Calibration of rain gauges

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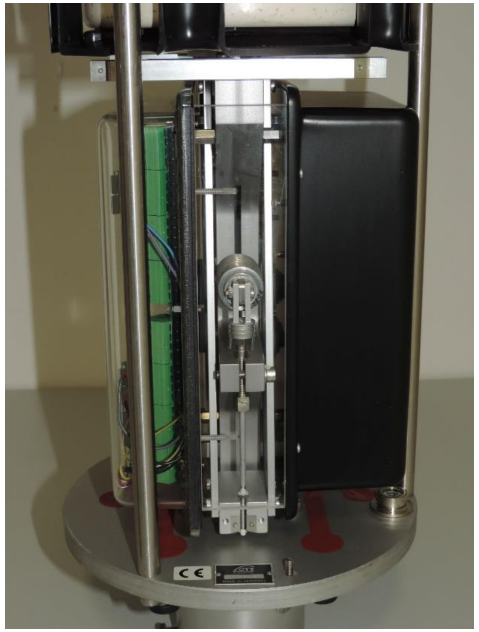
Calibration of rain gauges – example #1 (DWD)

- collecting rain gauge using a weighing unit
  - this rain gauge collects the rain with a container
  - the container is weighed together with the collected rain
  - digital readout of amount and intensity

assembled rain gauge

with housing removed



detailed view of the weighing unit

Calibration of rain gauges – example #1

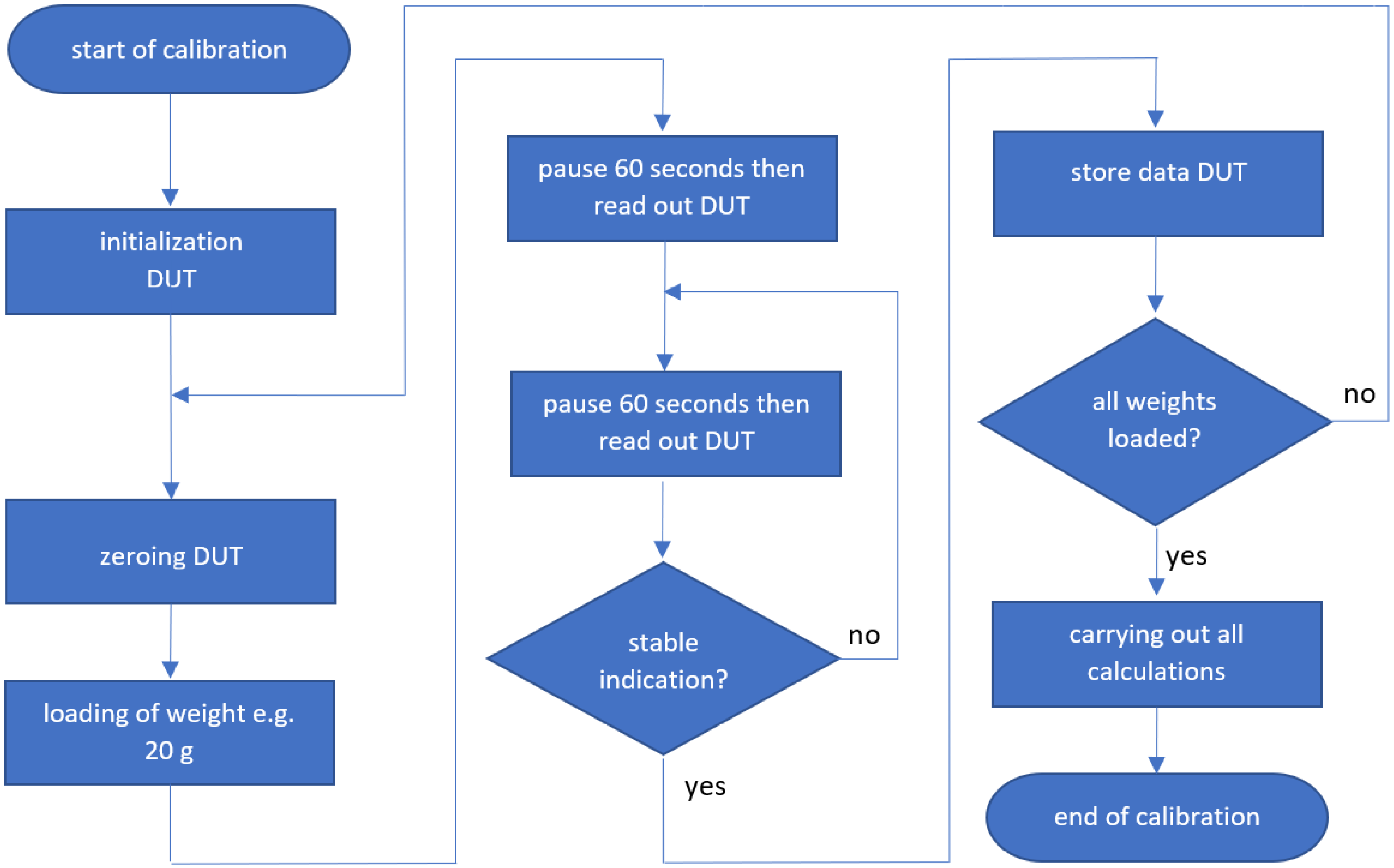
- the container is removed and a plate with a spindle is placed on top for centring
- instead of water, specially made weights with a hole are placed on the plate

set of weights

loaded weights

- the weights make it possible to simulate the intensity of the rain and the accumulated rain

Calibration of rain gauges – example #1



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Calibration of rain gauges – example #1

- type A uncertainties
  - due to the very long stabilization times, repetitions are not possible
  - therefore, no type A measurement uncertainties are taken into account

- type B uncertainties
  - uncertainty of the weights (from calibration certificate)
  - resolution of the device under test (DUT)
  - drift of the weight (calibration history)
  - repeatability (experiences)
  - temperature-coefficient DUT

Calibration of rain gauges – example #1

- model:

$$\Delta rain = dut - reference + \delta dut\_resolution + \delta dut\_repeatability + \delta dut\_temperature\_coefficient - \delta reference\_drift$$

Δrain	result (dut - reference)
dut	indication of dut intensity
reference	indication of reference intensity

Calibration of rain gauges – example #1

- uncertainties:

δdut_resolution	the resolution of the DUT is 0.01 mm
δdut_repeatability	the repeatability of the DUT is 0.01 mm
δdut_temperature_coefficient	the temperature coefficient is 0.005 mm/K → maximum expected temperature change 1 K
δreference_drift	the estimated drift is less than 0.1 mg / 2 years

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Calibration of rain gauges – example #1

- result: Δrain = -0.01 mm ± 0.01 mm (*k* = 2)

Quantity	Value	Stand. uncert.	Distribution	DoF	Sensit. coeff.	Uncert. contribution	Rel. contribution	Bar chart
dut	0,09 mm							
δdut_resolution	0,0 mm	0,00289 mm	Rectangular	∞	1,00 mm^{-1}	0,00289	33,33 %	
δdut_repeatability	0,0 mm	0,00289 mm	Rectangular	∞	1,00 mm^{-1}	0,00289	33,33 %	
δdut_temperature_coefficient	0,0 mm	0,00289 mm	Rectangular	∞	1,00 mm^{-1}	0,00289	33,33 %	
reference	0,09996150 mm	6,00E-6 mm	Normal	∞	-1,00 mm^{-1}	-6,00E-6	0,00 %	
δreference_drift	0,0 mm/min	2,89E-6 mm/min	Rectangular	∞	-1,00 min·mm^{-1}	-2,89E-6	0,00 %	

	Value	Comb. stand. uncertainty	Effective degrees of freedom		Sign. digits
Δrain	-0,00996	0,00500	∞		3

	Value	Expanded uncertainty	Coverage factor (Probability)	Distribution	Sign. digits
Result	-0,010	± 0,010	2,00 (95,45 %)	Normal	2

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- **Calibration example #2**

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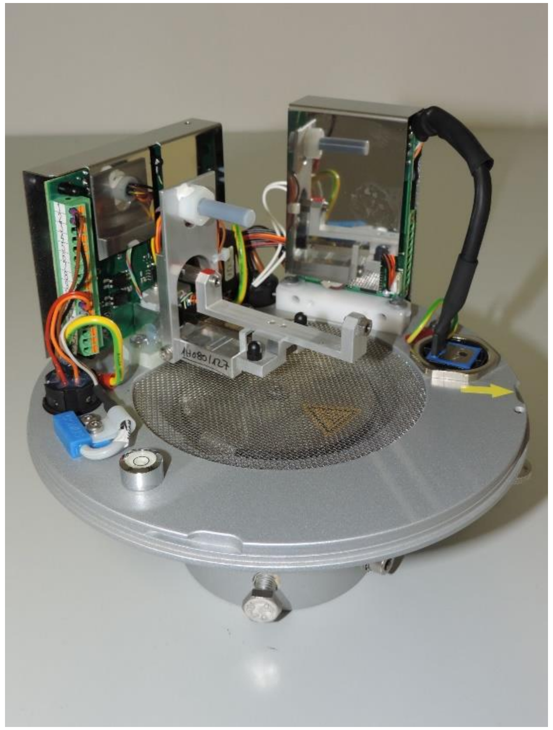
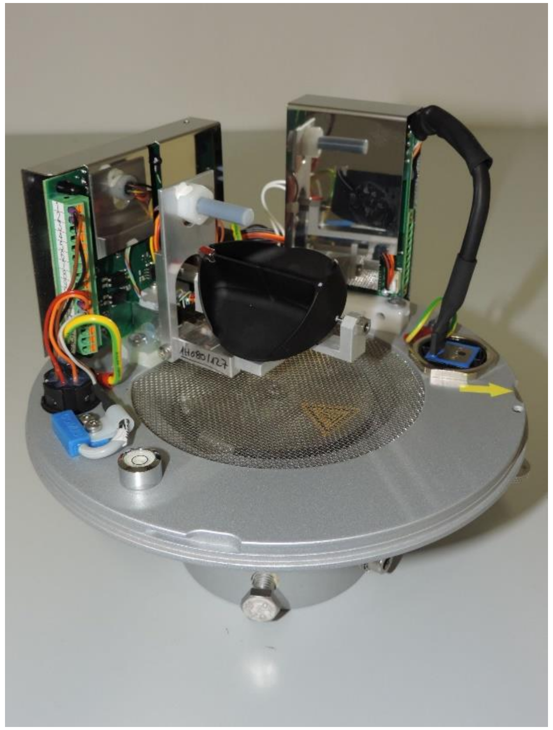
Calibration of rain gauges – example #2 (DWD)

- collecting rain gauge using a combination of tipping bucket and a weighing unit

assembled rain gauge



detailed view of the weight measuring unit



detailed view with installed tipping bucket

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Calibration of rain gauges – example #2

- the protective housing with the funnel is removed and the precipitation gauge is placed on a container made of PVC pipe
- this container is positioned on a precision balance together with the precipitation gauge
- instead of the original funnel, a replica of the funnel is positioned above the tipping bucket
- a pump whose speed can be varied to simulate the intensity of precipitation serves as a source

Calibration of rain gauges – example #2

- the precision scale shall be placed on a very stable surface such as a measuring table with a granite plate (in this case a concrete platform was used)

- to avoid vibrations, the pump is decoupled from the measurement setup as much as possible

- the DUT is connected to the computer with a cable (USB, RS485 + power supply)

- this cable naturally influences the weighing but it has been demonstrated that the impact is nearly negligible compared to the total mass

Calibration of rain gauges – example #2

- a stable room temperature is necessary
  ⇒ if air conditioning is used, it shall be designed in such a way that draughts cannot influence the results of the precision balance (if necessary, the entire setup shall be shielded)

- a suitable equalization time must be provided to avoid temperature differences between the water and air temperature

- the water can be reused, but should be replaced with fresh water from time to time

- the precision balance shall be adjusted every day using calibrated reference weights

Calibration of rain gauges – example #2

- the entire calibration process with three intensity levels (ten repetitions) is supported by a computer software
- the computer software controls the pump and reads the measured values from the device under test (DUT) and the precision balance
- the scale and the DUT are zeroed before each start of the pump

Calibration of rain gauges – example #2

- it is essential that the air pressure, temperature and relative humidity are measured in a suitable place

```
TI33C3/SLN
00309564
PTB
20190729
10:17:49;1005.25
10:17:59;1005.25
10:18:09;1005.25
10:18:19;1005.25
```

air pressure data

```
TI33C3/SLN
00351871
HC2-USB
20190729
00:00:03; 19,18; 66,86
00:00:13; 19,15; 66,80
00:00:23; 19,16; 66,78
00:00:33; 19,14; 66,74
```

data of temperature and relative humidity

- the measured values are used to calculate the air density, the density of the water and thus to calculate the air *buoyancy correction*
- a precipitation amount is calculated from all these calculations and the measured value of the precision scale

Calibration of rain gauges – example #2

the complete calibration setup

detailed view

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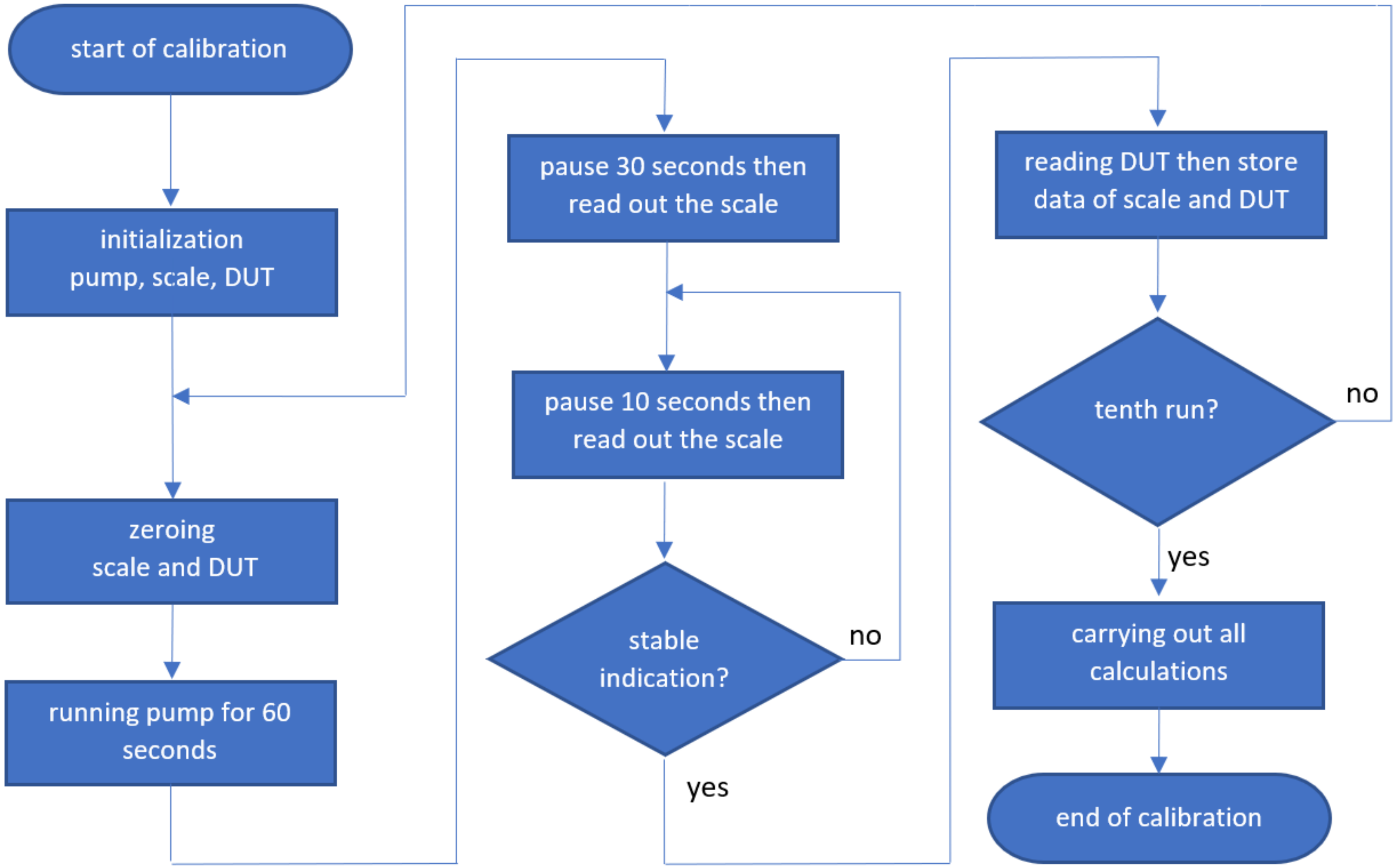
Calibration of rain gauges – example #2



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Calibration of rain gauges – example #2

- it is assumed, that the water temperature is the same as the temperature of air with an uncertainty of 5 K (not very critical) → type B

- the uncertainty for the temperature of air is 2 K → type B
- the relative humidity uncertainty is 3 % → type B
- the air pressure uncertainty is 0.5 hPa → type B

Calibration of rain gauges – example #2

- calculation of the amount in mm with modified formulas from EURAMET Calibration Guide No. 19 Version 3.0 (09/2018)

$$\varrho_{water} = 0.999974950 *(1 - ((t_{water} - 3.983035)^2 * (t_{water} + 301{,}797)) /$$

$$(522528{,}9 * (t_{water} + 69{,}34881))) +$$

$$(-4{,}612*10^6 + 0.106*10^6 * t_{water}) + \delta t_{water}$$

- note: All units are missing. Exact details in EURAMET CG 19 (1), (2)+(3), (5)!

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Calibration of rain gauges – example #2

- calculation of the amount in mm with modified formulas from EURAMET Calibration Guide No. 19 Version 3.0 (09/2018)

$$\varrho_{air} = ((0.34848 * p_{air} - 0.009 * u_{air} * \exp(0.061 * t_{air})) /$$

$$(t_{air} + 273{,}15)) / 1000 +$$

$$\delta t_{air} + \delta air\_pressure + \delta relative\_humidity$$

- note: All units are missing. Exact details in EURAMET CG 19 (1), (2)+(3), (5)!

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Calibration of rain gauges – example #2

- calculation of the amount in mm with modified formulas from EURAMET Calibration Guide No. 19 Version 3.0 (09/2018)

$$\text{reference\_in\_mm} = (\text{reference\_indication\_g} * 1 / (\varrho_{water} - \varrho_{air}) *$$

$$(1- (\varrho_{air} / \varrho_{reference\_weight}))) / 20 +$$

$$\delta\_\varrho_{water} + \delta\_ \varrho_{air}$$

- note: All units are missing. Exact details in EURAMET CG 19 (1), (2)+(3), (5)!

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Calibration of rain gauges – example #2

- model:

$$\Delta rain = dut - reference + \delta dut\_resolution + \delta dut\_splashed\_droplets + \delta dut\_evaporation + \delta dut\_emptying\_bucket - \delta cable\_influence - \delta reference\_evaporation - \delta reference\_resolution - \delta time$$

Δrain	result (dut - reference)
dut	indication of DUT intensity
reference	indication of reference intensity

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Calibration of rain gauges – example #2

- uncertainties:
  - type A: in this example there are ten readings of the precision scale and the DUT

reference_indication_g | dut

Name

Method Direct

No.	Estimated value
1	0,99
2	1,01
3	1,02
4	0,98
5	0,97
6	1,00
7	0,99
8	0,97
9	1,02
10	0,99

dut_indication | reference_indication_g

Name

Method Direct Unit g

No.	Estimated value
1	20,01
2	19,99
3	19,98
4	20,02
5	20,01
6	19,98
7	19,97
8	19,96
9	20,03
10	20,04

  - the distribution is a t-distribution and the uncertainty estimation is Bayesian standard uncertainty

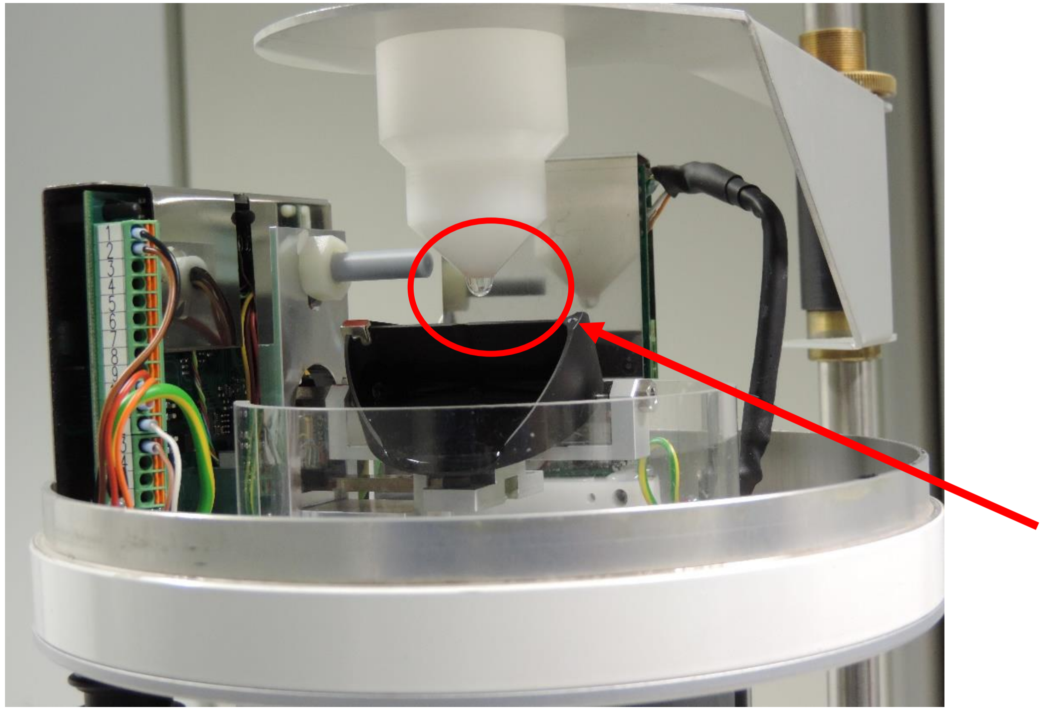
Calibration of rain gauges – example #2

- uncertainties type B:

δdut_resolution	the resolution of the DUT values is 0.001 mm
δdut_splashed_droplets	some droplets are splashed and do not end up in the bucket 0.0005 mm
δdut_evaporation	evaporation may occur at DUT 0.00025 mm
δdut_emptying_bucket	during the tilting movement, water may still flow into the bucket to be emptied 0.005 mm
δcable_influence	influence of the cable 0.001 mm
δreference_evaporation	evaporation may occur at reference 0.00025 mm
δreference_resolution	resolution of the reference values are 0.00025 mm

Calibration of rain gauges – example #2

- uncertainties:
  - δtime



Will this drop fall?

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Calibration of rain gauges – example #2

- uncertainties:
  - δtime
    - a residue of water can remain at the bottom of the funnel
    - this can fall down or get stuck depending on the dynamics and flow
    - experiments show that the mass of the falling drop can be as much as 0.14 g
    - the scale is read out first, then the DUT

      $\Rightarrow$ the drop could fall between the two readings

    - observations show, however, that the event of a drop coming loose is extremely rare
    - in this uncertainty analysis, this contribution is taken into account with 0.2 g or 0.01 mm and a rectangular distribution

Calibration of rain gauges – example #2

- result: Δrain = -0.01 mm ± 0.02 mm (k = 2)

Quantity	Value	Stand. uncert.	Distribution	DoF	Sensit. coeff.	Uncert. contribution	Rel. contribution	Bar chart
φwater	0,99773 g/cm^3	0,66x10^{-3} g/cm^3						
t_{water}	22,2 °C	2,9 °C	Rectangular	∞	-0,23x10^{-3} °C^{-1}	-0,66x10^{-3}	0,58 %	
φair	0,001208 g/cm^3	0,012x10^{-3} g/cm^3						
p_{air}	1,0268x10^{3} hPa	0,29 hPa	Rectangular	∞	-1,0x10^{-6} hPa^{-1}	-0,30x10^{-6}	0,00 %	
u_{air}	31,5 %rH	1,7 %rH	Rectangular	∞	0,10x10^{-6} %rH^{-1}	0,18x10^{-6}	0,00 %	
t_{air}	22,2 °C	2,9 °C	Rectangular	∞	3,8x10^{-6} °C^{-1}	0,011x10^{-3}	0,00 %	
reference	1,00329 mm	0,79x10^{-3} mm						
reference_indication_g	19,9990 g	0,0085 g	t-distribution	9	-0,050 g^{-1}	-0,43x10^{-3}	0,24 %	
φreference_weight	8 g/cm^2							
dut	0,9940 mm	0,0058 mm	t-distribution	9	1,0 mm^{-1}	0,0058	44,08 %	
δdut_resolution	0,0 mm	0,29x10^{-3} mm	Rectangular	∞	1,0 mm^{-1}	0,29x10^{-3}	0,11 %	
δdut_splashed_droplets	0,0 mm	0,29x10^{-3} mm	Rectangular	∞	1,0 mm^{-1}	0,29x10^{-3}	0,11 %	
δdut_evaporation	0,0 mm	0,14x10^{-3} mm	Rectangular	∞	1,0 mm^{-1}	0,14x10^{-3}	0,03 %	
δdut_emptying_bucket	0,0 mm	0,0029 mm	Rectangular	∞	1,0 mm^{-1}	0,0029	10,87 %	
δcable_influence	0,0 mm	0,58x10^{-3} mm	Rectangular	∞	1,0 mm^{-1}	0,58x10^{-3}	0,43 %	
δreference_evaporation	0,0 mm	0,14x10^{-3} mm	Rectangular	∞	1,0 mm^{-1}	0,14x10^{-3}	0,03 %	
δreference_resolution	0,0 mm	0,14x10^{-3} mm	Rectangular	∞	1,0 mm^{-1}	0,14x10^{-3}	0,03 %	
δtime	0,0 mm	0,0058 mm	Rectangular	∞	1,0 mm^{-1}	0,0058	43,50 %	
	Value	Comb. stand. uncertainty			Effective degrees of freedom			Sign. digits
Δrain	-0,0093	0,0088			46			2
	Value	Expanded uncertainty			Coverage factor (Probability)		Distribution	Sign. digits
Result	-0,01	± 0,02			2,00 (95,45 %)		Normal	1

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Calibration of Rain Gauges
End of Part 3

Thank you.

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