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-4: Calibration Examples (2)

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

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Calibration of rain gauges – example #3 (TSMS)

- a tipping bucket rain gauge uses a tipping balance with two buckets

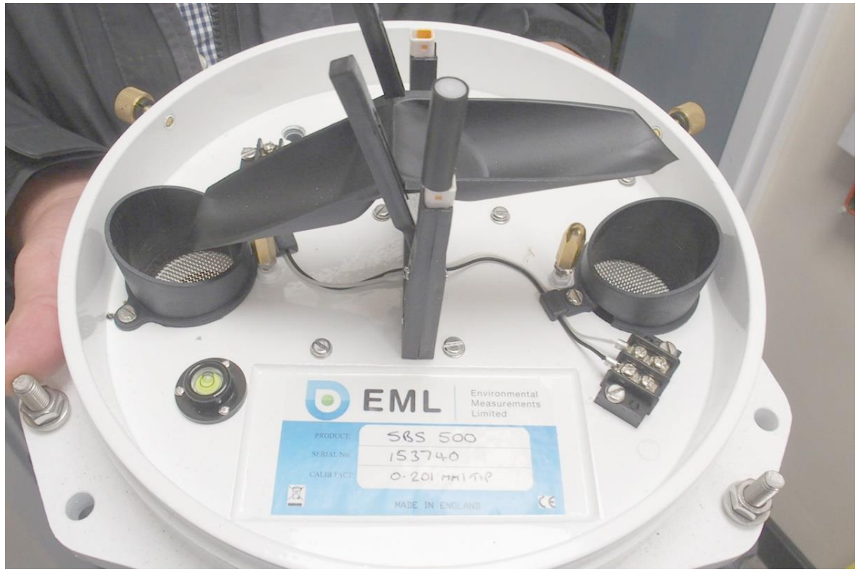

Photo: DWD Mr. Bender

- at very high intensities, the movement of the tipping-bucket trough can be stalled

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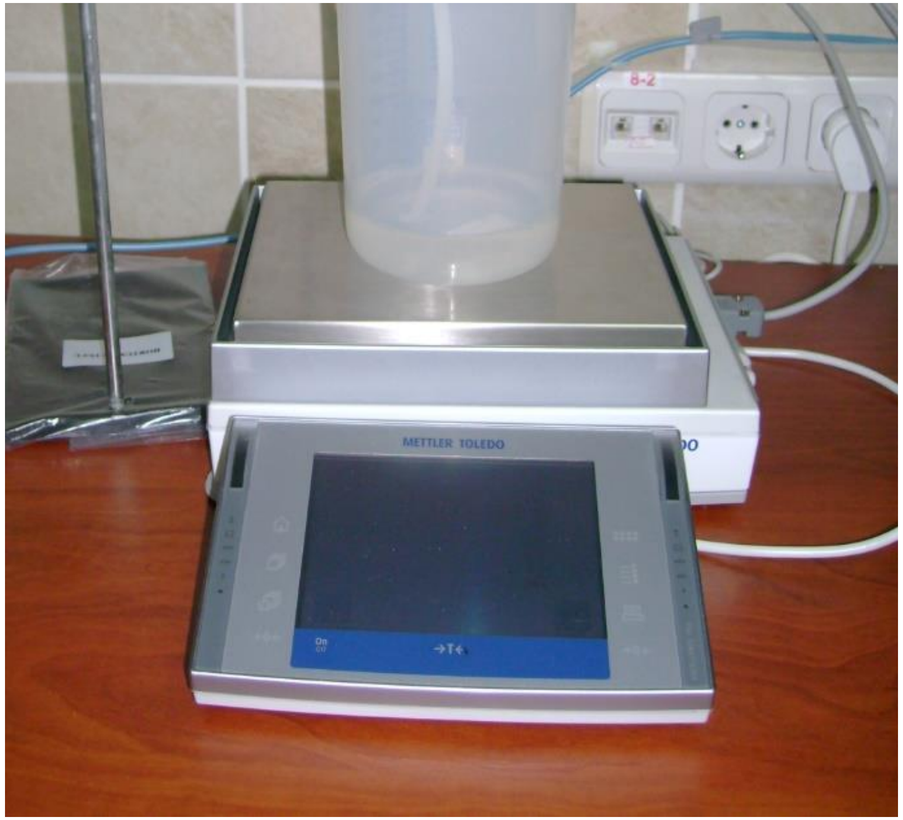
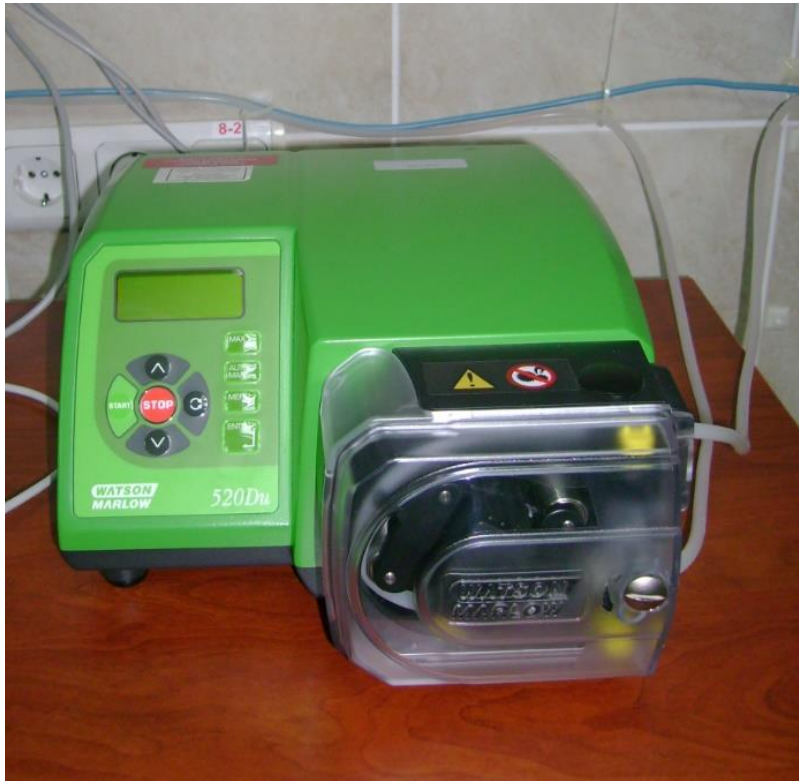
Calibration of rain gauges – example #3

- reference device (precision balance):
  - a precision balance is used as reference standard of the laboratory



Calibration of rain gauges – example #3

- rain simulator:
  - calibration procedure of tipping bucket rain gauges requires measurements at different rain intensities
  - in order to simulate various intensities, a peristaltic pump is used



Calibration of rain gauges – example #3

- calibration points (levels):
  - for example, four different intensities may be chosen (10, 30, 50, 100 mm/h)
  - the reason to choose different rain intensity levels is to evaluate the performance of rain gauge since the tipping is affected mainly by the rain intensity as a fundamental source of errors

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Calibration of rain gauges – example #3

- calibration measurements:

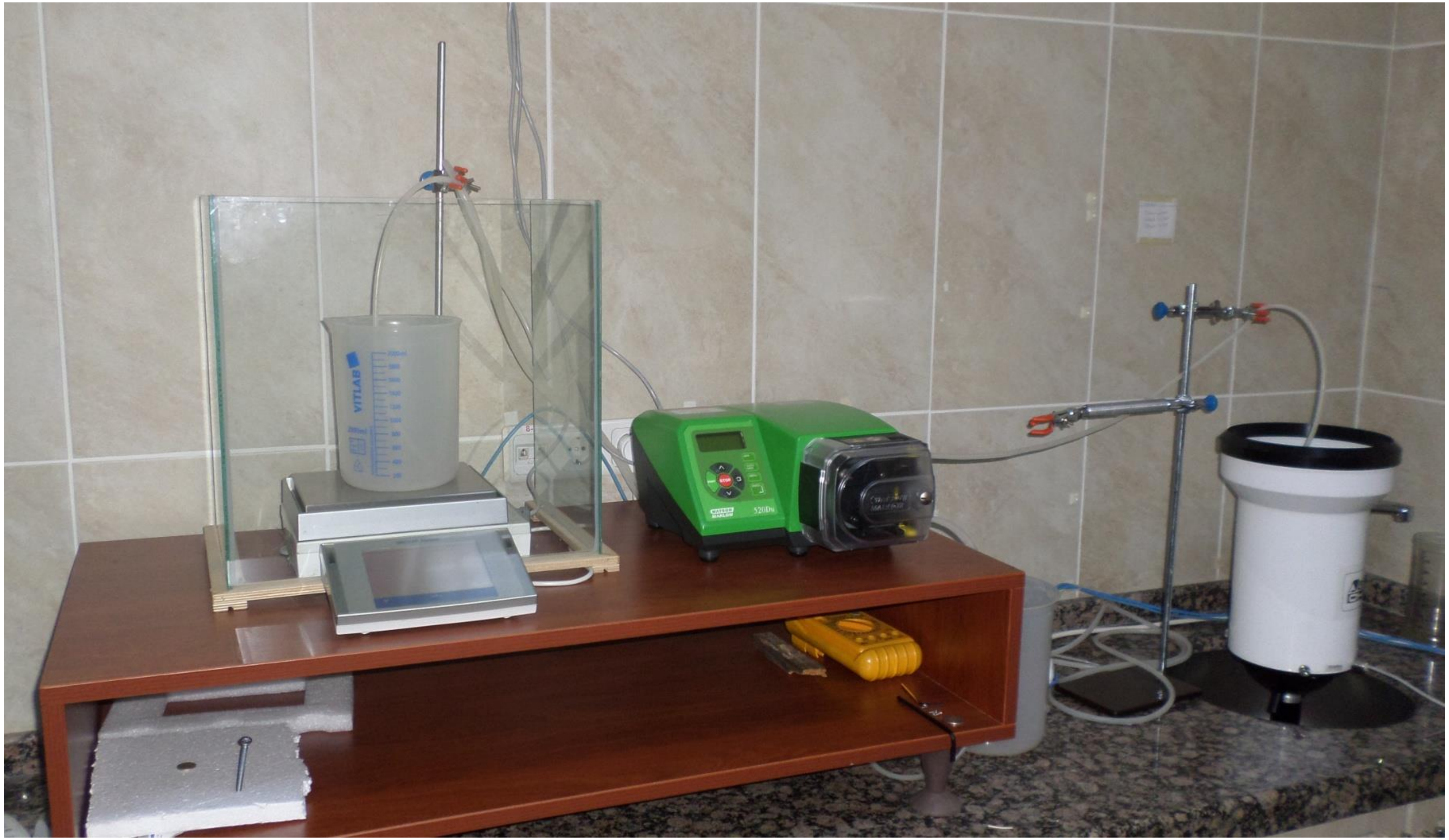
  - reference measurement is the difference between the values of precision balance (units: g) at the start and the end of rain simulation for each calibration point

  - this value is transferred into rain intensity (mm/h) by using time elapsed (unit: hours) and collection area of the rain gauge (cm^2)

Calibration of rain gauges – example #3

- calibration measurements:
  - test device measurements are taken in terms of number of pulses and then transferred into rain intensity by using bucket resolution (g) and rain gauge collection area (cm^2) to be able to compare with the reference values
  - since the measurements of reference balance is in terms of mass (g), while tipping bucket sensors measure rain amount (g)
  - both measurements should have been translated into same units as rain intensity (mm/h)

Calibration of rain gauges – example #3



Calibration of rain gauges – example #3

- model:

$$t_x = t_s + \Delta t + \delta_{r\_unc} + \delta_{r\_res} + \delta_{r\_rep} + \delta_{r\_drift} +$$

$$\delta_{sys\_rep} + \delta_{pump\_unc} + \delta_{evapo} + \delta_{DUT\_res} + \delta_{t\_delay}$$

t_x	rain intensity (RI_{DUT}) of the DUT
t_s	rain intensity (RI_{Ref}) of the reference
Δt	error ($RI_{DUT} - RI_{Ref}$)

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Calibration of rain gauges – example #3

- uncertainties:

δ_{r_unc}	uncertainty of the reference
δ_{r_res}	resolution of the reference
δ_{r_rep}	repeatability of the reference
δ_{r_drift}	drift of the reference
δ_{sys_rep}	repeatability of the calibration system
δ_{pump_unc}	uncertainty of the peristaltic pump
δ_{evapo}	effect of the water evaporation of the system
δ_{DUT_res}	resolution of the DUT
δ_{t_delay}	effect of the system time delay

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Calibration of rain gauges – example #3

- uncertainties:

UNCERTAINTY PARAMETERS	ESTIMATED VALUE	DISTRIBUTION	DENOMINATOR	COEFFICIENT	STANDARD UNCERTAINTY	PARTIAL VARIANT (g)
Reference Uncertainty (g)	0,1000000000	normal	2	1	0,0500000000	0,0025000000
Reference Resolution (g)	0,05	rectangular	1,73	1	0,0289017341	0,0008353102
Reference Repeatability (g)	0,0447213595	normal	1	1	0,0447213595	0,0020000000
Reference drift (g)	0,2	rectangular	1,73	1	0,1156069364	0,0133649637
System Repeatability (g)	0,0577350269	normal	1	1	0,0577350269	0,0033333333
Pump Uncertainty (g)	1,9000000000	normal	1	1	1,9000000000	3,6100000000
Evaporation effect of System(g)	0,2645751311	normal	1	1	0,2645751311	0,0700000000
DUT Resolution (g)	4,0000000000	rectangular	1,73	1	2,312138728	5,3459854990
Time Delay Effect (g)	0,1000000000	normal	1	1	0,1	0,0100000000

Total Variant (g)	9,0580191063
Standard Uncertainty (g)	± 3,009654317
Expanded Uncertainty (k=2) (g)	± 6,019308633
Rounded up Uncertainty (g)	**± 6,02**
UNCERTAINTY	**%2**

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Calibration of rain gauges – example #3

- result:

Reference Rain Intensity (mm/h)	DUT Rain Intensity (mm/h)	Counted Pulses of DUT (Number of Tips)	Error (kg/m²)	Relative Error (%)	Uncertainty (%)
10.32	10.2	51	-0.12	-1.16	2
30.84	30.8	154	-0.04	-0.13	2
51.46	51.4	257	-0.06	-0.12	2
102.61	102.6	513	-0.01	-0.01	2
Resolution of DUT: 0.2 mm Collection area of DUT: 200 cm^2					

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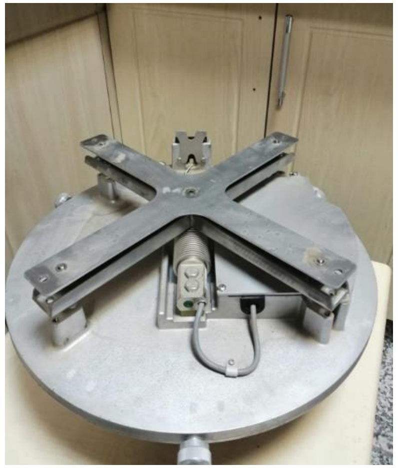
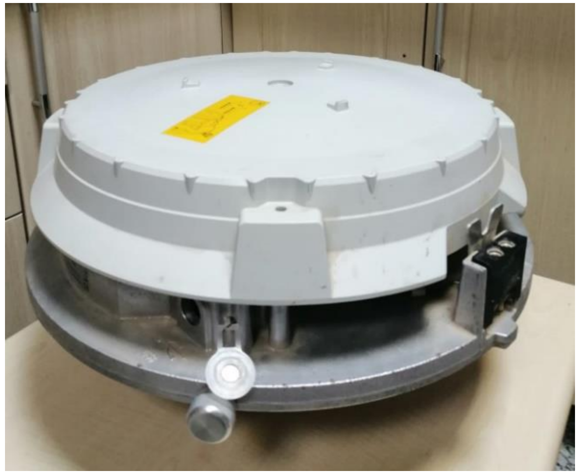
Calibration of rain gauges – example #4 (TSMS)

- collecting rain gauge using a weighing unit

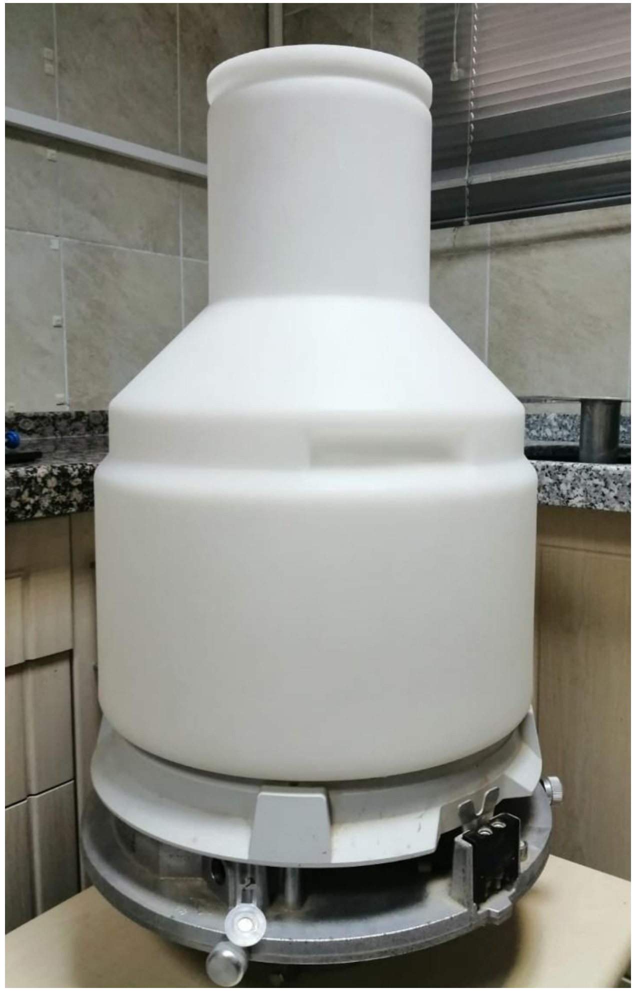
- this rain gauge collects the rain in a container
- digital readout
- collecting area is 400 cm^2



detailed view of the weighing unit



with housing removed



assembled rain gauge

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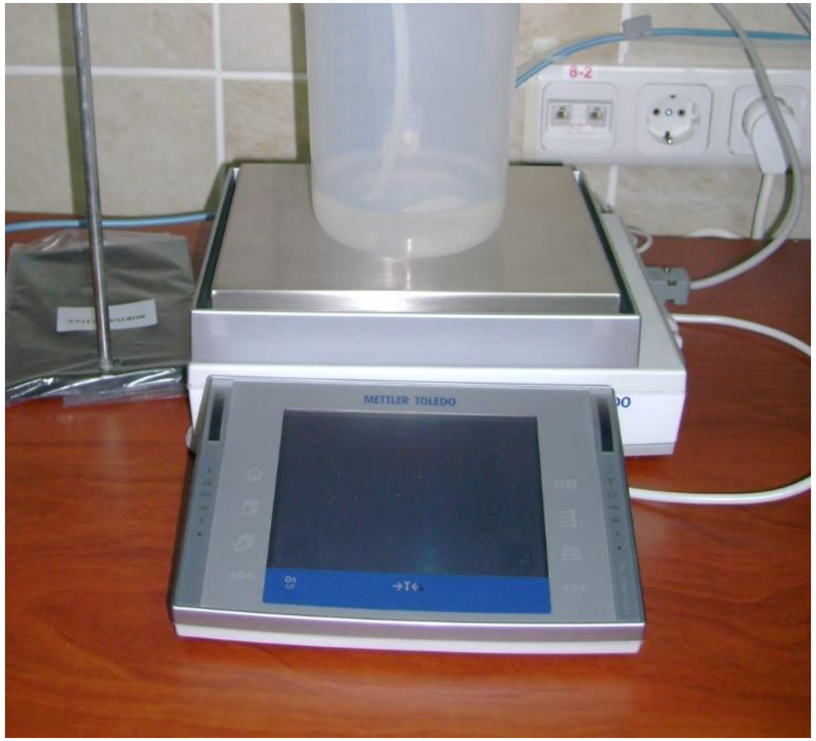
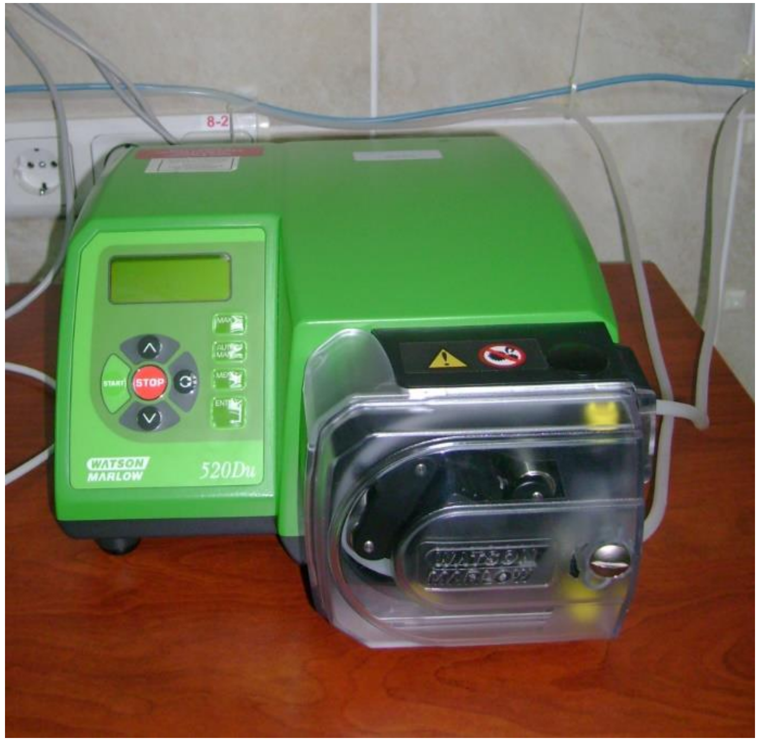
Calibration of rain gauges – example #4

- as in the previous example, a precision scale and a pump are used to simulate precipitation





Calibration of rain gauges – example #4

- calibration points (levels):

  - calibration for almost any kind of measurement instrument is advised to be made in different amounts of measurement range to reveal the performance of the instrument

  - for example, four different amounts may be chosen (50, 100, 500, 2000 g)

Calibration of rain gauges – example #4

- calibration measurements:
  - measurements taken from the device under calibration and reference balance for each calibration point are recorded
  - reference measurement is the difference between the values of precision balance (units: g) at the start and the end of rain simulation for each calibration point
  - test device measurements are taken in terms of rain amount (mm) it is transferred into rain amount (units: g) to compare with the reference value

Calibration of rain gauges – example #4

- model:

$$W_{error} = W_{DUT} - W_{ref} + \delta_{r\_unc} + \delta_{r\_res} + \delta_{r\_rep} + \delta_{r\_drift} + \delta_{sys\_rep} + \delta_{pump\_unc} + \delta_{sys\_evapo} + \delta_{DUT\_evapo} + \delta_{DUT\_res} + \delta_{t\_delay} + \delta_{other}$$

W_{error} error

W_{DUT} reading of the DUT

W_{ref} reading of the reference

Calibration of rain gauges – example #4

- uncertainties:

δ_{r_unc}	uncertainty of the reference
δ_{r_res}	resolution of the reference
δ_{r_rep}	repeatability of the reference
δ_{r_drift}	drift of the reference
δ_{sys_rep}	repeatability of the calibration system
δ_{pump_unc}	uncertainty of the peristaltic pump
δ_{sys_evapo}	effect of the water evaporation of the system
δ_{DUT_evapo}	effect of the water evaporation of the DUT
δ_{DUT_res}	resolution of the DUT
δ_{t_delay}	effect of the system time delay
δ_{other}	estimated other effects

Calibration of rain gauges – example #4

- uncertainties:

UNCERTAINTY PARAMETERS (50 g)	ESTIMATED VALUE	DISTRIBUTION	DENOMINATOR	COEFFICIENT	STANDARD UNCERTAINTY	PARTIAL VARIANT (g)
Reference Uncertainty (g)	0,1000000000	normal	2	1	0,0500000000	0,0025000000
Reference Resolution (g)	0,1000000000	rectangular	1,73	1	0,0578034682	0,0033412409
Reference Repeatability (g)	0,0000000000	normal	1	1	0,0000000000	0,0000000000
Reference drift (g)	0,2000000000	rectangular	1,73	1	0,1156069364	0,0133649637
DUT Repeatability (g)	0,2262741700	normal	1	1	0,2262741700	0,0512000000
System Repeatability (g)	0,0547722558	normal	1	1	0,0547722558	0,0030000000
Pump Uncertainty (g)	0,2200000000	normal	1	1	0,2200000000	0,0484000000
Evaporation effect of System (g)	0,0836660027	normal	1	1	0,0836660027	0,0070000000
Evaporation effect of DUT (g)	0,0836660027	normal	1	1	0,0836660027	0,0070000000
DUT Resolution (g)	0,0500000000	rectangular	1,73	1	0,0289017341	0,0008353102
Time Delay Effect (g)	0,1000000000	normal	1	1	0,1	0,0100000000
Other Uncertainty (g)	0,4000000000	normal	1	1	0,4	0,1600000000

Total Variant (g)	0,3066415149
Standard Uncertainty (g)	± 0,553752214
Expanded Uncertainty (k=2) (g)	± 1,107504429
Rounded up Uncertainty (g)	**± 1,11**
UNCERTAINTY (%)	2,215008857

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Calibration of rain gauges – example #4

- uncertainties:

UNCERTAINTY PARAMETERS (2000 g)	ESTIMATED VALUE	DISTRIBUTION	DENOMINATOR	COEFFICIENT	STANDARD UNCERTAINTY	PARTIAL VARIANT (g)
Reference Uncertainty (g)	0,1000000000	normal	2	1	0,0500000000	0,0025000000
Reference Resolution (g)	0,1000000000	rectangular	1,73	1	0,0578034682	0,0033412409
Reference Repeatability (g)	0,0000000000	normal	1	1	0,0000000000	0,0000000000
Reference drift (g)	1,1879393924	rectangular	1,73	1	1,1879393924	1,4112000000
DUT Repeatability (g)	0,2000000000	normal	1	1	0,1156069364	0,0133649637
System Repeatability (g)	0,0547722558	normal	1	1	0,0547722558	0,0030000000
Pump Uncertainty (g)	6,6000000000	normal	1	1	6,6000000000	43,5600000000
Evaporation effect of System (g)	0,0836660027	normal	1	1	0,0836660027	0,0070000000
Evaporation effect of DUT (g)	0,0836660027	normal	1	1	0,0836660027	0,0070000000
DUT Resolution (g)	0,0500000000	rectangular	1,73	1	0,0289017341	0,0008353102
Time Delay Effect (g)	0,1000000000	normal	1	1	0,1	0,0100000000
Other Uncertainty (g)	0,4000000000	normal	1	1	0,4	0,1600000000

Total Variant (g)	45,1782415149
Standard Uncertainty (g)	± 6,721476141
Expanded Uncertainty (k=2) (g)	± 13,44295228
Rounded up Uncertainty (g)	**± 13,44**
UNCERTAINTY (%)	0,672147614

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Calibration of rain gauges – example #4

- result:

Reference Reading (g)	DUT Reading (g)	Calculated Rain Amount of DUT (mm)	Error (g)	Relative Error (%)	Uncertainty (%)
50.20	50.00	1.25	-0.20	-0.40	2.70
100.30	99.60	2.49	-0.70	-0.70	2.40
500.40	498.00	12.45	-2.40	-0.48	1.20
2000.60	1987.20	49.68	-13.40	-0.67	1.00
DUT collection area: 400 cm^2 By calculation; 1 mm rain amount of DUT = (400 cm^2 x 1000 g) / 10000 cm^2 = 40 g					

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References and links

- JCGM 200:2012

  International Vocabulary of Metrology - Basic and general concepts and associated terms (2012)

  https://www.bipm.org/en/committees/jc/jcgm/publications

- JCGM 100:2008(E) – in English

  Evaluation of measurement data - **Guide to the expression of uncertainty in measurement** (2008)

  https://www.bipm.org/en/committees/jc/jcgm/publications

References and links

- **Guide to Instruments and Methods of Observation (WMO-No. 8)**

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- Goodison, B. E.; Louie, P. Y. T.; Yang, D. WMO Solid Precipitation Measurement Intercomparison (WMO/TD-No. 872). Final report. Instruments and Observing Methods (IOM) Report No. 67; World Meteorological Organization (WMO): Geneva, 1998.

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  https://www.euramet.org/publications-media-centre/calibration-guidelines

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Calibration of Rain Gauges
End of Part 4

Thank you.

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