Rückführung der Absolutschweremessungen mit dem hannoverschen FG5X-220 auf SI-Einheiten

Traceability of absolute gravity measurements to SI units with the FG5X-220 in Hannover

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Motivation

FG5X-220 at TU Clausthal

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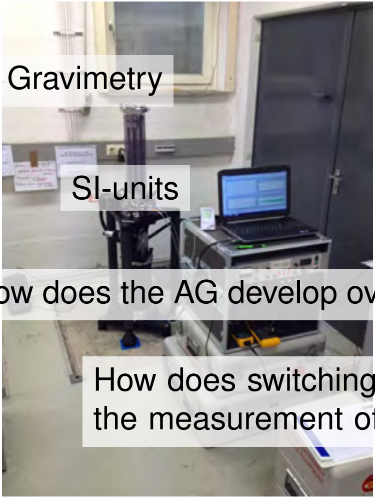


Absolute Gravimetry

SI-units

How does the AG develop over time?

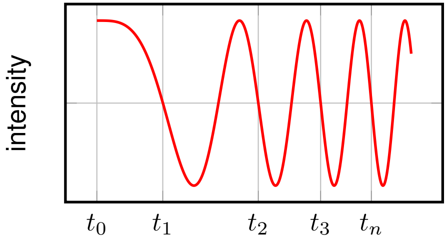
How does switching parts affect the measurement of g?

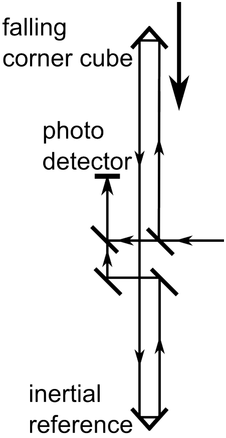
FG5X-220 at TU Clausthal

Principle of AG by laser interferometry

- Falling macroscopic object
- Observation of distance and time
  - Drop 20 cm/0.2 s FG5
  - Drop 31 cm/0.25 s FG5X

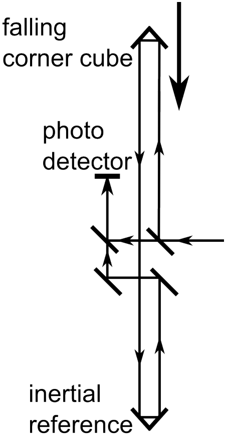
$\rightarrow$ FG5X: reference height +4 cm



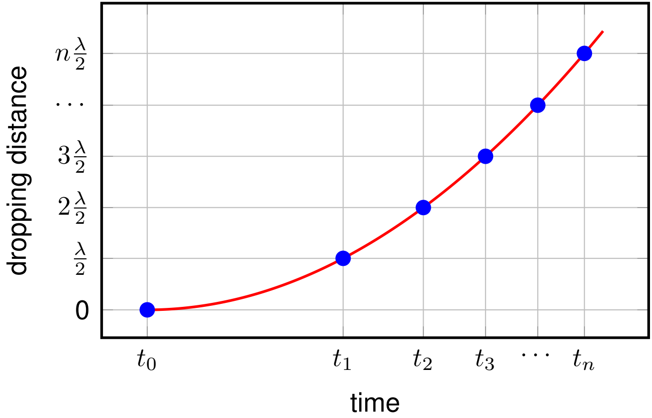


Principle of AG by laser interferometry

- Falling macroscopic object
- Observation of distance and time
- Length standard: HeNe Laser ($\lambda = 633\,\mathrm{nm}$)
- 10 MHz rubidium oscillator



Absolute Gravimetry



parabola fit to time-distance measurements

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Least squares adjustment

$$z(t) = z_0\left(1 + \frac{\gamma}{2}t\right) + v_0\left(t + \frac{\gamma}{6}t^3\right) + \frac{1}{2}g_0\left(t^2 + \frac{\gamma}{12}t^4\right)$$

z_0, v_0, g_0 : initial position, velocity, gravity

γ : vertical gradient in gravity

Absolute Gravimetry

"Absolute" $\rightarrow$ measurement includes standards

- No external references, e.g. gravity network or reference point
- Determination of g only dependent on internal standards
- Establishment of gravity networks with accuracy independent of distances between stations

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Offsets between AGs at the order of some $10\,\mathrm{nm\,s^{-2}}$ have to be considered.

Laser-System

- Iodine stabilized HeNe Laser with 633 nm wavelength
- Frequency reproducibility ± 5 kHz ($\approx 1 \times 10^{-11}$) [Chartier et al., (1993)]
- Practical realization of the definition of the SI meter by CIPM [Quinn, T.J. (2003)]

SI Units in AG

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Laser frequency modulation (8333 Hz) for detection of iodine peaks
$\rightarrow$ influence is negligible ($\approx 0.1\,\mathrm{nm\,s^{-2}}$ per 0.1 Hz)

SI Units in AG

10 MHz rubidium oscillator [Niebauer et al. (1995)]

- Frequency uncertainty 3.4×10^{-10}
- Drift 4×10^{-11}/month $\rightarrow 0.4 \times 10^{-3}$ Hz/month
- Effect $\Delta f = 5 \times 10^{-3}$ Hz $\rightarrow 10\,\mathrm{nm\,s^{-2}}$

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Comparison with GPS stabilized rubidium clock (Meinberg GRP portable frequency reference)

Accuracy

- $\pm 2 \times 10^{-12}$ GPS locked
- $\pm 5 \times 10^{-11}$ no GPS

Additionally: comparisons at metrology laboratories

Frequency comparison FG5X-220 – GRP

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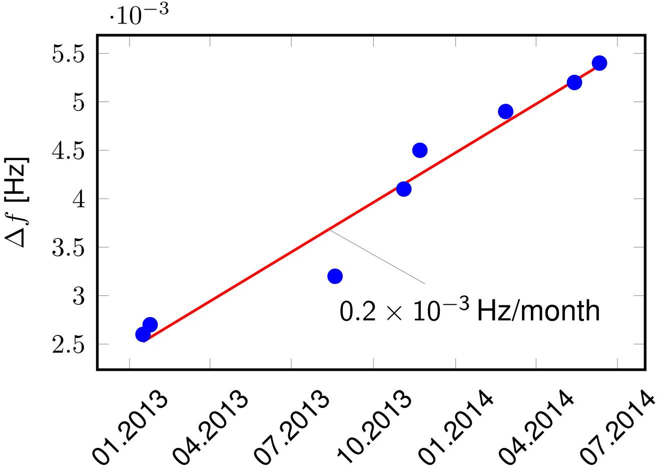

Traceability

Two different approaches

- Individual tests of standards of length and time
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Draft *CCM - IAG Strategy for metrology in AG*

→ Comparison of frequencies

→ Key comparison of absolute gravimeters

CIPM-MRA defines various configurations for KC of international and regional scope

Traceabilityby comparisons of instruments

How to compare to a reference value without instrument of higher order available?

$\rightarrow$ Group of AG: *Key Comparison Reference Value*

- ICAG/ECAG (CCM.G-K*x*/EURAMET.M.G-K*x*)
- Regional comparison

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Procedure (CIPM-MRA):

- KC participants: NMI/DI[1]
- Determination of KCRV/Degree of Equivalence

[1] National Metrology Institute and Designated Institute

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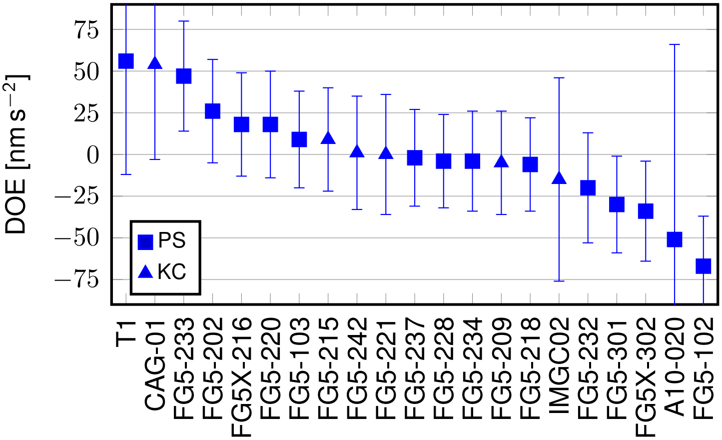
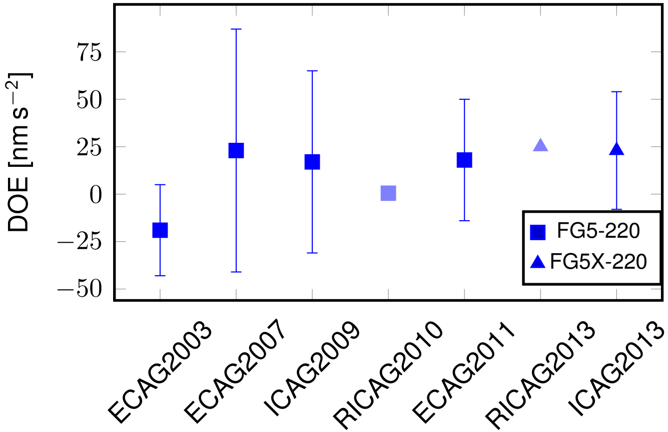


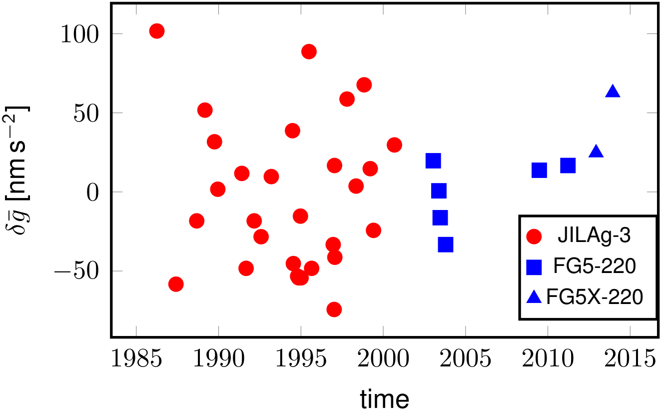
Result of ECAG-2011/EURAMET.M.G-K1 with (expanded) uncertainties [Francis et al., (2013)]

Traceability by comparisons of instruments



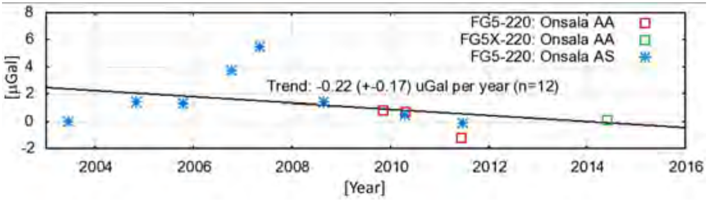
KC of FG5(X)-220 with uncertainties according to final report.
Results of RICAG/BKG are deviation to mean of participants.

Traceability by comparison to station



Measurements of IfE AGs at TU Clausthal

Traceability by comparison to station



Measurements of FG5(X)-220 in Onsala (Sweden).
Corrected with SG data since 2009 [Timmen et al. (2014)].

FG5X fits into trend of FG5 data.

Traceability with singe instruments

Difference of FG5(X)-220 and FG5-215/233 results before and after upgrade in 2012.

	ΔFG5-233 [$\mathrm{nm\,s^{-2}}$]	ΔFG5-215 [$\mathrm{nm\,s^{-2}}$]	
RICAG 2010	-25	-3	FG5-220
ECAG 2011	-29	9	
RICAG 2013	-6	20	FG5X-220
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Onsala 2014	7		

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- Limited number of simultaneous observations
- Apparent offset of 20 nm s^{-2} after upgrade

Conclusion

Test of standards

- Laser wavelength not tested
- Comparison of $10\,\mathrm{MHz}$ oscillator with GRP shows linear drift of $0.2 \times 10^{-3}\,\mathrm{Hz/month}$

Test of instrument

- Participation at KCs show a DOE of $20\,\mathrm{nm\,s^{-2}}$ with KCRV independent of FG5 upgrade
- Measurements at some stations show slightly higher *g* after upgrade
- Comparison with selected FG5 show apparent offset after upgrade

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→further investigations necessary

Thank you for your attention

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abkverz

AG	absolute gravimetry
CCM	Consultative Committee for Mass and related quantities
CIPM	Comité International des Poids et Mesures, bzw. International Committee for Weights and Measures
DI	Designated Institute
DOE	Degree of Equivalence
ECAG	European Comparison of Absolute Gravimeters
ICAG	International Comparison of Absolute Gravimeters
KC	Key Comparison
KCRV	Key Comparison Reference Value
MRA	Mutual Recognition Arrangement
NMI	National Metrology Institute
PS	Pilot Study