Comment on ‘Measurement of the speed-of-light perturbation of free-fall absolute gravimeters’

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Abstract
The paper by Rothleitner et al (2014 Metrologia 51 L9) reports on the measurement of the speed-of-light perturbation in absolute gravimeters. The conclusion that the perturbation reaches only 2\(\frac{3}{3}\) of the commonly accepted value violates the fundamental limitation on the maximum speed of information transfer. The conclusion was deluded by unaccounted parasitic perturbations, some of which are obvious from the report.

Keywords: absolute gravimeter, speed-of-light correction, parasitic perturbations

(Some figures may appear in colour only in the online journal)

1. The \(2\frac{2}{3}\) result and its interpretations

The speed-of-light perturbation in absolute gravimeters is due to the fact that the laser beam reflected from the test mass delivers the information on its position with some delay. The light reflected at the moment \(t\) reaches the beam splitter at a later moment \(t'\), so that

\[
 t' = t + \frac{z}{c},
\]

where \(z\) is the distance travelled by the light and \(c\) is the speed of light (figure 1).

The paper [1] reports on the experiment which agrees better with the formula

\[
 t' = t + \frac{2}{3} \frac{z}{c}.
\]

As there are only two values, \(z\) and \(c\), involved in the correction (1), the only two possible interpretations of the result (2) would be

\[
 \frac{2}{3} \frac{z}{c} = \frac{2}{3} \frac{z}{c} \quad \text{or} \quad \frac{2}{3} \frac{z}{c} = \frac{z}{\frac{2}{3} c}.
\]

The first interpretation means that the path travelled by the light is one-third less than the distance to the beam splitter.

Another equivalent interpretation means that the information was delivered 50% faster than the speed of light.

2. The experiment

The experiment compared the values of the gravity acceleration obtained at different drop lengths. Based on the fact that the speed-of-light perturbation depends on the drop length, the analysis of the data has revealed that the observed dependence
is better described by the commonly accepted formula, if it is multiplied by the factor $\frac{2}{3}$. The experiment included two sets of lengths resulted from varying either the first fringe (FF) or the last fringe (LF) of the drop. The longest drops were the same in both sets, spanning 30 cm covered by the test mass in 0.222 s.

The major difficulty of the experiment is that almost all instrumental perturbations also depend on the drop length, so their influences had to be excluded as part of the data analysis. Though much effort was devoted to identifying and eliminating other perturbances, there is evidence that the analysis is incomplete.

3. Some problems with the data analysis

The formula for the speed-of-light perturbation of the acceleration [2] used in the analysis yields 14.18 µGal for the longest drops in both sets, so that one-third of the correction is 4.73 µGal. However, in figure 4 of [1] (FF set) this difference reaches only 2.2 µGal, and in figure 5 (LF set) it is only 1.1 µGal. In addition to being much lower than the right value, the LF and FF results disagree between themselves, even though the longest drops are the same in both sets. These facts indicate the presence of large non-speed-of-light perturbations not accounted for in the analysis.

According to [1], one of the harmonics present in the stacked residuals has an amplitude of 0.025 nm and a frequency of 7 Hz. Figure 2 shows the perturbation caused by the harmonic found by fitting a quadratic parabola to it using the same data points as in the original experiment [1]. The calculations show that the perturbation can reach 4 µGal at the shortest drops. This value is in good agreement with the result of [3] (section 4.2.1) and about an order of magnitude higher than 0.46 µGal estimated in the report (probably, for the longest drop only). The exact influence of the harmonic on the experiment depends on the initial phase (figure 2). No phase, however, leaves any chance to the $\frac{2}{3}$ result to withstand.

4. Conclusions

The paper [1] presents the first attempt at a measurement of the speed-of-light perturbation in absolute gravimeters. The result that the perturbation reaches only $\frac{2}{3}$ of the commonly accepted value requires the information to be delivered faster than the speed of light. The result is caused by other perturbations not accounted for in the analysis. We have analysed only one perturbation and found that its magnitude is about nine times higher than reported in [1]. It is possible that the analysis of other perturbations can also benefit from review by other researchers. Because few of them possess technical means to reproduce the experiment, it is desirable that the authors of [1] (should they stand by their conclusion) publish a more detailed description of the data processing along with the raw data used in the analysis\(^2\). This would allow for independent verification of the result and enhancement of future experiments.

References

[1] Rothleitner Ch, Niebauer T M and Francis O 2014 Measurement of the speed-of-light perturbation of free-fall absolute gravimeters Metrologia 51 L9
[2] Robertsson L 2005 Absolute gravimetry in a shifted Legendre basis Metrologia 42 458
[3] Svitlov S 2012 Frequency-domain analysis of absolute gravimeters Metrologia 49 706

\(^2\) Many modern journals including Metrologia allow for online publishing of such supplementary materials.