Evaluation of the uncertainty of the coefficient of thermal expansion of a ceramic dimensional gauge block measured by interferometry.

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This project focuses on evaluating the standard uncertainty of the coefficient of thermal expansion of a ceramic dimensional gauge block using a Michelson interferometer. The precise knowledge of the physical properties of gauge blocks used as references in the calibration of dimensional magnitude measuring instruments is crucial for reliable measurement. Part of the project is the proposed design of the measurement system and the calculation of the best estimate to evaluate the uncertainty of the coefficient of thermal expansion.

Thermal Expansion Model

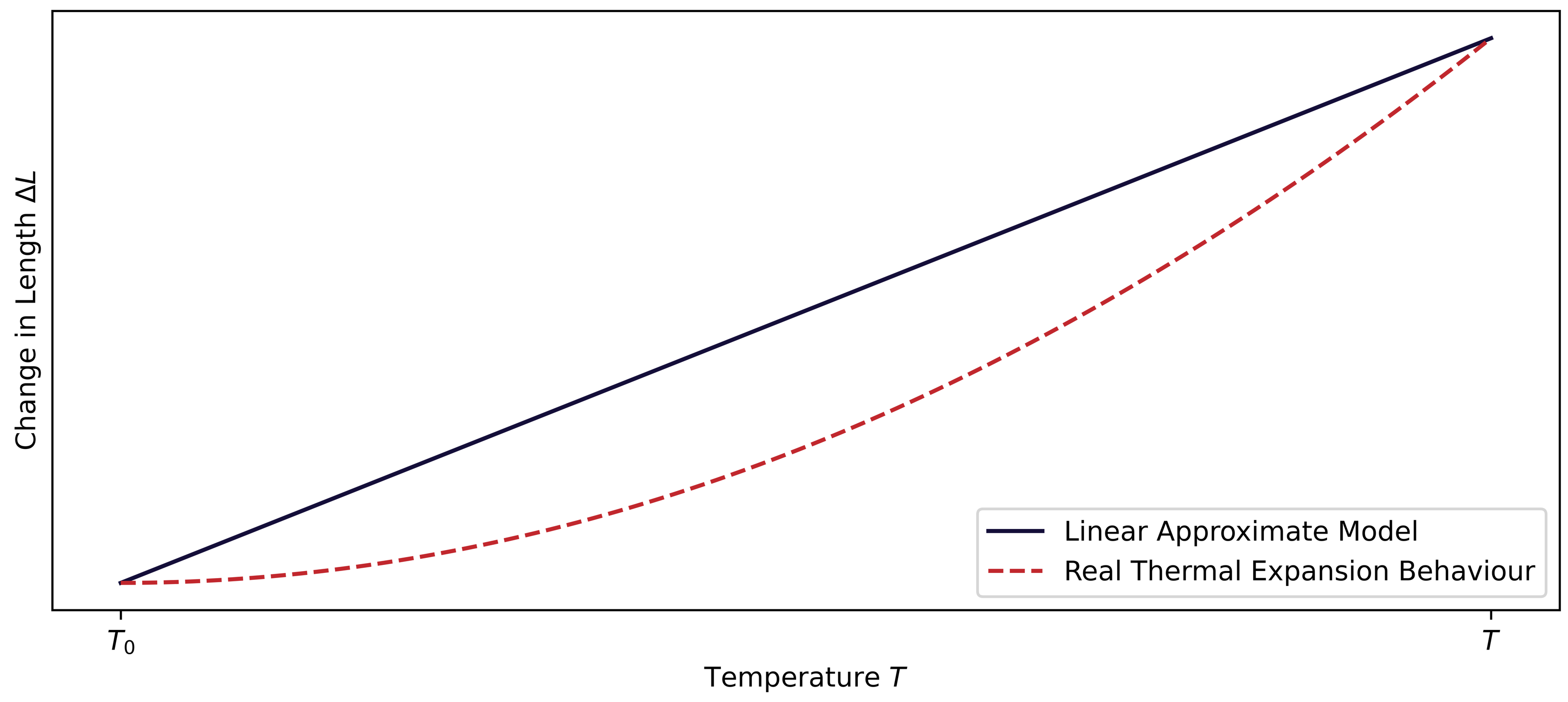

Figure 1. Model representation of the response of length of an object given a change in the temperature of the object.

By considering the thermal expansion of solids as a linear model when taking a defined difference in temperature, it is possible to determine the coefficient of expansion α as the rate of change of length when a change in temperature is applied to said solid. The coefficient of expansion can be expressed as

$$\alpha = \frac{N\lambda}{2\,L_0\,(T - T_0)}$$

where N is the number of transitions of the interference pattern, λ is the wavelength of the laser used in the method, L_0 represents the original length of the block at a temperature T_0, and T is the temperature at which the count of transitions stops, or the final temperature.

Standard Combined Uncertainty

$$u(\alpha) = \left[\left(\frac{\alpha}{L_0}\cdot u(L_0)\right)^2 + \left(\frac{\alpha}{(T-T_0)}\cdot u(T)\right)^2 + \left(\frac{\alpha}{(T-T_0)}\cdot u(T_0)\right)^2 + \left(\frac{\alpha}{N}\cdot u(N)\right)^2 + \left(\frac{\alpha}{\lambda}\cdot u(\lambda)\right)^2\right]^{1/2}$$

Contribution of Uncertainties

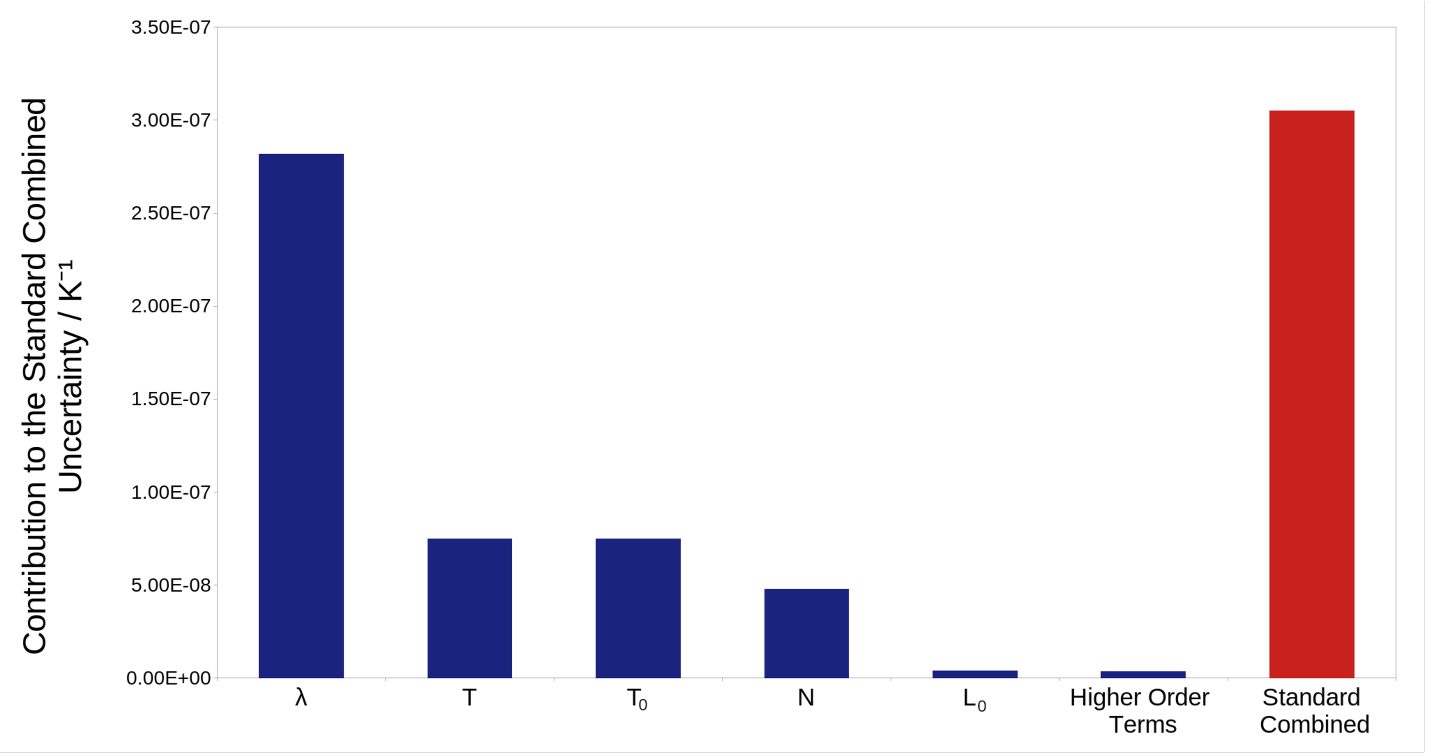

Figure 2. Weight Graph of Contributions to the Standard Combined Uncertainty of the Coefficient of Thermal Expansion

No.	Source of Uncertainty	Input Magnitude	Original Uncertainty	Type, Distribution	Contribution ($°C^{-1}$)
1	Number of Transitions N	125	-	-	$48,0 \times 10^{-9}$
1a	Maximum N Error	-	± 1	B, Rectangular	$48,0 \times 10^{-9}$
2	Wavelength λ	532 nm	-	-	$281,9 \times 10^{-9}$
2a	Maximum λ Error	-	$\pm$ 25 nm	B, Rectangular	$281,9 \times 10^{-9}$
3	Initial Length L_0	80 mm	-	-	$3,7 \times 10^{-9}$
3a	Maximum L_0 Error	-	$\pm$ 0,05 mm	B, Rectangular	$3,7 \times 10^{-9}$
4	Object Temperature T	60 °C	-	-	$75,0 \times 10^{-9}$
4a	Maximum T Error	-	$\pm$ 0,5 °C	B, Rectangular	$75,0 \times 10^{-9}$
5	Temperature of Reference T_0	20 °C	-	-	$75,0 \times 10^{-9}$
5a	Maximum T_0 Error	-	$\pm$ 0,5 °C	B, Rectangular	$75,0 \times 10^{-9}$
-	Coefficient of Thermal Expansion	$1,039 \times 10^{-5}$ °C^{-1}	-	Normal	$u(\alpha) = 305,1 \times 10^{-9}$
Coefficient of thermal expansion $(\alpha) = (1,039 \pm 0,062) \times 10^{-5}$ °C^{-1} (k=2)					

Conclusions

When calculating the contribution of the first and superior order terms into the standard combined uncertainty, the results (Figure 2) show that only the first order terms are actually significant. Thus, the calculation of the standard combined uncertainty includes said terms only. The uncertainty regarding the wavelength is highly relevant, and so, the main focus relies on its later determination so the standard uncertainty can be reduced.

References

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