Confidence and traceability in beverage can dimensional measurements using non-contact techniques

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ABSTRACT

The food and beverage metal packaging industry produces millions of units daily. A key to controlling a highly complex manufacturing process is to conduct offline dimensional measurement of sampled products. In this paper, a methodology to verify the performance and validate the traceability of a non-contact measurement system, is demonstrated. A single-point laser triangulation sensor (laser) is used as part of a setup to measure the height of a finished can. The measured heights are compared on a contour measuring instrument to enhance the confidence of the results. An experiment, conducted in laboratory conditions, concluded that measuring a specific can height with the laser produced a systematic error which is within acceptable parameters.

1. Introduction

One of the most abundant metals on earth is Aluminium and it plays an important role in the construction, automotive, aerospace, and packaging industries. The attractiveness of Aluminium as a medium of packaging food and beverages, is favoured due to its unique physical and barrier properties. Aluminium is effective in protecting food and drink from quality-reducing effects such as odours, oxygen, light, moisture, micro-organisms, with minimum material and weight [1].

The metal packaging industry that produces beverage cans, relies on lightweight aluminium for its protection properties and recyclability, without compromising its robustness and functionality, through its inherent design. With high manufacturing rates and engineering complexities, there are many design considerations for the production of aluminium beverage cans. These include wall thickness, shape, distinctive features for strengthening and fit and adherence to dimensional tolerances.

The starting point in the can making process is the creation of a front-end can, otherwise referred to as an unfinished can. This starts with an aluminium disc that is cut from a roll. This disc is pressed into the shape of a cup, that then undergoes a series of presses from a body maker, to create a slim shaped cylinder with a dome shaped base. Finally, the can is trimmed to a specified height. At this stage, the front-end cans are sampled from the process and are measured to inspect the height, wall thickness and dome depth, to ensure functionality and quality. This is a pre-emptive check of the correct operation of the machinery used in the process. A total of 34 steps are used to create a finished can body (from an aluminium roll) and a further 36 steps used to create the lid. Each step is engineered and designed to create specific geometric features that give the can its robustness and functionality. Having good control and understanding of these geometric features is key to achieving an end product where two parts of a beverage can, body and end, are joined (see Fig. 1) to form a structural shape. This functional structure, allowing the storage of beverages under high pressure also facilitates simple packaging and reduces transportation costs.

Therefore, a highly effective control of a process requires an appropriately accurate and precise measurement strategy, to increase the confidence in early decision making. The choice of a measurement strategy is not only dictated by the metrological performance of a measurement system, but also the convenience and practicality of obtaining the data required, to estimate the value of the measurand. For fast paced, high volume production environments, such as those in the beverage can industry, optical metrology offers the flexibility and speed needed, to measure complex geometric characteristics, potentially too expensive or impractical with contact probe systems.

The ability of optical systems to capture large amounts of data in short time periods, make it ideal as a choice of measurement method in such cases.

However, as practical as they are, there are technical challenges associated with non-contact systems. They include surface colour, reflectivity and surface texture, which affect the validity and traceability of the measurement and contribute to its uncertainty.

It is important to define how good a measurement system is through a statement of measurement uncertainty. This provides the confidence of the result and its suitability for purpose, by defining a calculated level of confidence which, in this paper, is carried out on the flange feature as shown in Fig. 1, extracting the height of the can.

The work carried out in this paper is consistent with the 'Guide to the Expression of Measurement uncertainty' (GUM by BIPM), that is commonly referred to as the gold standard for calculating uncertainties associated with measurement [2,3]. In short, it provides standard procedures in the evaluation and expression of uncertainties, over a range of scenarios from quality control monitoring, to achieving traceability to a national standard using a chain of unbroken calibrations, each with its own calibration uncertainty.

In this work, we validate the traceability at various angles of a laser spot triangulation probe (laser), that is commonly used for measuring geometric features in beverage cans and calculate an uncertainty for it.

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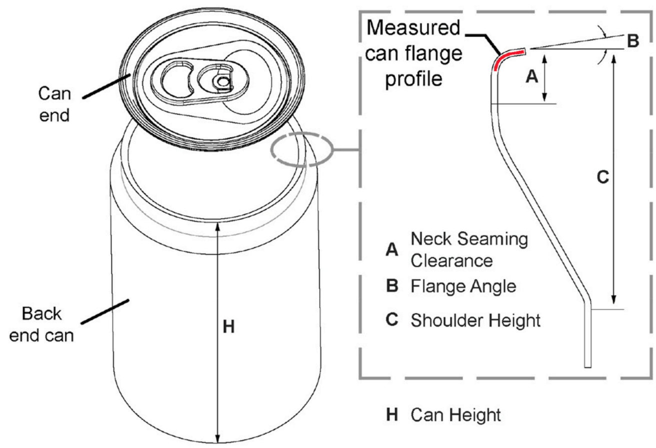

Fig. 1. The can and some key dimensions.

We carry out a set of comparative experiments, with the aim of measuring systematic effects, observed between traceable contact measurement and non-contact measurement systems, on the flange feature (as in Fig. 1). We calculate a systematic uncertainty, taking into account the measurement uncertainty at different angles of the laser.

2. Experimental setup

A design of experiments was carried out in a laboratory-controlled environment with a laser at different angles and traceable ceramic gauge blocks: Mitutoyo CERA Blocks (gauge blocks), to obtain a first uncertainty. In addition, profile comparisons between traceable contact measurement, using a contour measuring instrument: Mitutoyo FormTracer SV-C3000 (FormTracer): and a laser (Keyence LK-G80), on the can flange, is carried out to quantify a systemic error and its uncertainty. Automation and acquisition of data collection was carried out using a custom-built application in the LabVIEW software environment, with the post-processing in MATLAB.

2.1. Non-linearity (MPE)

To quantify the performance of the laser at different angles, a non-linearity study was carried out, reference the setup shown in Fig. 2. The non-linearity of the laser was evaluated over a range of angles varying from 0° to 45° in steps of 15° using an adjustable angle plate. A motorised linear stage was used to drive reference step height samples. The samples used to create the reference step heights were part of a set of grade 2 gauge blocks. Data collected from this setup is used to find a linear relationship between the laser and reference height values, as a 'first order best fit line'. The deviation from the best fit line defines the non-linearity.

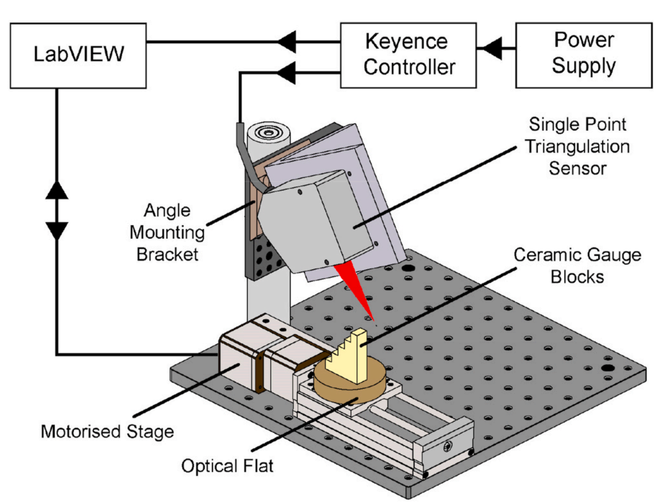

Fig. 2. Setup diagram showing the characterisation of the single point laser triangulation at different angles.

2.2. Comparative study between contact and non-contact

A comparative study between the laser and FormTracer was carried out on a specific feature of the can as shown, reference Fig. 3. Both measurement instruments were used to capture the flange profile of the can, from which measurements of the can height were obtained. To validate the traceability in this comparative study, a measurement uncertainty analysis was included. In the uncertainty analysis, major contributing factors such as the thermal expansion of the can, repeatability of the can measurement at different areas and the performance characteristics of the laser and FormTracer were considered.

Measurements with the FormTracer were carried out using a C-3000 measurement head with a measurement range of ±25 mm. The height of the can was compared to a stack gauge blocks at nominal height, placed next to the flange profile of the can, reference Setup B, Fig. 3.

Similarly, measurements with the laser, mounted at an angle of 30°, to mitigate the measurement issues associated with the outer edge of the flange and can body, were carried out. A motorised stage facilitated extraction of the horizontal profile of the outer flange, with measurements across 3 stacks of gauge blocks, used to create a calibration curve, reference Setup A, Fig. 3. Accuracy of gauge blocks was essential to compensate for the angular error, associated with the incident angle of the laser and to set the height reference.

3. Results

The laser is capable of yielding a distance result within a range of ±15 mm. To eliminate residual effects primarily from the motorised stage, an evaluation on the performance of the measurement was carried out. Here, measurements from two identical gauge blocks, set side by side, with a ±0.25 μm and ±0.30 μm tolerance on the flatness and parallelism respectively, were placed on the motorised stage to compensate for any systematic effects. This provided a correction factor for subsequent measurements to compensate for any tilt during the movement of the stage.

Linear relationships at different angles, between the raw data from

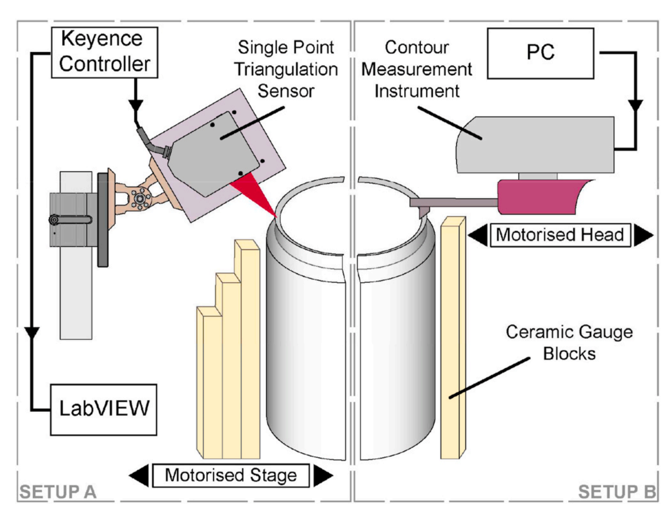

Fig. 3. Setup diagram showing the comparative study of a can on the flange feature. The diagram on the left shows the setup with the laser, the diagram on the right shows the setup with FormTracer.

the laser and a stack of gauge blocks, placed side-by-side to form step heights with a range between 2 and 5mm, is shown in Fig. 4. The equations generated from these linear relationships, represent the transfer functions used to obtain a calculated height value from the raw laser data. Similarly, the graphs shown in Fig. 5 represent the non-linearity error across the different angles, with a confidence range of ±5μm, as shown by the error bars. The quantification of this value is explained below through an uncertainty analysis for the peak-to-peak error, taking into account contributing factors that account to more than 0.1%.

In accordance to the GUM, the mathematical model that expresses the result as a function of contributing factors is:

$$y = f(x_1, x_2, x_3 \ldots x_N) \tag{1}$$

The main contributing factors are shown in Table 1 and they represent 99.9% of the uncertainty contribution. However, other contributing factors, such as gauge block calibration, resolution and average laboratory temperature, were considered but found to be negligible, as they contributed to less than 0.1% of the uncertainty. The mathematical model used to quantify the uncertainty is:

$$\text{p2p} = \left(\text{Error}_1 - \text{Error}_2 + e_{drift} + e_{rep} + e_{flatness}\right) + \left[T_{diff} \times \left((\alpha_{ceramic} \times \text{Ref}_1) - (\alpha_{ceramic} \times \text{Ref}_2)\right)\right] \tag{2}$$

where:

Error_1 and Error_2 – peak-to-peak values, corresponding to the max and min errors as shown in Fig. 5.

Ref_1 and Ref_2 – gauge block heights corresponding to the max and min errors, shown in Fig. 5.

e_{drift} – drift error due to thermal effects.

e_{rep} – random error, characterised through a repeatability study, the repeatability of the laser and placement of the gauge block by the operator.

$e_{flatness}$ – error of flatness of the platen reference surface.

T_{diff} – temperature fluctuation between different measurements of a gauge block at different angles.

$\alpha_{ceramic}$ – the thermal coefficient of the gauge blocks.

For the comparative study between contact and non-contact, a flange feature of a: 330 ml sleek can: with a nominal height of 145.4 mm was scanned (see Fig. 3). Using a 145.4 mm gauge block placed next to the side of the can, the maximum height of the can at 15 radial positions was obtained. The same: 330 ml sleek can: was also measured using the laser with a set of gauge blocks (140, 145 and 150 mm) placed next to the can, to calculate the same maximum height value. A comparison between the mean of both measurements resulted in an overall mean error of 4.2μm. This mean error will have a quantified uncertainty that is calculated similarly to that for the peak-to-peak error. The peak-to-peak error and its calculated uncertainty, will play a part in contributing towards the uncertainty of the systematic average error of 4.2μm.

As a measured systematic error, a measurement uncertainty should be quantified to maintain traceability to international standards. The uncertainty will be quantified by taking into consideration the major contributing factors on the two setups, reference Fig. 3. This mathematical model is used to quantify the uncertainty:

$$\text{S}_{\text{error}} = \left[H_{laser} + e_{p2p} + e_{u_{p2p}} + e_{rep} + e_{drift} + T_{\Delta l} \times (H_{nom} \times \alpha_{can})\right] - (H_{nom} \times \alpha_{ceramic}) - \left[H_{cont} + e_{Z.MPE} + T_{\Delta c} \times (\alpha_{can} \times H_{nom}) - (\alpha_{ceramic} \times H_{nom})\right] + e_{repcan} \tag{3}$$

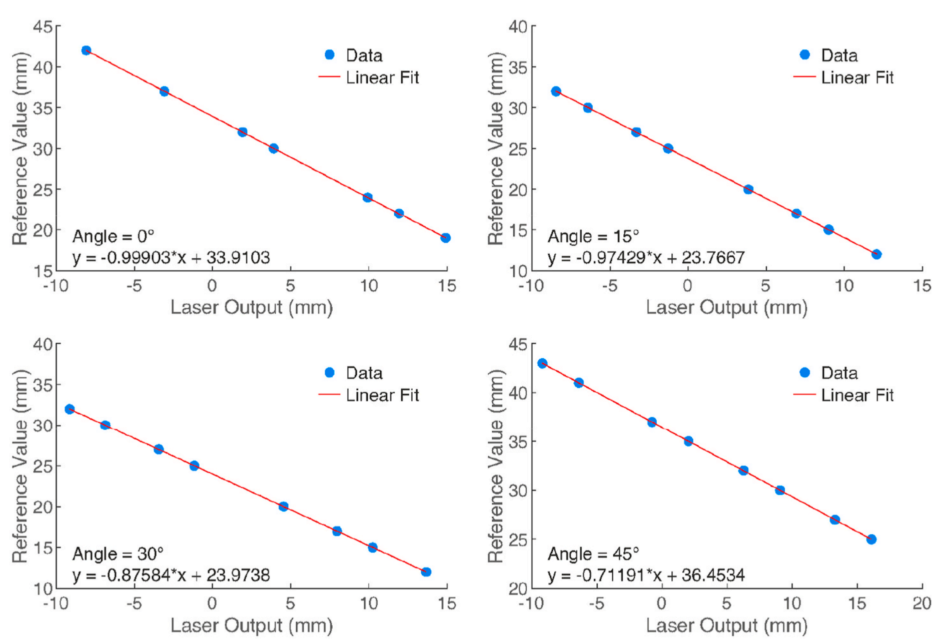

Fig. 4. Non-linearity profile across different angles.

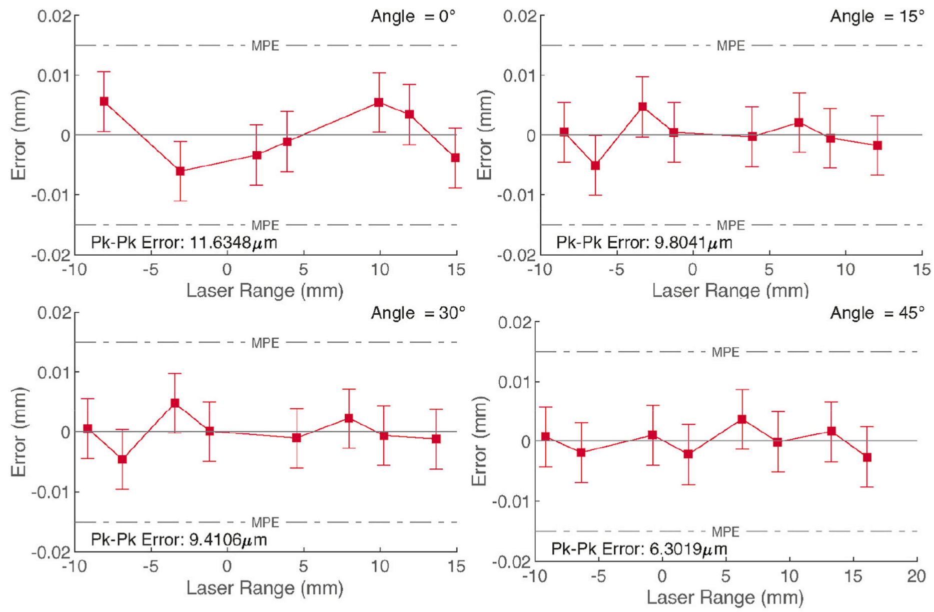

Fig. 5. Error analysis across different angles with the maximum permissible error (MPE) at ±15μm as stated by the manufacturer.

Table 1
Uncertainty Analysis for the peak-to-peak error.

Source of Uncertainty	Value	Divisor	Sensitivity Coefficient	Standard Uncertainty (mm)
e_{drift}	0.003 mm	$\sqrt{3}$	1	0.00173
e_{rep}	0.002 mm	1	1	0.002
$e_{flatness}$	0.002 mm	$\sqrt{3}$	1	0.000115
T_{diff}	1 °C	$\sqrt{3}$	0.0003 mm/°C	0.00017
$u_c = \sqrt{\sum_{i=1}^{N} c_i^2 u^2(x_i)}$				0.00288
Expanded uncertainty, $(k = 1.98)$@95% CI				0.00572

Table 2
Uncertainty Analysis for the calculated systematic error.

Source of Uncertainty	Value	Divisor	Sensitivity Coefficient	Standard Uncertainty (mm)
e_{p2p}	0.0094 mm	$\sqrt{3}$	1	0.0057
$T_{\Delta c}$	3 °C	$\sqrt{3}$	0.0021 mm/°C	0.0037
$T_{\Delta l}$	3 °C	$\sqrt{3}$	0.0021 mm/°C	0.0037
$e_{u_{p2p}}$	0.0029 mm	1	1	0.0029
$e_{rep_{can}}$	$\frac{0.007}{\sqrt{14}}$ mm	$\sqrt{3}$	1	0.0018
e_{drift}	0.003 mm	$\sqrt{3}$	1	0.0017
e_{rep}	0.0015 mm	1	1	0.0015
$e_{Z.MPE}$	0.002 mm	$\sqrt{3}$	1	0.0012
$u_c = \sqrt{\sum_{i=1}^{N} c_i^2 u^2(x_i)}$				0.0088
Expanded uncertainty, $(k = 1.98)$@95% CI				0.0175

where:

S_{error} – systematic error by measuring the surface of the can using the laser.

$H_{laser}$and H_{cont}– heights measured by the laser and FormTracer.

e_{p2p} – peak to peak error at 30° (see Fig. 5).

$e_{u_{p2p}}$ – uncertainty of the peak to peak error as quantified in Table 1.

e_{drift} – drift error due to thermal effects.

$e_{Z.MPE}$ – maximum permissible error (MPE) of the height from the FormTracer.

$T_{\Delta l}$ – temperature deviation of the reference during measurement with the laser.

$T_{\Delta c}$ – temperature deviation of the reference during measurement with FormTracer.

$\alpha_{can}$and $\alpha_{ceramic}$– thermal expansion coefficients of the can and the gauge blocks respectively.

$e_{rep_{can}}$ – random error due to part variation and mispositioning of the can when carrying out same measurement on both instruments.

4. Conclusions

The height of a: Back end can: has a manufacturing tolerance of 250–300μm, directing manufacturers to source a measurement instrument with an accuracy, 10 times better than 250μm. The methodology concluded that the laser shows a systematic uncertainty of: *4.2* ± *17.5*μm *at 95% confidence (k=1.98) @ 20* ± *3°C*: which makes the laser and the measurement, fit for purpose. The systematic error and its uncertainty will be expected to vary, depending on the can style and the type and thickness of coating. In addition, various features of the can will behave differently, dependant on surface properties. The same methodology demonstrated in this paper, could be implemented for different geometric features measured with any optical instrument.

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