Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Measurement uncertainty estimation of gap and profile in the automotive sector

To cite this article: G D'Emilia *et al* 2020 *J. Phys.: Conf. Ser.* **1589** 012017

Measurement uncertainty estimation of gap and profile in the automotive sector

G D'Emilia, A Gaspari, C Iavicoli and E Natale

University of L'Aquila, Department of Industrial and Information Engineering and of Economics, Piazzale E. Pontieri, Monteluco di Roio, 67100 L'Aquila, Italy

giulio.demilia@univaq.it

Abstract. In this paper, a methodology is described aiming at assessing the variability causes, affecting the measurement instruments typically used in the automotive sector for the analysis of dimensional defects of coupled components, to check the conformity of the width of the gap between two adjacent parts and the profile, i.e. the alignment of the two surfaces. The inspection may be performed by means of different gap/flush tools, such as feeler gages, calipers and Laser scanner devices; depending on the choice, a different measurand has to be considered. The obtained measurements need to be consistent, because these devices are used indistinctly, depending on the severity of the control and on the typology of the control itself. The paper proposes a methodology to verify the metrological conformity of measurements provided by both traditional and laser-based instruments, so that it is possible to interpret them in an interchanging manner. A 3D geometric model is realized, used as a basis for the analysis of the most influencing uncertainty causes and measurement biases. The methodology will demonstrate to be able to identify and evaluate in a parametric way, the typical variability causes of the instruments considered. It will also highlight possible improvements in the integration of the obtained results.

1. Introduction

Industry 4.0 deploys several instruments for quality control, each of which preserves its own validity and scope [1]. In complex industrial applications, advanced algorithms for data processing coming from different sources of information have to be merged with simulation results, also taking advantage of innovative frameworks made available by the enabling technologies of cloud computing [2-3].

A good interpretation of measurement results support also improved design methodologies, tending towards making decisions in quality evaluations, on a more logical and scientific basis [4].

The geometrical determination of surface defects requires a careful geometrical modelling of the defect itself [5-6]. In this context, one of the most important issue resides in the need of guaranteeing the reproducibility of measurements provided by different devices.

Using uncertainty budgeting techniques has proven to be a very effective approach to face complex problems [7-8], thus suggesting to evaluate the main variability causes. Moreover, the aspects connected to the on-line calibration impose the need to understand if some approaches are potentially subject to bias.

In this paper, a methodology is described aiming at assessing the variability causes, affecting the measurement instruments typically used in the automotive sector for the analysis of dimensional defects of coupled components. In facts, once the vehicles are assembled, a quality control has to be performed, in order to check the conformity of the width of the gap between two adjacent parts and the alignment of the two surfaces (namely, flushness or profile) [9-12].

Figure 1 gives a graphical representation of the above-mentioned defects, which are very common situations in the automotive sector. In particular, the work focuses on the analysis of dimensional defects: (a), gap, i. e. a constant distance between two parallel surfaces, (b), profile/flush, i.e. the height between to two parallel surfaces, (c), gap conicity and (d) profile conicity, respectively intended as a variation of gap or flush, due to the presence of a constant angle between the two surfaces analyzed.

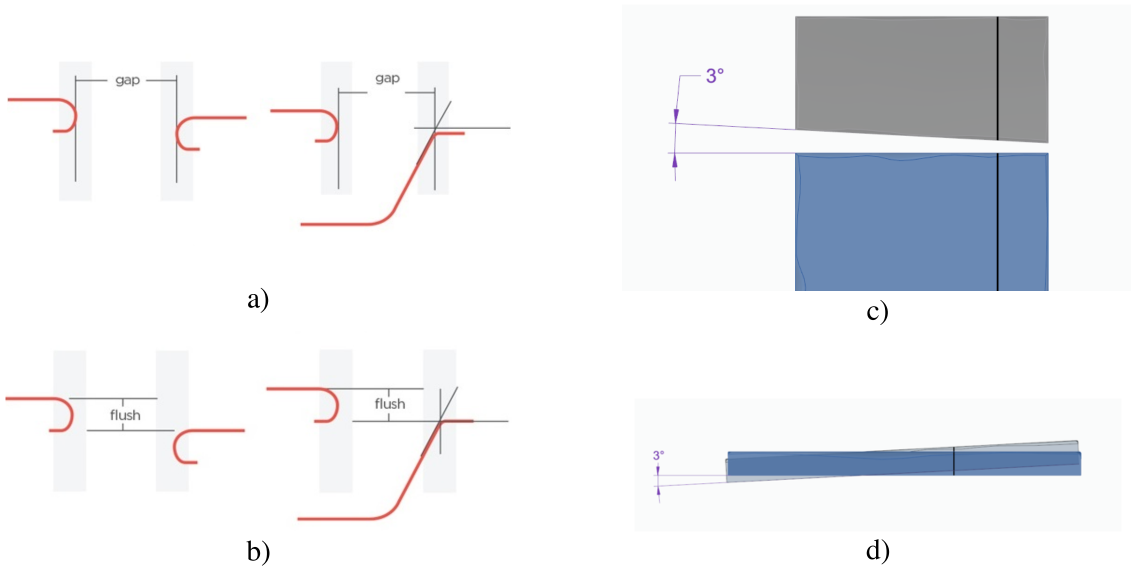


Figure 1. Scheme of the measurand: a) Gap; b) Profile; c) Gap conicity; d) profile conicity.

The inspection may be performed by means of different gap/flush tools, such as feeler gauges, calipers and Laser scanner devices, both portable or fixed ones.

In very short terms, feeler gauges are able to measure gaps, and used as a template to check the dimensional correspondence of a component by means of a go/no go test. Calipers are suitable for the depth measurement of a furrow. Lase-based devices rely upon the measurement of the distance of a set of points with a remarkable sampling density, namely point cloud, providing information about distances, sections and volumes, through the use of suitable processing algorithms. Fixed laser scanner devices, like Coordinate-Measuring Machines (CMM), are usually employed in quality control lines, for high-precision applications, with fixed positions in time and space, acquiring the same scene representing the object to be controlled. Portable devices denote reduced dimensions, arranged on tripod or directly handled by an operator.

Depending on the choice, a different measurand has to be considered, as the picture in figure 2 aims at emphasizing.

In this work, we will refer to a laser gun, i.e. a laser scanner device that can integrate the geometrical information acquired by means of a point cloud, with the radiometric information provided by a camera, connected to the laser. The aspects linked to the laser scanner measurements are particularly stressed.

All the obtained measurements need to be consistent, because these devices are used indistinctly, depending on the severity of the control and on the typology of the control itself. An *ad hoc* procedure for the evaluation of the variability causes in a parametric manner is expected to lead to the identification of possible improvements in the measurement accuracy of the instruments taken into account; it will also allow us to build efficient procedures to also integrate the use of instruments with very different performances among each other. Understanding the interaction between measurand and instrument may help avoiding trivial errors, to push the potentialities of each technique to the limit and to improve the integration of the obtained results.

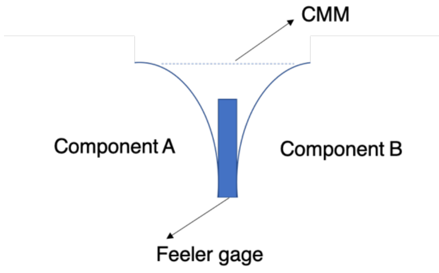


Figure 2. Scheme of different measurands, using different instruments.

Goal of the paper is to verify the metrological conformity of measurements provided by both traditional and laser-based instruments, so that it is possible to interpret them in an interchanging manner.

2. Methodology

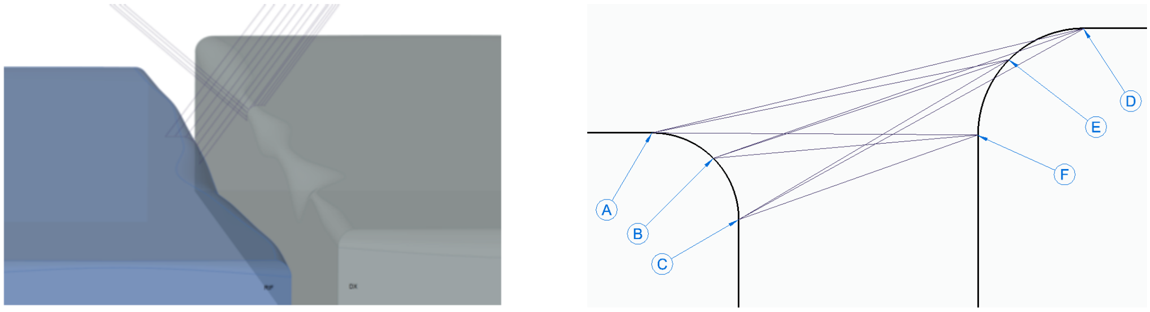
The methodology consists of the following main steps:

1. To build a 3D model, realized by means of a Computer-Aided Design (CAD) software
2. To identify some reference distances
3. To identify the variability causes
4. To assess the nominal distances
5. To assess the distances evaluated by the device (from the model)
6. To compare the obtained results in terms of differences between estimated values and nominal values
7. To normalize the obtained results
8. To evaluate the variability

A 3D geometric model is realized, used as a basis for the analysis of the most influencing uncertainty causes and measurement biases. The model is built in order to represent the main defects of interests (figure 1) and in the most generic conditions in terms of corner radii of two plates (figure 3a). In particular, figure 3b depicts the reference distances especially useful for the analysis of the laser scanner device, representing the possible distances that can be calculated among the mean points and the outermost points of the radii, between the two plates.

The model has been built keeping the following hypotheses:

- The reference plate (RIF) has the shape of a rectangle (100*150*10)mm.
- Null surface roughness
- Variable corner radii, on all the edges of the superior face of the plate, in the range [0.1,4.0] mm
- Gap of 3 mm; Flush of 2 mm;
- Gap conicity: conicity angle of 3° (null flush);
- Profile conicity: conicity angle of 3° (gap of 3 mm).



a) b)

Figure 3. 3D model with random radii (a) and possible reference distances (b).

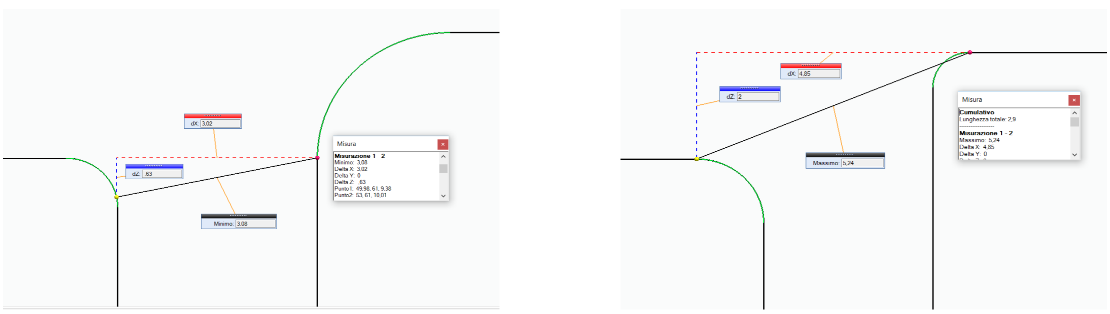
The analysis has been carried out looking at the possible interactions between the measurement device and the measurand, in different situations.

As far the case of the feeler gauge for the gap evaluation, the procedure consist of the following steps:

1. Partition in 18 random sections
2. Determination of the reference values:
    a. Corner radius of the reference plate (RIF)
    b. Corner radius of the other plate (DX)
    c. Maximum distance
    d. Minimum distance
3. Simulation of the variability causes:
    a. Inclination of the feeler gauge on RIF
        i. Feeler gauge: 2.50 mm
        ii. Feeler gauge 2.75 mm
    b. Inclination of the feeler gauge on DX
        i. Feeler gauge: 2.50 mm
        ii. Feeler gauge 2.75 mm
4. Evaluation of the inclination angle (depending on the random radius, with a constant profile)
5. Evaluation of the difference between nominal and assessed gap

The methodology aims at demonstrating to be able to identify and evaluate in a parametric way, the typical variability causes of the instruments taken into account. Possible improvements in the integration of the obtained results, is also expected.

It has to be pointed out that the geometrical parameters of interest are evaluated in an automatic way, being as much accurate as possible, and these are taken as reference values. Figure 4 shows an example of the evaluation looking at the CAD software.



a) b)

Figure 4. Example of the automatic determination of internal and external outermost radii.

3. Results

The methodology has been applied to the analysis of gap and flushes by means of two main measurement devices: feeler gauges and laser scanner devices.

3.1. Feeler gauges

As far feeler gauges, the method allows us to identify as the main uncertainty causes the following ones:

- the depth of insertion,
- the direction of insertion,
- the corner radius of the surface on which the feeler gage is inclined.

As an example, picture in figure 5 shows a possible situation of erroneous direction of insertion of a feeler gauge. Looking at figure 5a it is possible to note that simple trigonometric equations lead to the gap value: biases are changing if the side of inclination of the feeler gauge is changed too, between the two plates considered.

The maximum difference obtained is in the range from 2.52% to 5,15%, depending on the inclination of the feeler gauge for the specific case in exam.

.

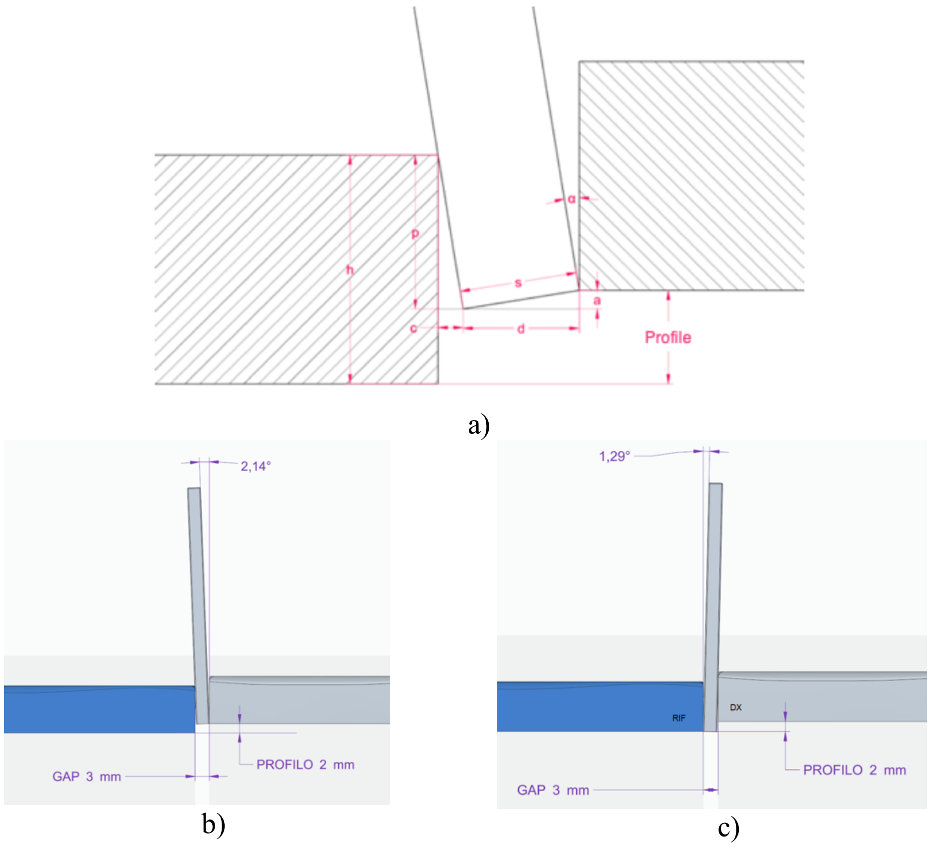
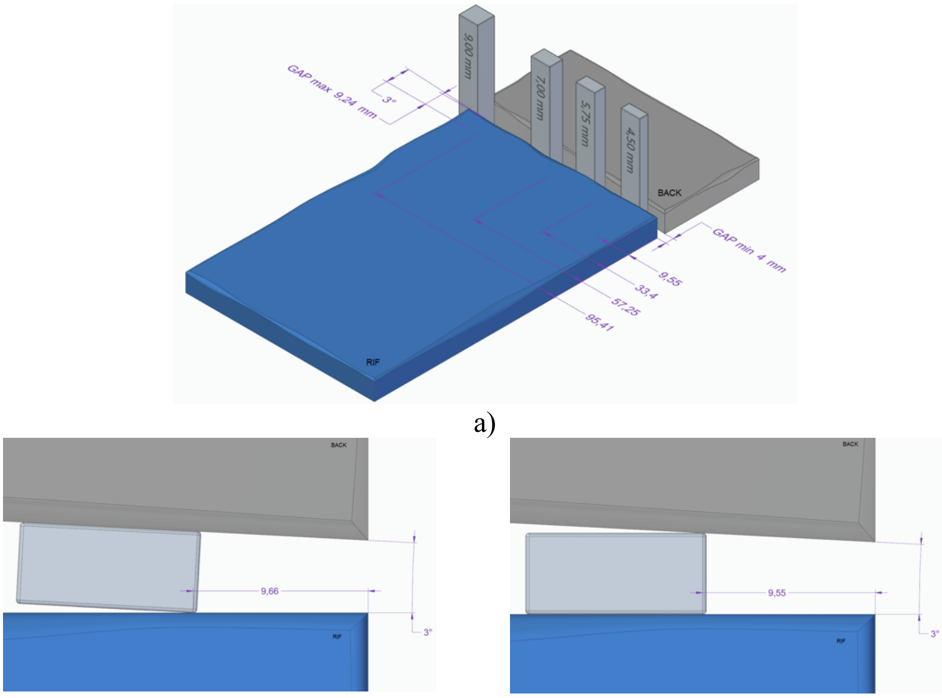


Figure 5. Scheme of an erroneous angle of insertion of a feeler gage: a) trigonometric parameters; b) inclination of the feeler gauge on RIF; c) inclination of the feeler gauge on DX..

The methodology has been also applied to the analysis of the gap conicity, requiring a preliminary selection of the group of feeler gauges to be used, as depicted in Figure 6a. Figure 6b and figure 6c show the variability due to the inclination of the feeler gauge on each plate, similarly to the above-mentioned situation. Then, nominal and estimated distances between the point where the feeler gauges reaches its maximum insertion and the external side of the reference plates are evaluated, with respect to both the reference plate (RIF) and the other plate (BACK). Figure 7 shows the obtained results considering eight feeler gauges ranging from 4.5 mm to 9 mm. It also shows the comparison in terms of differences (Δ).

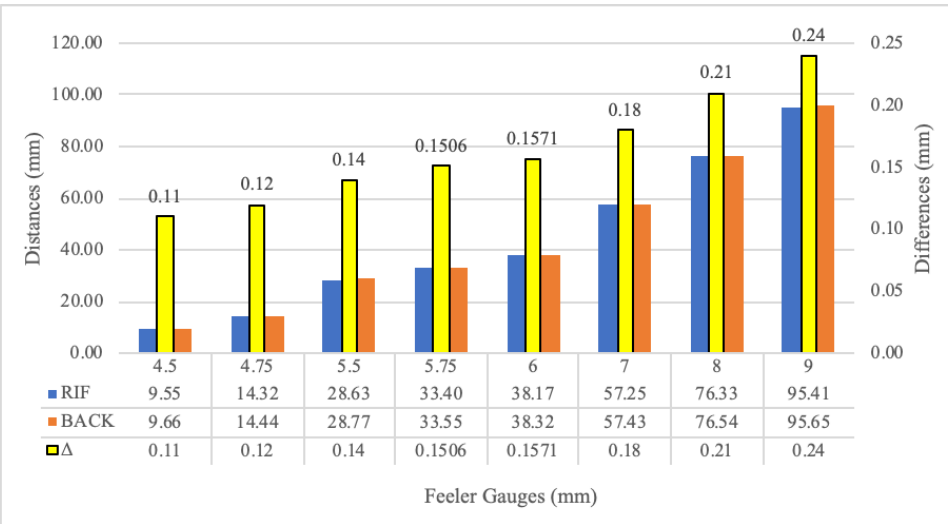
The normalization of the results (Δ% = Δ/RIF*100) lead us to the assessment of the maximum variability for the considered case, which is in the order of Δ% ≤ 1,14%.



a)

b) c)

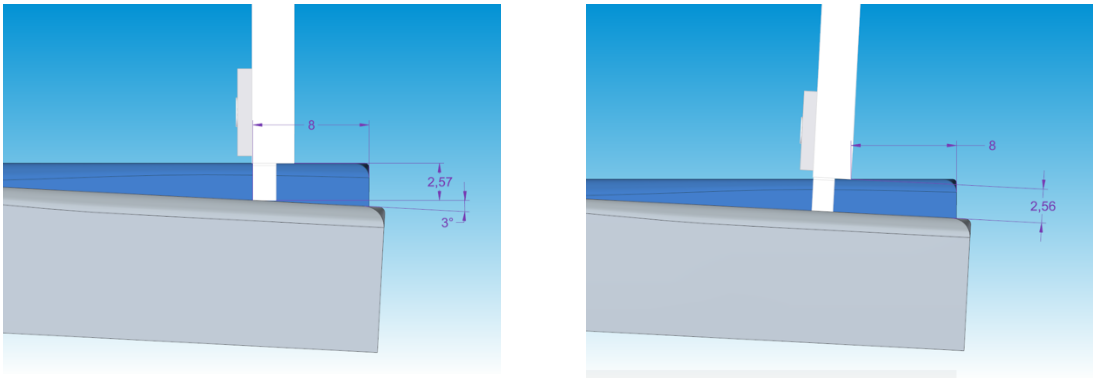
Figure 6. Scheme for measurement of gap conicity by means of feeler gage (a), contact surface BACK (b), contact surface DX (c).



	4.5	4.75	5.5	5.75	6	7	8	9
RIF	9.55	14.32	28.63	33.40	38.17	57.25	76.33	95.41
BACK	9.66	14.44	28.77	33.55	38.32	57.43	76.54	95.65
Δ	0.11	0.12	0.14	0.1506	0.1571	0.18	0.21	0.24

Figure 7. Feeler gauges, gap conicity 3°.

3.2. Calliper
Similar considerations apply to the case of the profile conicity. A scheme is provided in figure 8. The white area represents the caliper measuring the depth in the two cases of inclination considered.



a) b)

Figure 8. Scheme of the caliper measuring the profile conicity, according to the reference plate (a) or to the other plate (b).

With the analysis of the gap/flush conicity a common behavior can be observed. The main variability cause is primarily attributed to the choice of the contact surface between measurand and measurement device. For both the two cases, as gap or flush increase because of the conicity, so do the behavior of Δ, i.e. the difference between the estimated gap with respect to the nominal values, which increases linearly; consequently, the normalized values of $\Delta\%$ are inversely proportional to the gap and profile values.

3.3. Laser scanner
On the other hand, Laser scanners are based on the measurement of the distances of a point cloud of geometric samples on the surface of the subject [13]. These points can then be used to extrapolate the shape of the subject being monitored. In this case, the main uncertainty causes reside in the following:

- resolution of the point cloud,
- choice of the outermost points of the radius on the fitted curve.

It has to be pointed out that, although increasing the resolution provides a lower variability of the measurements, the choice of the outermost points of the radius affects the measurement variability considerably.

In figure 9, the distance CF (D_min) is the distance that is usually taken as a reference by the commercially available devices, i.e. the distance between the two lower outermost radii.

The analysis carried out by means of the automatic procedure for the study of the variability causes, with reference to an ad hoc solid 3D geometric model highlighted that the distance BE in figure 9 is less sensitive to the variation of both resolution of point cloud and choice of the outermost points of the radius.

In particular, taking into account two different cases as far the resolution (namely, 0.1 mm and 0.3 mm), the variability of CF with respect to BE is about ten times reduced, as it can be seen on in table 1.

With reference to a resolution of 0.1 mm and to one of the 18 sections examined, figure 10 represents the differences between the estimated gap and the nominal one, with reference to the nine possible combinations of the positions of the starting points of the radius, supposing it at different distance from the real one.

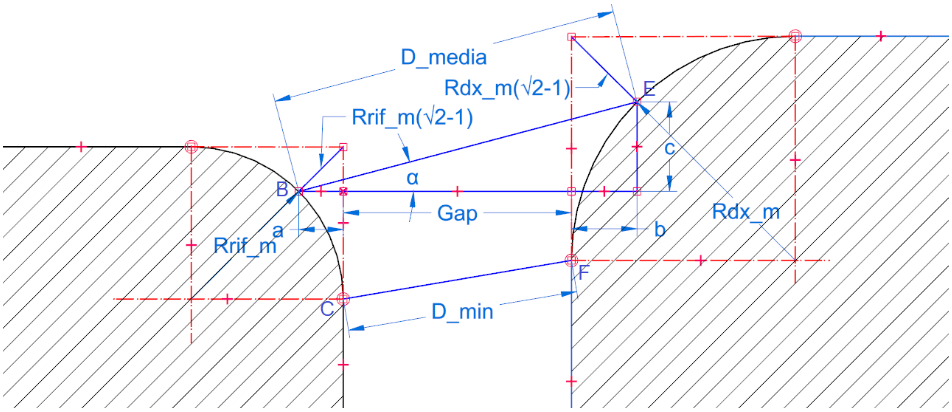


Figure 9. Reference distances for gap measurements by laser scanner.

Table 1. Comparison of the variability (Δ%).

Resolution	0,1 mm	0,3 mm
Distance CF	0,18% < Δ% < 1,26%	0,75% < Δ% < 3,91%
Distance BE	0,0099% < Δ% < 0,028%	0,060% < Δ% < 0,25%

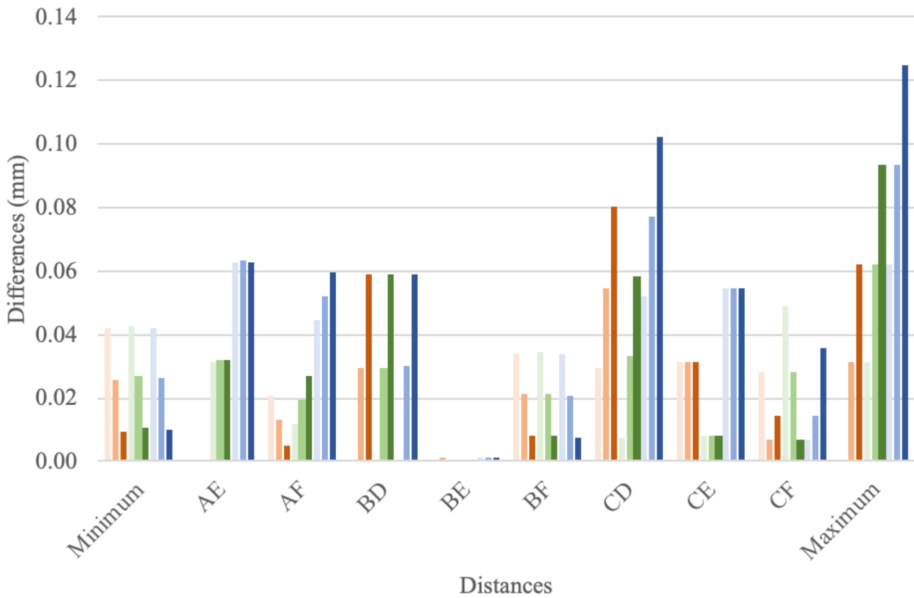


Figure 10. Comparison of the differences between estimated and nominal distances, with reference to the reference distances of figure 3b.

Although the distance BE, i.e. the distance between the two mean points of the radii, is further from the unknown value of the Gap to be obtained, this distance results more accurate: both variability and bias error depending from operating settings are at a minimum.

By means of simple trigonometric equations and looking at Fig. 9 and Eq. 1, it is possible to find the desired value of the gap, where R_{RIFm} and R_{DXm} represent the mean radius of the RIF plate and DX plate, respectively.

$$Gap = x - (\sqrt{2} - 1)cos45°(R_{RIFm} + R_{DXm}) \qquad \text{(Eq. 1)}$$

According to the considerations of Section II (Methodology), referring to this datum, the traceability of laser scanner is improved for their measurements and for cases it is used as a reference for feeler gauges.

4. Conclusions

In this paper, the main uncertainty causes in the measurement of dimensional defects, such as gaps, profiles, and gap/profile conicity have been individuated. With reference to feeler gauges and calipers, these can be summarized as follows:

- inclination,
- depth of insertion,
- corner radii of the adjacent surfaces.

As far laser scanner devices, the main contributions to the variability can be associated to the resolution and the position of the outermost point of the radii.

A simulation 3-D model, quite strenuous but flexible, allowed us to obtain satisfactory results, i.e. the identification of the main uncertainty causes and also its preliminary evaluation.

The analysis carried out as an example allowed us to identify a reference distance for the evaluation of the gap by means of the laser scanner device resulting less affected by variability and bias.

This analysis may contribute to the identification some improvement actions supporting the reproducibility of results.

Improving the reproducibility of methods means reducing the need of instruments calibration.

References

[1] Beckers R, Emmer C, Pfouga A, Glaesner K H, Stjepandic J 2020 Technology management on 3D measurement for industry 4.0 *Int. Assoc. Manag. Technol. Conf., IAMOT* 1444-55

[2] Saravanan A., Jerald J., Delphin Carolina Rani A. 2020 An intelligent constitutive and collaborative framework by integrating the design, inspection and testing activities using a cloud platform *Int J Computer Integr Manuf*

[3] D'Emilia G, Di Ilio A, Gaspari A, Natale E, Perilli R and Stamopoulos A G The role of measurement and simulation in additive manufacturing within the frame of Industry 4.0 2019 *IEEE Int. Workshop Metrol. Ind. 4.0 IoT, MetroInd 4.0 IoT - Proc.* 382-7

[4] Jayaram K and Mohanraj J 2016 Influence of Tolerancing Methods and Aspects of Perceived Quality on Side Closures of Luxury Cars *Procedia CIRP* **43** 160-5

[5] Kamani P, Noursadeghi E, Afshar A, Towhidkhah F, Roghani E, 2011 Automatic Paint Car Body Paint Defect Inspection Using Rotation Invariant Measure of the Local Variance and One-Against-All Support Vector MachineDefect Detection and Classification of Car Body, *First International Conference on Informatics and Computational Intelligence*

[6] Muñoz A, Mahiques X, Solanes J E, Martí A, Gracia L,Tornero J 2019 Mixed reality-based user interface for quality control inspection of car body surfaces, *Journal of Manufacturing Systems* **53**, 75-92

[7] UNI EN ISO 14253-2:2011 – Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification

[8] D’Emilia G and Gaspari A 2016 Measurement-uncertainty as an innovative management tool in modern engineering systems, *IMEKO TC Workshop Tech. Diagn. New Perspect. Meas., Tools Techniques Syst. Reliab., Maintainab. Saf.* 197-202

[9] Minnetti E, Chiariotti P, Castellini P, Violini L, Garcia G, Vicente H and Paone N 2019 Smart portable laser triangulation system for assessing gap and flush in car body assembly line *IEEE Int. Workshop Metrol. Ind. 4.0 IoT, MetroInd 4.0 IoT - Proc.* 49-53

[10] Zhou S., Xu J., Tao L., An L., Yu Y 2018 Automated inspection of gaps on the free-form shape parts by laser scanning technologies *Proc SPIE Int Soc Opt Eng* **10621** 1062116
[11] Kosmopoulos D and Varvarigou T 2001 Automated inspection of gaps on the automobile production line through stereo vision and specular reflection *Computers in Industry* **46** 49-63
[12] Tran T-T, Ha C K Non-contact gap and flush measurement using monocular structured multi-line light vision for vehicle assembly 2018 *Int. J. Control Autom. Syst.* **16** 2432-45
[13] D'Emilia G, Gaspari A and Natale E Accuracy improvement of measurement management systems: requirements for reliability of data and practical examples 2020 *IEEE International Instrumentation and Measurement Techncology Conference*