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Control of involute curve of gear tooth using the fuzzy logic

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Abstract. Three dimensional coordinate metrology is a firmly established technique in industry. Scanning technology is now widely used in coordinate metrology and is increasingly used for the measurement of small features. This paper presents a new real shape approach to closest point inspection involutes curve of gear tooth by coordinate measuring machinery (CMM). This method aims to select the most likely contact point for each successive arc by applying geometrical criteria and a fuzzy logic estimator. This method is particularly, but not exclusively, suitable for the metrology of features with small radii as well as metrological discontinuities. It does not require obtaining the normal vector traditionally used for probe tip correction. Elapsed time is 144.09 s. Tests have been done on limps of machine tool speed (pinion type cutter), which is highly applied in our country.

Keywords: CMM; gear; scan probe; fuzzy logic

Nomenclature

Notation	Nomenclature
P_i:	center ball style
X_{si}:	point determine of vector normal (mm)
Δz_i:	distance between line $(P_{i+1}P_{i-1})$ and point P_i (mm)
Δk_i:	distance between line $(P_{i-2}P_{i-1})$ and point P_i (mm)
$\Delta\alpha_i$:	angle between normal vector (P_iX_{si}) and fuzzy logic vector (P_iX_{pi}) (radian)
ε_i:	error acceptance (mm)
r:	ball radius (mm)
X_{pi}:	Point determined by the logic fuzzy
X_{ci}:	Point of contact between sphere of probe and tooth surface in reality

1 Introduction

Coordinate measuring machines (CMMs) are becoming increasingly important in measurements and verification of dimensional quality of manufactured parts and products. On the other hand, the now a days gear measurement inspection of today refers to a description of the nominal gear geometry, which is limited to only a few prescribed tracks across the flank (profile, lead) or singular points (pitch). Principle of the new method of corrected measured point determination in coordinate metrology. It means, in order to accurately measure, amongst other things, small features, we propose a new algorithm for the compensation of the stylus tip radius in a CMM scanning process (as shown in Fig. 1). The proposed algorithm is dedicated to high definition measurement. Advantages of the algorithm are that we do not calculate the normal vector and we do not use a NURBS for smoothing (filtrating) of the measured shape [1]. The method is based on the fuzzy logic algorithm, which is a well known method to approximate the ideal position that minimizes the sum of squared residual errors between the clearance and the model. This choice is motivated by the robustness of this method and it is important to underline here that, no attempt to implement it within Coordinate Measuring Machines (CMMs) software has been reported in the three-dimensional metrology literature. A numerical application treating the case of a tooth of the toothed wheel which equips the gear box on limps of machine tool speed (gears of turn) in our country is presented. The comparison between the real surface obtained by acquisition and the ideal model led to the calculation of the form defects of the tooth gear. But this accuracy is generally achieved only for the measurement of well-known shapes as well as when feature size largely exceeds probe tip radius because of the algorithms used for stylus tip radius correction. For instance, free surfaces form profiles, which are not sections of a known geometric primitive such as a plane, (circle, sphere, cone, gear, etc.) [2]. Present particular difficulties in establishing the normal correction vector.

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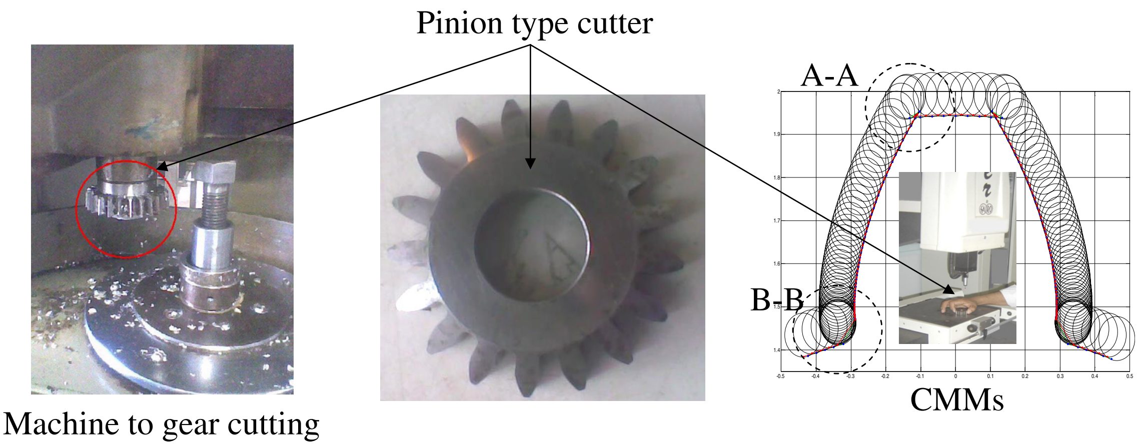

Fig. 1. (Color online) The data input from file.

2 The gears control according to standard references

It is known that fuzzy logic is used in the whole notably electronic technology mode, data processing, communications etc. then it gave coordinate measuring machines result by the contribution of the other methods. Indeed, it would reinforces recent technology of metrology, where the big accuracy exists when using the three dimensional measuring machine. In fact we sustained several authors even if this axis of measure procedure for example the works that is published by the article [1, 3–7], we can consider this work has a continuity of the precedent one.

3 Problems and adopted algorithm

Considerable work dealing with the estimated surfaces (mathematical model) to digitized points (Mi) on a real mechanical part with a coordinate measuring machine (CMM) were done in the seventies [2]. Then our problem represents the transfer coordinate measure by the machine measures three-dimensional from center of sensing finger ball to coordinate them contain the curve of developed it of the cogwheel. But the method normal back (vector) are not able to determine the point's transfers notably between the intersections of two curves. See Figure 1. To solve this problem which means, we are going, we used the fuzzy logic to solve this problem that say one is going to specify the curve path. You know that the path precision becomes interested when we are going to calculate the features dimensional.

4 The algorithm presentation

for the presentation of the fuzzy logic algorithm many variable have been introduced, which affect one or more stages of the original algorithm to try to increase its performances specially accuracy and speed, giving birth to several alternatives of fuzzy logic algorithm some of these variants expand also the abbreviation to the iterative corresponding point claiming that this would better suit the algorithm. See Flow chart of the fuzzy logic estimator Figure 2. In order to make a choice of an algorithm, several criteria should be checked: speed, accuracy, stability, robustness, and simplicity. The importance of the one or the other of those criteria depends on the use and the application of the final program. The development of a complete system of inspection and quality control of manufactured parts requires the coordination of a set of complex processes allowing data acquisition, their dimensional evaluation and their comparison with a reference model. For that it is essential to make some profitable conceptual knowledge relating not only to the object to be analyzed, but also to its environment. In our case, the objective of the present work consists in establishing an automation procedure for modeling and inspecting complex parts surfaces, enabling the correction of relative deviations within manufacturing parameters, then the criteria adopted which are: speedy convergence, system robustness, and interface simplicity [8]. The new algorithm can be summarized by the following flow chart (Figs. 3, 4).

5 The calculation of corrected measured points

We used the following equations to achieve these results (Figs. 2–4).

5.1 Equation of lines

$$y_i = a_i x_i + b_i \text{ (between } P_{i+1}, P_{i-1}); \tag{1}$$

$$y_i = c_i x_i + d_i \text{ (the line pass } P_i \text{ and perpendicular line } (P_{i+1}P_{i-1})); \tag{2}$$

$$y_i = e_i x_i + f_i \text{ (between } P_{i-1}, P_{i-2}); \tag{3}$$

$$y_i = m_i x_i + n_i \text{ (the line pass } P_i \text{ and perpendicular line } (P_{i-1}P_{i-2})). \tag{4}$$

We take cash held tolerance values for each point gained in range (0.0001. rand).

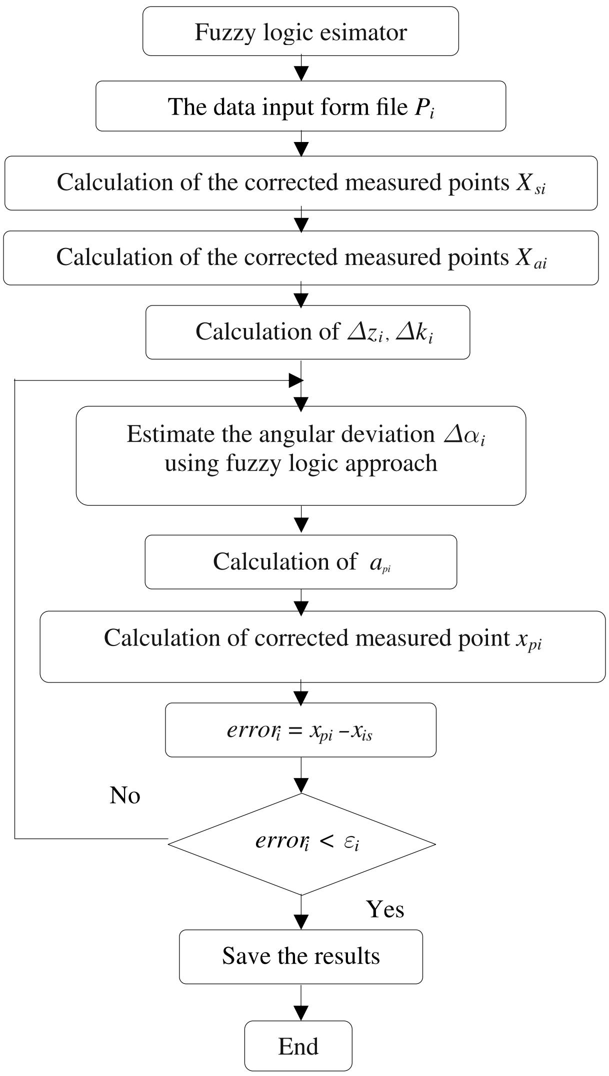

Fig. 2. Flow chart of the fuzzy logic estimator.

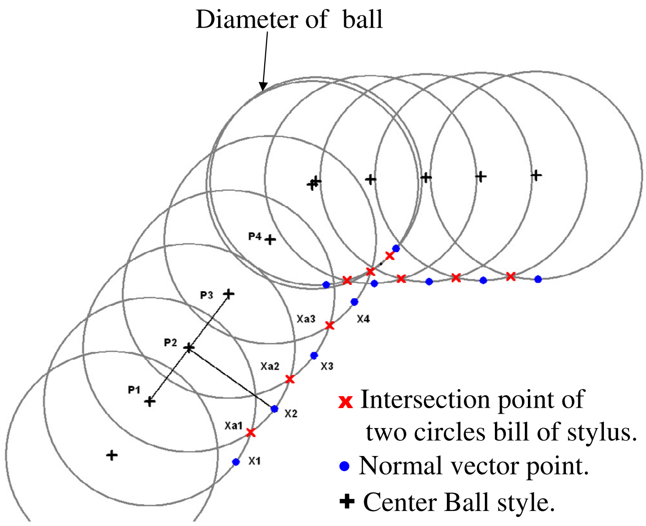

Fig. 3. (Color online) View A-A.

5.2 Equation of circle

$$(x - x_i)^2 + (y - y_i)^2 = r^2. \tag{5}$$

See Figure 4.

Such that r is ball probe radius ($r = 0.2$ to 0.5 mm).

5.3 Values $a_i, b_i, c_i, d_i, \Delta_i$

$$\begin{cases} a_i = \frac{y_{i+1}-y_{i-1}}{x_{i+1}-x_{i-1}} \\ b_i = y_{i-1} - \frac{y_{i+1}-y_{i-1}}{x_{i+1}-x_{i-1}} x_{i-1} \\ c_i = -1/a_i \\ d_i = y_i - c_i x_i \\ e_i = \frac{y_{i-1}-y_{i-2}}{x_{i-1}-x_{i-2}} \\ f_i = y_{i-1} - e_i x_{i-1} \\ m_i = -1/e_i \\ n_i = y_i - m_i x_i \end{cases} \tag{6}$$

$$\Delta_i = (2d_i c_i - 2y_i c_i - 2x_i)^2 + 4(x_i^2 + (d_i - y_i)^2 + r^2) \times (c_i + 1). \tag{7}$$

You can take numbers vary between $i = 1$ point until there 200 point.

Remark 1. The time of machine response between two contacts is considered to be 0.25 s.

5.4 The coordinates of point $X_{si}(x_{si}, y_{si})$ X_{si} can be calculated as follows

$$\begin{cases} x_{si} = \frac{-(2d_i c_i - 2c_i y_i - 2x_i) \pm \sqrt{\Delta_i}}{2(c_i+1)} \\ \text{and} \\ y_{si} = c_i x_i + d_i. \end{cases} \tag{8}$$

See Figure 4 and equations (7), (8).

The coordinates of point X_{ai} (x_{ai}, y_{ai}) can be calculated as follows (relationship taken from the article [1]).

$$\begin{cases} x_{ai} = \frac{x_i + x_{i-1}}{2} \pm a_{oi} \frac{\sqrt{4r^2 - (x_i - x_{i-1})^2 - (y_i - y_{i-1})^2}}{2\sqrt{a_{oi}+1}} \\ \text{and} \\ y_{ai} = \frac{y_i + y_{i-1}}{2} \pm a_{oi} \frac{\sqrt{4r^2 - (x_i - x_{i-1})^2 - (y_i - y_{i-1})^2}}{2\sqrt{a_{oi}+1}}. \end{cases} \tag{9}$$

See Figures 4, 9 and 10.

5.5 Values: Δz_i, Δk_i

$$\begin{cases} \Delta z_i = \sqrt{\left(\left(\frac{d_i-b_i}{a_i-c_i} - x_i\right)^2 + \left(a_i\left(\frac{d_i-b_i}{a_i-c_i} + b_i - y_i\right)\right)^2\right.} \\ \text{and} \\ \Delta k_i = \sqrt{\left(\left(\frac{n_i-f_i}{e_i-m_i} - x_i\right)^2 + \left(e_i\left(\frac{n_i-b_i}{e_i-m_i} + f_i - y_i\right)\right)^2\right.}. \end{cases} \tag{10}$$

The values of Δz_i and Δk_i can be obtained from Figure 4 and equations (5), (6).

According to the fuzzy logic graphs, we can conclude the value of $\Delta\alpha_i$ (see Fig. 5).

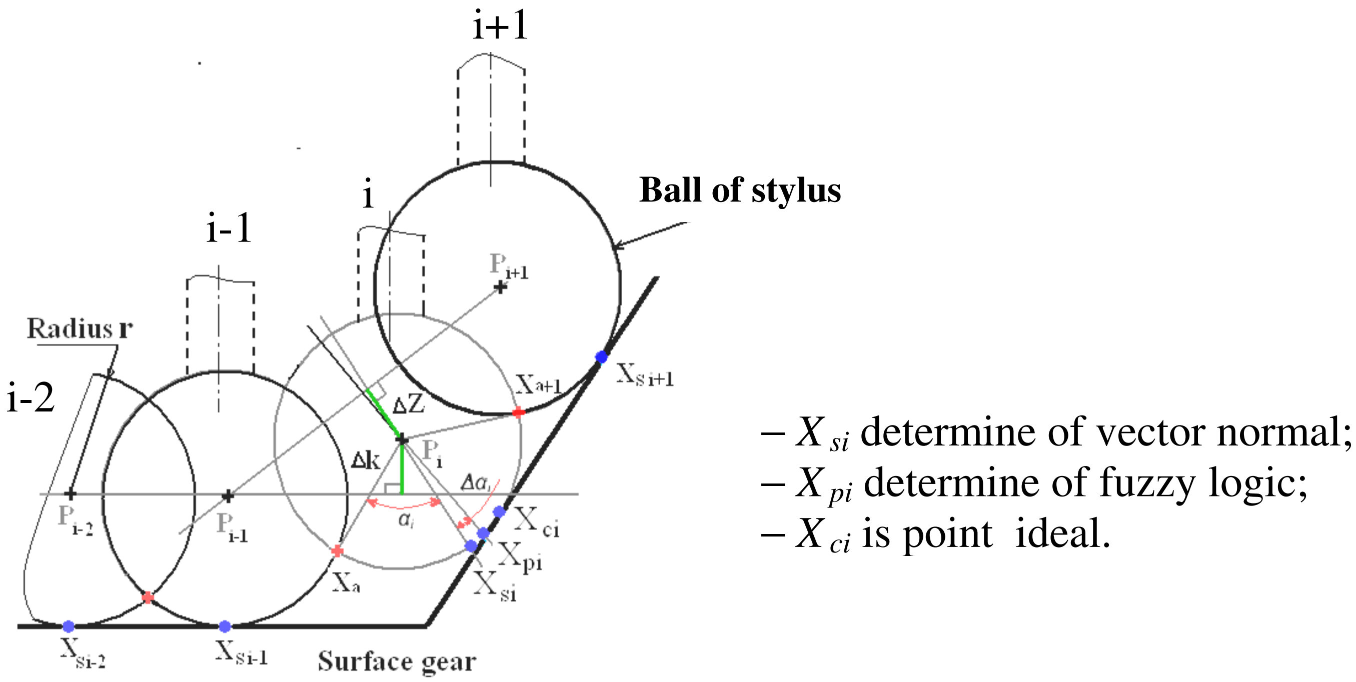

Fig. 4. (Color online) Principle termination $\Delta k, \Delta\alpha, \Delta z$ (view B-B) [1].

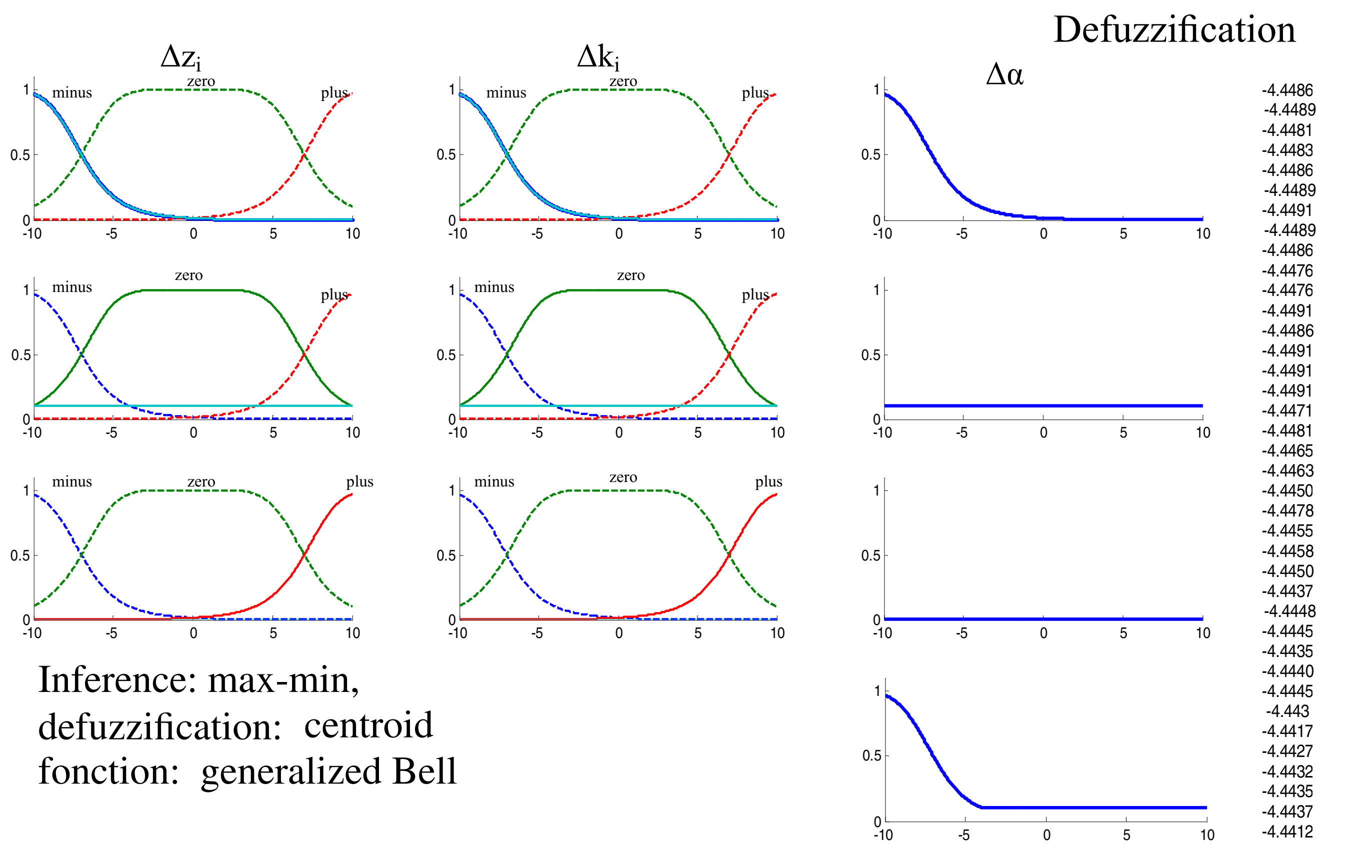

Fig. 5. (Color online) Screen printout of the premises, conclusions and rules and its graphical representation for the $\Delta\alpha_i$ evaluation.

5.6 Values $\Delta\alpha_i$

By formula (10) from the previous relationship by these quantities we determine the value $\Delta\alpha_i$ using the fuzzy logic, using max-min inference and function generalized bell then defuzzificate by the centroid method. See Figure 5.

5.7 Generalize bell shape

$$y_i = \frac{1}{(1 + (((x_i + 14)/7)^3)^2)}. \tag{11}$$

See Figure 5.

Where $z(r)$ and $k(r)$ denote values of linguistic deviations variables Δzi and Δk_i and $A(r)$, stands for the value of the conclusion, the angular deviation $\Delta\alpha_i$. Figure 5 shows a screen printout of the linguistic values defined for each input variables and the conclusion. For example, the rule is presented below in linguisting form [6]:

5.8 Rule

If delta z is "minus" and delta k is "minus" then delta α is "minus".

If delta z is "zero" and delta k is "zero" then delta α is "zero".

If delta z is "plus" and delta k is "plus" then delta α is "plus" [9].

All rules can be defined by an expert and can be quickly changed to accommodate the knowledge of another company or other expert skills. In some difficult cases, new techniques based on neural networks could be applied to generate rules as explained. The paper [1] includes a brief discussion of presented fuzzy logic set up optimization with examples of the improved performance. Initially, in order to represent the value of these variables, we chose the simplest approach of using the bell function. After the general process of tuning, we have confirmed them with very little changes. Figure 5 shows the shape of these linguistic labels.

5.9 Determination of a_{pi}

a_{pi} can be calculated as follows [1]:

$$a_{pi} = \frac{\sin(\Delta\alpha_i)\cos(\Delta\alpha_i)(a_{li}^2 + 1) - a_{li}}{\cos^2(\Delta\alpha_i)(a_{li}^2 + 1) - 1}. \tag{12}$$

The coordinates of point $X_{pi}(x_{pi}, y_{pi})$ can be calculated as follows

$$\begin{cases} x_{pi} = x_i + \frac{r}{\sqrt{a_{pi}^2+1}} \\ \text{and} \\ y_{pi} = y_i + \frac{r}{\sqrt{a_{pi}^2+1}}. \end{cases} \tag{13}$$

6 Simulation results

Currently used methods for tip radius correction involve defining a direction in which to apply the radius compensation. It may result in unfavorable scattering and disordering of the corrected points as well as incorrect smoothing of the measured profile. In this paper, a new stylus tip envelop method (STEM) algorithm for tip radius correction for the metrology of free form and 2D contours of small features (relative to the tip radius) is proposed. The method is for use in HDCM context, as is now possible with scanning probes, where the density of points per scanned distance ensures that the successive probe ball positions overlap partially with each other [2]. The proposed method for correcting measurements can be applied directly to the data collected during a CMM measuring process. After our simulation control gear as it took into account the required control condition (module = 2.5 mm, number of teeth = 20 tooth, pitch = 7.85 mm, thickness = 25 mm, $error = 0.0001$.rand tolerance programming). We obtained the graphs of Figure 9, in which we find the trace the points earned by black round dot is the center ball, the green points is a point calculated by method normal vector, the blue dots is a point calculated by fuzzy logic method.

6.1 Values of Δz_i

The diagram according Figure 6, we saw that Δz_i varies for each point but there are four peaks in early intersections (curve developed inner cylinder and curve-curve and curve developed outer cylinder and the other side) in the 10^{-5} mm to 800×10^{-5} mm interval (Eq. (10)).

6.2 Values of Δk_i

According to Figure 7, the same note previous interval varies from 10^{-5} to $10\,000 \times 10^{-5}$ mm (Eq. (10)). Then, it has three peaks, they take the consecutive values 9000×10^{-5}, 8500×10^{-5}, 1100×10^{-5} mm.

6.3 Values of $\Delta\alpha_i$

According to Figure 8, the same remark in previous interval -4.45×10^{-5} to -4.14×10^{-5} radians. Then, it has two peaks, they take the consecutive values 4.17×10^{-5}, -4.21×10^{-5} radian.

7 Analyze of results

In order to justify our analysis and clarify our results, different view on the tooth are taken as follows ((A-A), (B-B), (C-C)), Figs. 10–12).

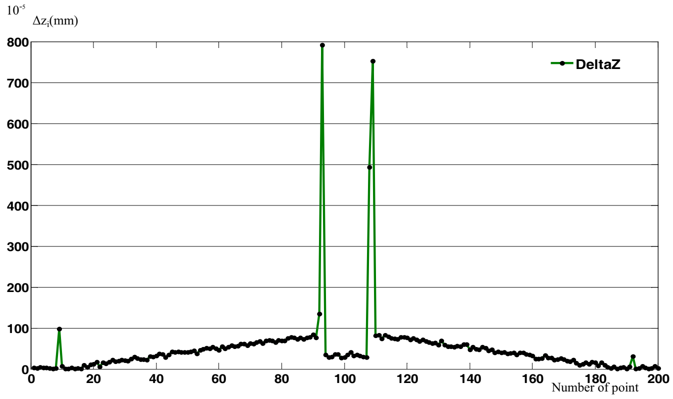

Fig. 6. (Color online) Value Δz_i.

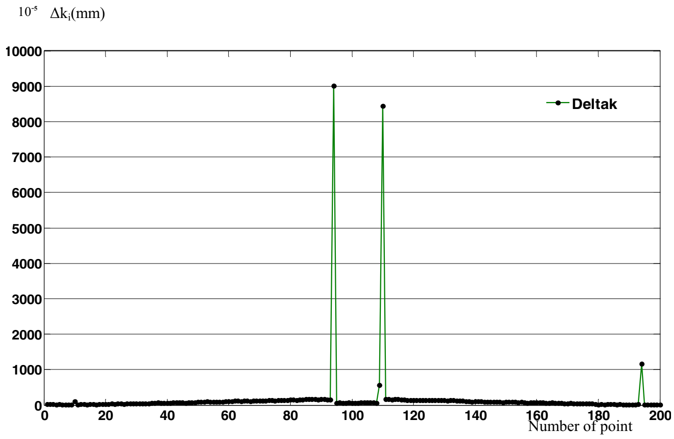

Fig. 7. (Color online) Value Δk_i.

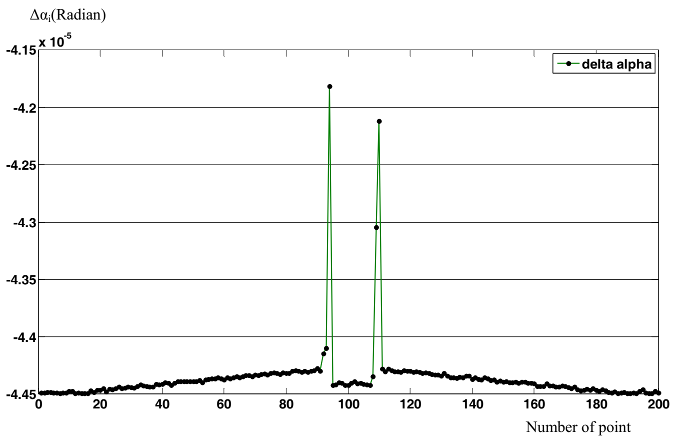

Fig. 8. (Color online) Value $\Delta\alpha_i$.

7.1 In view A-A

We notice that the green trace is greater as when tracing the intersection between cylindrical and circular curve developed signs of tooth trust that the outside diameter larger diameter by contributing to ideal Figure 10.

7.2 In view B-B

In this case there is no difference between the two methods is to say closer to zero error Figure 13.

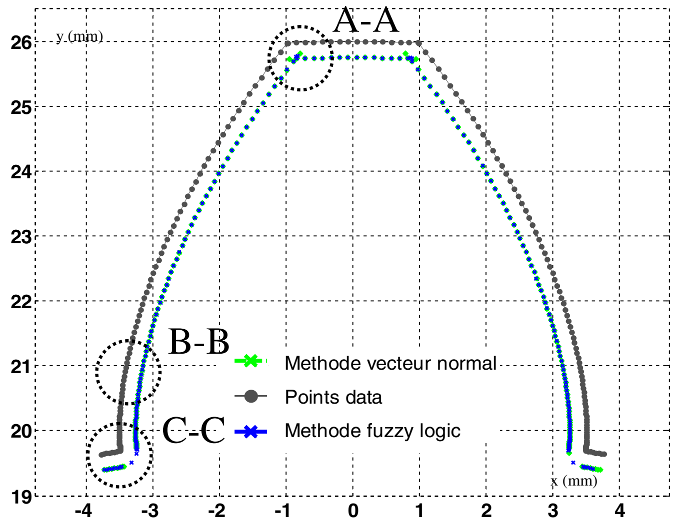

Fig. 9. (Color online) Curve involutes of gear box tooth.

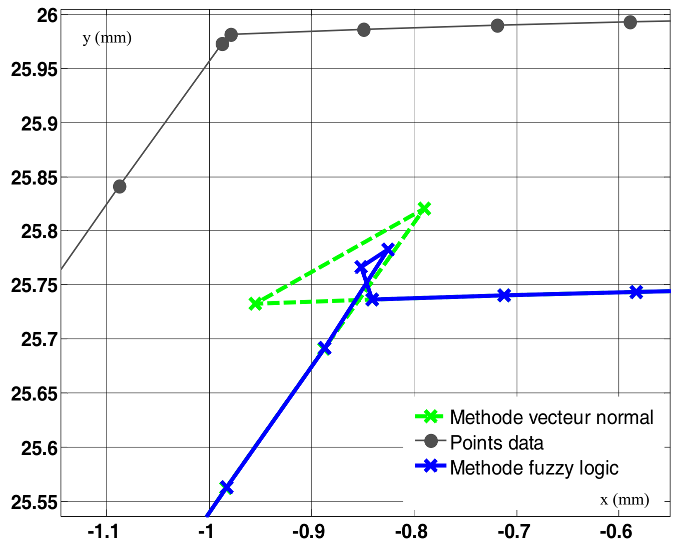

Fig. 10. (Color online) View A-A.

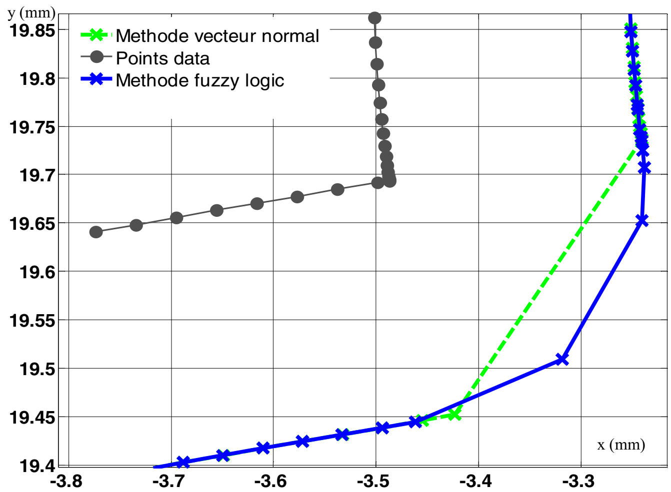

Fig. 11. (Color online) View C-C.

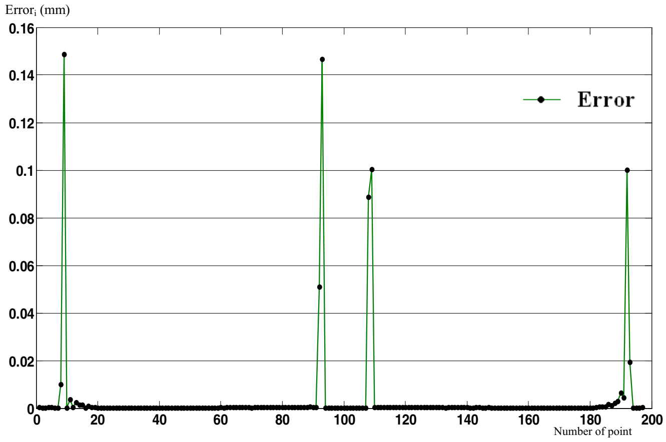

Fig. 12. (Color online) Errors of from on the tooth in mm.

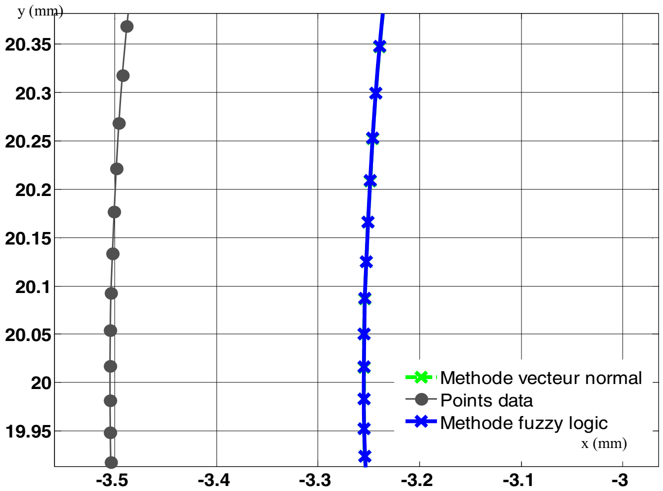

Fig. 13. (Color online) View B-B.

7.3 In view C-C

The intersection between the circles developed tooth and the inner cylinder such that it rounded the ideal form, so we mentioned that the fuzzy logic method closest to the ideal method normal vector Figure 11. That is to say, it is 7 points with the route to determine ideal for vector method not appear normal except for 2 points.

7.4 Analysis the advantages and disadvantages

Under CC, the fuzzy logic method gives high precision, the intersection between the curve (in blue) and the inside circle, give several points, but by the normal vector method, there is no point, that is to say the area is vague. In section AA, when we measure the outside diameter of the gear calculated, it will be two different diameters of the normal vector method is 25.82 mm and by the fuzzy logic is 25 765 mm, which is near the ideal. In the section BB we have same results.

8 The calculation of error

In conclusion, the proposed method, has the maximum error values, in the positions of peaks in the range of 0.16 mm. Same time in the method of normal vector is largest Figure 12. We deduce that the method of fuzzy logic is closer to the real curve, because it gave a few points that we could not be calculated by the previous method (normal vector).

8.1 Calculating the difference between two method

$$\begin{cases} error_i = \sqrt{(x_{pi} - x_{si})^2 + (y_{pi} - y_{si})^2} \\ \text{and} \\ error_i \leqslant \varepsilon_i. \end{cases} \tag{14}$$

So we draw graph based on points earned.

See Figure 12.

9 Conclusions and perspectives

In this paper, the fuzzy logic algorithm is used to estimate the actual surface of the gear tooth. The performance results given by our approach was compared with the performance of these data using the ideal model. It is clear that the use of the estimator of the fuzzy logic is appropriate and estimate the actual surface of the tooth which consists very complicated a path when it is the sensing of the tooth by CMMs, in this sense that the application of technology of logic fuzzy using estimation of nonlinear dynamic systems, special cases, the surface of the sprocket wheel that contains several parameters, and the complexity of form then the form control becomes very complicated etc. We can be overcome this problem by using this approach. So the role of this work is the determination of tooth curve to estimate default shape to be machined gear. In our future works, we try to implement other learning algorithms such us estimator or kalman fuzzy neural.

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