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Fuzzy approach to measures correction on Coordinate Measuring Machines: The case of hole-diameter verification

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ABSTRACT

In this paper we analyze the capabilities of a routine, based on Fuzzy logic, for elaborating a data set coming from a CMM (Coordinate Measuring Machine). We will show how to obtain, during holes measuring, the best measure, so that the approximation error is minimized. Moreover the CMM on-board software can elaborate these data and select the mathematical representation of the stored data, by identifying quotes, measures, axes, diameters, tolerances and so on.

Information on measured parts is usually elaborated by an algorithm based on the least square squared error method, in order to evaluate the good shape of the hole; our purpose is to propose a new kind of approach, based on the Inferential Fuzzy system method, both to reduce the number of measured points, and to obtain the same accuracy. Our approach enables to measure the holes with a number of points lower than those usually needed for the CMM software. Thus time spent for obtaining a good measure is significantly reduced.

1. Introduction

By definition a circle has the geometrical property that it can be expressed by a mathematical equation. However, to verify this definition is not easy because not only of measurement errors, but also because of the extension of the concept of the circle to similar forms [1–3].

In technical contexts, this fact has been well expressed, in the tolerance system that defines the correspondence between a form and a circle when the form is contained in the space between two concentric circumferences with a distance between them having a tolerance value **t**. When a circular element is realized, whether this is a hole or a pin, it is essential that the obtained form respects the established tolerance, and therefore the object must be measured; however, even a perfect circle may not be qualitatively satisfactory because its real diameter may not respect the established dimensional tolerance.

Modern systems, for dimensional control, foresee the use of Coordinate Measuring Machines that are able to measure point clouds to obtain the characteristic measurements of the piece that has to be compared with the established tolerances. Since the form cannot be measured continually, some technical statistics must be applied to determine the values of these points, in order to perform the global measurement [4–5].

The identification of the real circumference using the method of quadratic minimums inevitably suffer from the presence of points that are deviated to quite a degree from the average value, and therefore the number of measured points must be increased to reduce the variancy. Fuzzy analysis of the deviation of points from the average leads to an optimization of this process. This work presents a fuzzy approach that allows the calculation of the corrective factor to be applied to the diameter of a circular element, calculated with a certain number of points, in order to guarantee accuracy even with a reduced number of measured points [6–11].

2. Coordinate measurements

It is well known that a large number of industrial products undergo to geometrical and dimensional tolerance tests. These tests are essential for the correct function of the product, and when the component is part of a global assembly, this also includes its compatibility with the other components. In fact, given the inevitable lack of precision in manufacturing processing, a pre-established dimension cannot be manufactured rigorously to perfection, but in order to perform its function, it is sufficient that it can be included within two admissible dimension limits, whose difference constitutes the ***tolerance***.

The invention of the CMM (or ***Coordinate Measuring Machine***) has revolutionized the attitude towards product ***testing***; these are the result of a well thought-out project which originated from a precise necessity: the upgrading of the ***quality control*** stage on a

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level with the rest of the productive process. A necessity that became imperative when ***automation*** became the predominant operational model in medium and large-scale industries.

Therefore a move was made from testing according to criteria that could be considered as being almost artisan level, but however where the expertise and manual work of the technician was necessary, to the use of programmable measuring machines that were therefore able to operate in a completely automatic manner. This enabled their integration to great advantage in today's ***manufacturing cells and work stations***, including those that do not require an operator, in order to perform dimensional tests and to control deviation from geometrical regularity on even very complex objects.

From a purely metrological point of view, the CMM represents the universal measuring instrument, because it includes all the possible dimensional and geometrical control functions. This creates considerable benefits of a basically metrological nature. With the means and criteria of conventional metrology, a range of measurements that involve both dimensional and geometrical control, implies the use of a variety of different specific measuring instruments. For dimensional control, calipers/gages, micrometer gages and fixtures, go-no-go gages, and gaged bushing are used; while for testing geometrical regularity, the use of a comparator and a surface plate are necessary (parallelism tolerance, planarity, concentricity) but other instruments may also be needed such as cylindrical squares (perpendicularity) and goniometers (angles of inclination).

This wide variety of measuring instruments signifies the coexistence of different calibration settings and different metrological characteristics; elements that lead to a lack of uniformity in uncertainty for the various measurements.

Coordinate Measuring Machines are moving systems using a ***probe*** device, according to three or more axes, within a determined work space. The work space is mapped by high precision linear transducers, one for each axis.

By following a specific manual or programmed path, the machine moves the probe into contact with various pre-selected points on the surface of the piece to be measured. When the probe makes contact with the piece, it transmits a signal to a computer, which, in turn memorizes that precise point based on the information sent by the transducers.

The coordinates of the contact points are then processed by a control unit, to provide a mathematical representation of the surface of the piece (***associated geometrical elements***) from which are obtained dimensions, hole diameters, interaxes, and the form and position tolerances are also controlled. It is possible to program a machine to generate a complete dimensional test certificate [12–14].

3. Calculation of the diameter of a circular element

Measuring the diameter of the circumference of a piece or of any other product using a CMM, is an operation which, like all normal measuring operations, involves a certain period of time. This time is directly proportional with the number of points that the CMM must probe on the circumference of the product, as well as the speed and the path from one point to another that is to be measured [3,15,16].

We also know that the accuracy of a measurement increases in relation to the number of measured points, because in fact, the processing software determines the required measurement using the method of quadratic minimums, starting from the distribution of the points touched on the surface of the piece to be measured.

In order to obtain a measurement result, for example the diameter of a circumference that is very accurate, certain factors must be taken into account [17], in particular, it is important to measure a very large number of points; and therefore as a result, the measuring time will be considerably longer.

A reduction in the number of points necessary for determining correct measurement requires the use of more accurate, and therefore, more expensive CMMs, or a prevision criteria and error compensation [18,19].

Other authors have studied the influence of inaccuracies due to the frequency of processing by introducing harmonic components of the error [20]. We introduce a fuzzy system with same accuracy of the traditional system, but it needs a lower number of points. The reduction of the process time is very important in the industries.

4. Fuzzy inferential system

4.1. Basic starting data

In order to define a Fuzzy inferential system certain data is required to characterize the problem. In particular, we have the following:

- Coordinates (X_i, Y_i) of the points touched by the CMM probe on the surface of the circumference according to any type of reference system.
- Diameter D_M processed by the CMM.

With proposed data, two parameters are calculated that will be used to define the rules necessary for the construction of the Fuzzy inferential system, and which permit the definition of the accuracy level of the measurement of the circumference diameter. These are:

$\Delta D_i = (D_M - D_{int})$ is the difference between the diameter processed by the machine and that of the circumference inscribed inside the point cloud, in other words, the largest circumference inside the distribution points.

$\Delta D_e = (D_{ext} - D_M)$ is the difference between the circumference diameter circumscribing the point cloud, in other words the smallest circumference outside the distribution points, and the diameter processed by the machine.

D_{int} is calculated by identifying all the possible circumferences, each one passing through three of the measured points, and controlling that the center of the circumference calculated in this way, is within the assigned point cloud. The circumference with the largest diameter is that chosen from the identified circumferences. The process is described in detail in the following stages.

The process for calculating ΔD_e is similar, except for the difference in that the circumference with the smallest diameter is chosen.

The condition of the passage through three measured points guarantees that the minimum and maximum diameters with a center inside the point cloud are respectively the largest internal and the smallest external circumferences.

4.2. Procedure for calculating ΔD_i

1. Possible combinations of three points $PC = \frac{n!}{k!(n-k)!}$ are identified (1):

$$[(X_i^I, Y_i^I); (X_i^{II}, Y_i^{II}); (X_i^{III}, Y_i^{III})] \quad \text{where } i = 1, \ldots, PC; \tag{1}$$

2. of the circumference passing through each triad of points, the following are calculated:

   (X_{ci}, Y_{ci}) = coordinates of the center of the i-th circumference;
   R_i = radius of the i-th circumference.
3. A check is made that (X_{ci}, Y_{ci}) is within the point cloud, controlling that