# SOME REVIEWS ON CIRCULARITY EVALUATION USING NON- LINEAR OPTIMIZATION TECHNIQUES

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**Abstract** - *This paper focuses on some reviews on circularity evaluation using nonlinear optimization techniques. In general, it is more important for optimization of form factor, circularity based on Minimum Zone Circle method using soft computing techniques. Circularity is a two-dimensional form tolerance that describes the allowable variability in the shape and appearance of a circle in a section view. The determination of center coordinates of round component is a non-linear optimization problem that can be solved by non-linear optimization techniques. In this paper, the review of some of the soft computing algorithm is employed to optimize the circularity addressed by the various researchers. The proposed computing algorithm with inertia weight factor decreasing linearly from 0.9 to 0.4 and the center coordinates obtained from the LSC method is used as the initial positions to obtain the optimized center-coordinate value of the circular component taken from Coordinate Measuring Machine observed by the researchers.*

***Keywords:*** **Circularity, Coordinate Measuring Machine, LSC.**

## 1. INTRODUCTION

In the present day advanced manufacturing scenario, the components produced must strictly adhere to the dimensional, positional and form specifications, in order to have an edge over competitor's products. The manufactured components have to be inspected to ensure that the geometric form of the components is conforming to the design specifications. The Computer Aided Inspection (CAI) procedures have gained a prominent role in the field of inspection and evaluation of the manufactured parts. In the recent years, the Coordinate Measuring Machines (CMMs) have gained popularity in automated inspection for both on-line and off-line inspection of manufactured components. The data for evaluation of form errors obtained from CMM will be in Cartesian coordinates given with reference to a system of mutually orthogonal planes and the data combines form and size aspects. This data has to be further processed using appropriate techniques to evaluate the form error. Finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones. Mathematically an optimization problem has a fitness function, describing the problem under a set of constraints which represents the solution space for the problem.

The tolerance of out-of-roundness is the annular space between two concentric circles. A work-piece is within the tolerance if these two circles enclose its profile. Numerical assessment of out-of-roundness is done by measuring the peak-to-valley deviation of the actual profile from a reference circle fitted to that profile. Four reference circles are internationally accepted for roundness measurements [1].

Roundness error of the work-piece and radial error of the spindle are measured simultaneously by using 4 probes mounted with certain angle arrangement. This method gives high accuracy for all harmonics, which is difficult for three-point method [2].

A novel algorithm for evaluating roundness is the concept and quantification of profile confidence level, which is used to reduce the uncertainty associated with filling the sampled data points in the determination of a roundness zone [3].

The circular features is one of the most common features that are evaluated on the CMM using different criteria like the Maximum Inscribed Circle (MIC), Minimum Circumscribed Circle (MCC), Minimum Zone Circle (MZC) and the Least Square Circle (LSC). The LSC method is the most popular approach for evaluating roundness error because of its easy computation [4].Evaluation of roundness error is formulated as a non-differentiable unconstrained optimization problem and hard to handle. The maximum inscribed circle and the minimum circumscribed circle are all easily solved by iterative comparisons. Based on the minimum zone circle, the maximum inscribed circle and the minimum circumscribed circle can be easily determined [5].A method for the approximation of geometry elements by Gauss/Tsechebyscheff algorithm was developed. Moreover, the Tsechebyscheff algorithm is an approach to determine the standardized form tolerances like roundness, flatness or cylindricity deviations. A modification of the conventional Tsechebyscheff algorithms leads to maximum inscribed & minimum circumscribed elements [6].

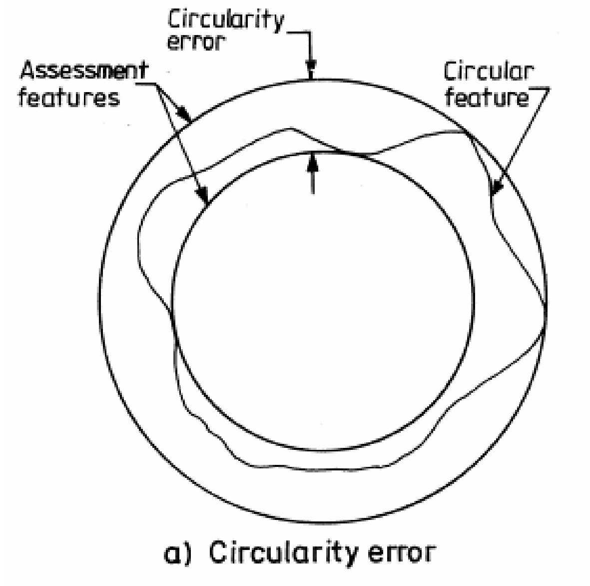


Fig.2 GA flow chart

### 1.1. Optimization:

Machining is one of the most important and widely used manufacturing processes. Due to complexity and uncertainty of the machining processes, soft computing techniques are being preferred to physics-based models for predicting the performance of the machining processes and optimizing them.

### 1.2. Optimization Techniques:

In this study, the Genetic algorithm and Particle Swarm optimization along with data fitting methods are observed.

## 2. Data fitting method:

### 2.1. Minimum Zone circle (MZC):

In this method, two circles are used as reference for measuring the roundness error. One circle is drawn outside the roundness profile just as to enclose the whole of it and the other circle is drawn inside the roundness profile so that it just inscribes the profile. The roundness error here is the difference between the radius of the two circles. [7]

### 2.2. Least Squares Circles (LSC):

The least squares circle (LSC) is fitted inside the profile such that the sum of the squares of radial ordinates between the circle and profile is minimized. The center of the LSC is then used to draw a circumscribed and an inscribed circle on the polar profile and the out-of roundness value is the radial separation of these two circles. The least squares circle and its center are unique because there is only one that meets the definition and its accuracy depends on the number of points taken. Manual calculation of the LSC is labored and time consuming but newer digital instruments simplify the process dramatically. [7]

### 2.3. Maximum Inscribed Circle (MIC):

This method fits the largest possible circle inside the profile. The circle can be determined by trial and error with a compass or with a template. After the circle has been drawn, the out-of roundness value is the maximum distance between the profile and the inscribed circle. [7]

### 2.4. Minimum Circumscribed Circle (MCC):

A center is found by drawing a circle that has the smallest possible radius but still contains the polar plot profile in this method. An inscribed circle is then drawn inside the profile based on the center of the minimum circumscribed circle. The out-of-roundness value is the difference between the radii of the inscribed and circumscribed circle. [7]

## 3. Non Linear Optimization Techniques to Measure Circularity Error:

### 3.1. Genetic Algorithm:

GA is the process of natural evolution by incorporating the “survival of the fittest” philosophy. In GA, a point in search space is represented by binary or decimal numbers, known as string or chromosome. Each chromosome is assigned a fitness value that indicates how closely it satisfies the desired output. A group of chromosomes is called population. A population is operated by three fundamental operations, 1.Reproduction (to replace the population with large number of good strings having high fitness values), 2.Crossover (for producing new chromosomes by combining the various pairs of chromosomes in the population) and 3.Mutation (for slight random modification of chromosomes). A sequence of these operations constitute one generation. The process repeats till the system converges to the required accuracy after many generations. The genetic algorithms have been found as a very powerful tool in optimization. [8]Genetic algorithms maintain a population of center candidates (the individuals), which are the possible solutions of the MZT problem. The center candidates are represented by their chromosomes, which are made of pairs of x and y coordinates. Genetic algorithms operate on the x and y coordinates, which represent the inheritable properties of the individuals by means of genetic operators. At each generation the genetic operators are applied to the selected center candidates from current population in order to create a new generation. The selection of individuals depends on a fitness function, which reflects how well a solution fulfills the requirements of the MZT problem, e.g. the objective function [9].**Sharmaet al. [10]** use a genetic algorithm for MZT of multiple form tolerance classes such as straightness, flatness, roundness, and cylindricity. There is no need to optimize the algorithm performance, choosing the parameters involved in the computation, because of the small dataset size (up to 100 sample points).

**Wenet al. [11]** implement a genetic algorithm in real-code, with only crossover and reproduction operators applied to the population. Thus in this case mutation operators are not used.

The algorithm proposed is robust and effective, but it has only been applied to small samples.

**Shakarji [12]** suggested use of Levenberg-Marquardt algorithm (LMA) to minimize the square of error distances for various features including circle. LMA is trust-region strategy which provides a numerical solution to the problem of minimizing non-linear function. LMA is more robust than GNA. However, even for well-behaved functions and reasonable starting parameters, the LMA tends to be a bit slower than the GNA. LMA can also be viewed as improved GNA with trust region approach. Also, convergence of the solution is highly dependent on choice of Levenberg-Marquardt parameter and its selection is challenging.

**Shumugam [13, 14]** suggested methods based on computational geometric techniques to deal with CMM measured data and form data. The present work aims to define a strategy that finds best fit circle for given set of data points to minimize circularity and it is named as “Maximum Distance Point Strategy (MDPS)”. For the purpose of comparison, results of MDPS are compared with LSM and CMM results.

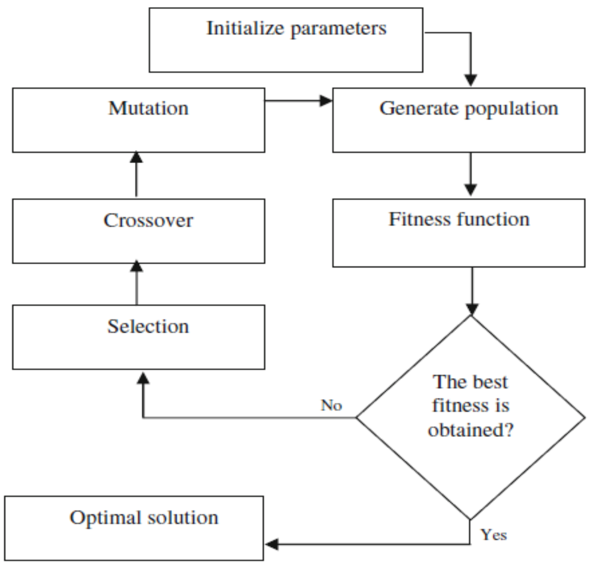


Fig3 PSO Chart

## 3.2. Particle Swarm optimization (PSO):

Similar to genetic algorithms (GA) s, PSO is based on two concepts—groups and fitness, on the basis of population iteration. The difference from GA is that: PSO doesn’t have genetic operators— selection, crossover, and mutation, it depends on collaboration and competition among individuals to find the optimal solution. Each particle represents a potential solution, and has a closely association with the velocity. It adapts search patterns by learning from its own experience and neighbors’ experience to change its velocity’s size and direction [15].

**Eberhart and Shi [16]** presented the developments, applications, and resources related to PSO that focuses on the applications in engineering and computer science. Their experimental results revealed that the maximum velocity factor Vmax is a critical factor that should not be ignored. If Vmax can be set with a good value, the modified optimizer can work well.

**Wang, Huang, Zhou, and Pang [17]** proposed a new application of PSO to traveling salesman problem (TSP). They combined the concept of swap operator, swap sequence, particle swarm optimization, and redefined some operators to resolve the TSP with good solutions.

**Li, Gong, and Xue [18]** constructed a roundness measurement method by using a series of Gaussian digital approximation filters, which was designed on the basis of approximation method and bilinear transformation. Most of existing roundness measuring methods are contact type and are operated by using a precise spindle to produce a relative rotational movement between a radial-mounted position transducer and the circular work piece. However, the research relating to non-contact roundness measuring methods are very limited.

**Chen, Tsai, and Tseng [19]** applied a 1203 stochastic optimization approach to develop a vision-based inspection system for computing the reference circles of maximum inscribing circle (MIC), minimum inscribing circle (MIC), minimum zone circle (MZC) methods. They proposed a hybrid optimization approach based on simulated annealing and Hook-Jeeves pattern search for roundness measurement.

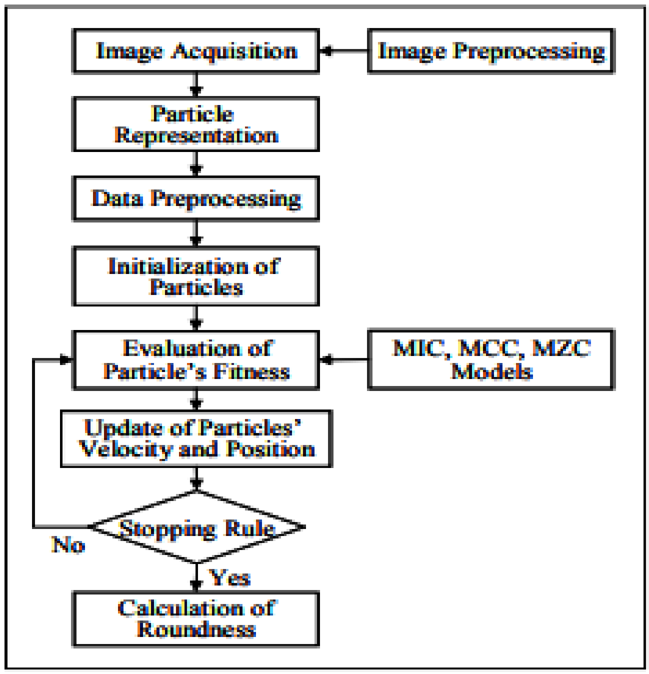


Fig3 PSO Chart

## Conclusion:

In this paper, a review of various optimization techniques of the circularity measurement has been studied.

- Researchers studied the nonlinear optimization process on different materials and concluded different remarks on circularity measurement. Due to potential advantages, these processes is now preferred in various industrial sectors for measurement of various complicated parts.

- LSC method is widely used for producing high precision results in data fitting of circularity error measurement.

- Other methods like MZC, MIC, and MCC are also used by researchers in data fitting of circularity error measurement.

- GA is the powerful optimization tool than compared to the other optimization techniques discussed previously. Though there are several optimization techniques, the hybrid optimization technique (combination of two optimization techniques such as Neuro-genetic approach, Neuro-fuzzy approach, integrated approach of ANN and SA) found to be more efficient.

- PSO method is used to calculate MIC, MCC and MZC under a machine vision system efficiently.

## References:

1. Dimensioning and Tolerancing, ANSI Standard Y14.5, the American Society of Mechanical Engineers, New York, 1982.

2. Technical drawings - Geometrical Tolerancing, ISO 1101, (1983)12-01.

3. Shunmugam M.S., on assessment of geometric errors, International Journal of Production Research, **24** (1986) 413-425.

4. Murthy T. S. R. and Abdin S. Z., Minimum zone evaluation of surfaces, International Journal of Machine tool Design and Research, **20** (1980) 123-136.

5.T. Kanada, Evaluation of spherical form errors – Computation of sphericity by means of minimum zone method and some examinations with using simulated data, Precision Engineering, **17** (1995) 281 – 289

6 Danish. P. B. and Shunmugam. M. S., An algorithm for form error evaluation using the theory of discrete and linear Chebyshev approximations, Computer Methods in Applied Mechanics and Engineering, **92 (**1991)309-324

7. WentaoSui1, Dan Zhang (2012) "Four Methods for Roundness Evaluation" Physics Procedia 24 (2012) 2159 – 2164

8. M.Chandrasekar, M.Muralidhar, C.Muralikrishna U.S Dixit (2010) "Application of soft computing techniques in machining performance prediction and optimization: a review" Inter journal of Adv Manufacturing technol 46:445-464

9. M.Sreenivasa Rao, S.Ravindar, A.Seshukumar (2014) "Parametric optimization of Abrasive Waterjet Machining for Mild steel: Taguchi approach" International journal of current Engineering and Technology P-ISSN 2347-5161

10. Sharma, R., Rajagopal, K. and Anand, S., A genetic algorithm based approach for robust evaluation of form tolerances, Journal of Manufacturing Systems, 2000, 19-n1, 46–57

11.Wen, X., Xia, Q., Zhao, Y., An effective genetic algorithm for circularity error unified evaluation, International Journal of Machine Tools and Manufacture 46, 2006, 1770– 1777.

12. Shakarji, 'Least-Squares Fitting Algorithms of the NIST Algorithm Testing System', Journal of Research of the National Institute of Standards and Technology, vol. 103 no. 6, pp 633-641, 1998.

13.Samuel and Shunmugam, 'Evaluation of circularity from coordinate and form data using computational geometric techniques', Precision Engineering, vol. 24 no. 3, pp 251- 263, 2000. doi: 10.1016/S0141-6359(00)00039-8.

14. Samuel and Shunmugam, 'Evaluation of circularity and sphericity from coordinate measurement data', Journal of Materials Processing Technology, vol. 139 no. 1-3, 90-95, 2003. doi: 10.1016/S0924-0136(03)00187-0

15. Zhongyong Wu 1, a, Jin Gou1, b, Changcai Cui2, c "An Improved Particle Swarm Optimization Algorithm Applied to the Unified Evaluation of Circularity Error" Applied Mechanics and Materials Vols. 44-47 (2011) pp 3937-3941.

16.R. C. Eberhart and Y. Shi, "Particle swarm optimization: developments, applications and resources," Proceedings of the IEEE Congress on Evolutionary Computation, ICEC 1, pp.81–86, 2001.

17. K. P. Wang, L. Huang, C. G. Zhou, and W. Pang, "Particle swarm optimization for traveling salesman problem," Proceedings of International Conference on Machine Learning and Cybernetics, pp.1583–1585, 2003

18. N. Li, D. Gong, and B. Xue, "Fast Gaussian filtering algorithm for roundness measurements," Journal of Nanjing University of Science and Technology, vol. 31 (3), pp.342–345, 2007.

19. M. C. Chen, D. M. Tsai, and H. Y. Tseng, "A Stochastic Optimization Approach for Roundness Measurements," Pattern Recognition Letters, vol. 20, pp.707–719, 1999.