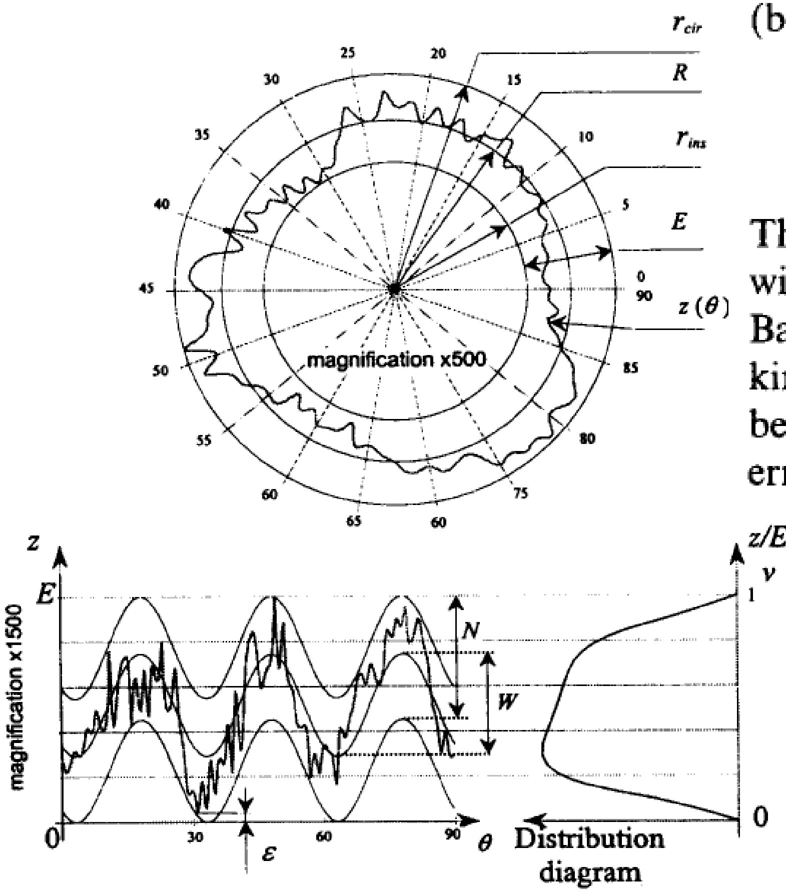
The model of form error



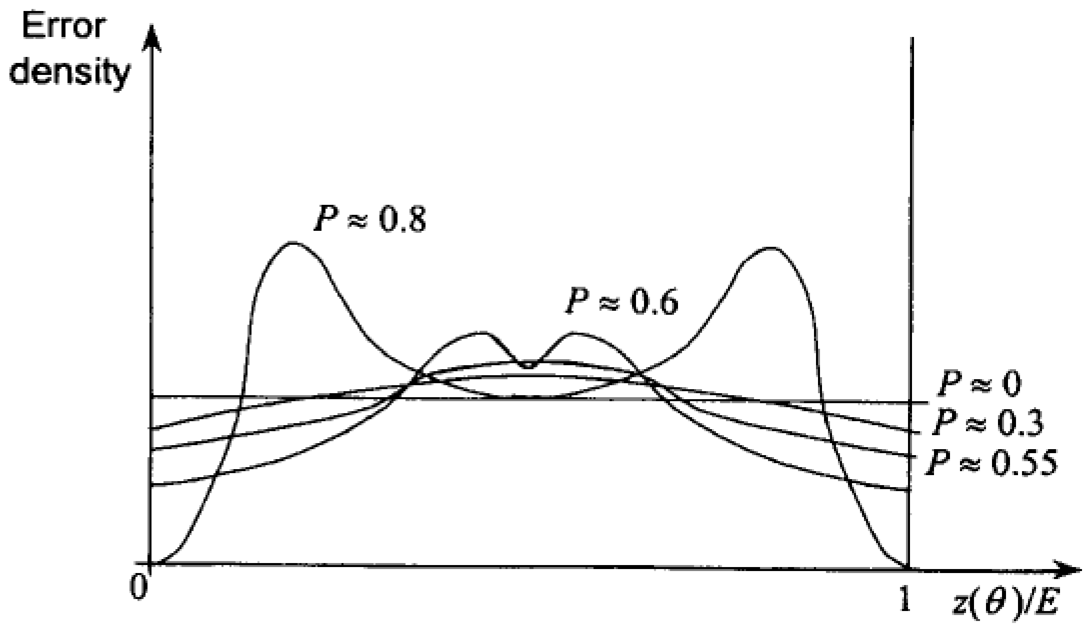
Parametric model and distribution diagram of roundness deviation in accordance with least-squares substitute geometry. Angle coordinates are expressed in $2\pi/90$ radians

In summary, in manufacturing processes two kinds of deviations are obtained:

(a) low-frequency waviness deviations, often caused by loss of centricity in the spindle of tools or parts;
(b) high-frequency waviness deviation (similar to a noisy error), often linked to a vibration in the cutting process or improper setting of the cutting parameters.

Thus a roundness deviation assumes a waviness form with a random perturbation superimposed (Fig. 1). Based upon the major influence of the two different kinds of manufacturing errors, the deviation appears to be more wavy and less random within a given range of error and vice versa.

Development of a classifier cyclic/noisy deviations



Distribution diagram versus percentage of wave amplitude within roundness error amplitude

Clustering Algorithm

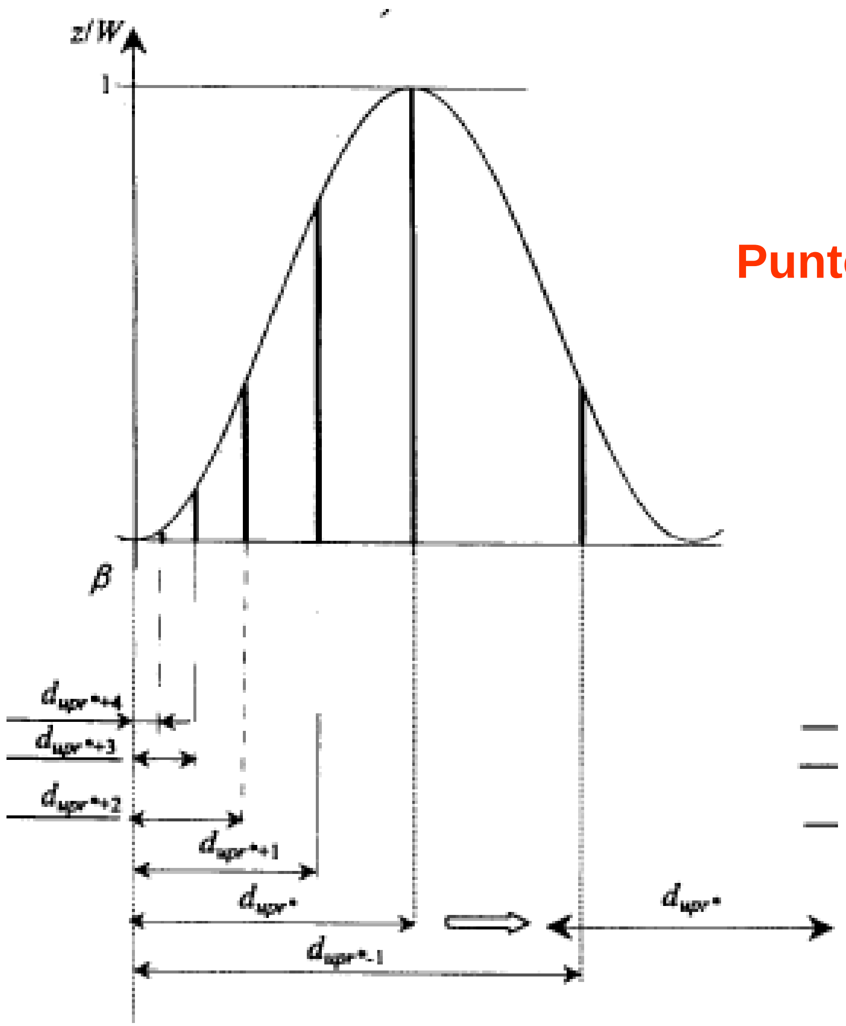


Fig. 3 Lobe-filtering system of a pure sinusoid deviati

Punto critico

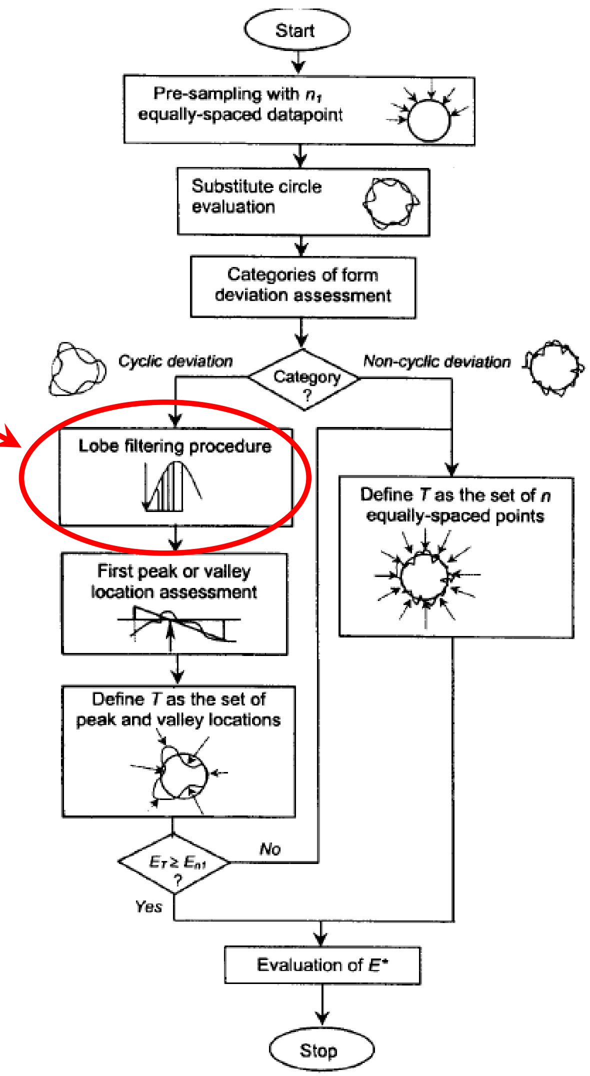
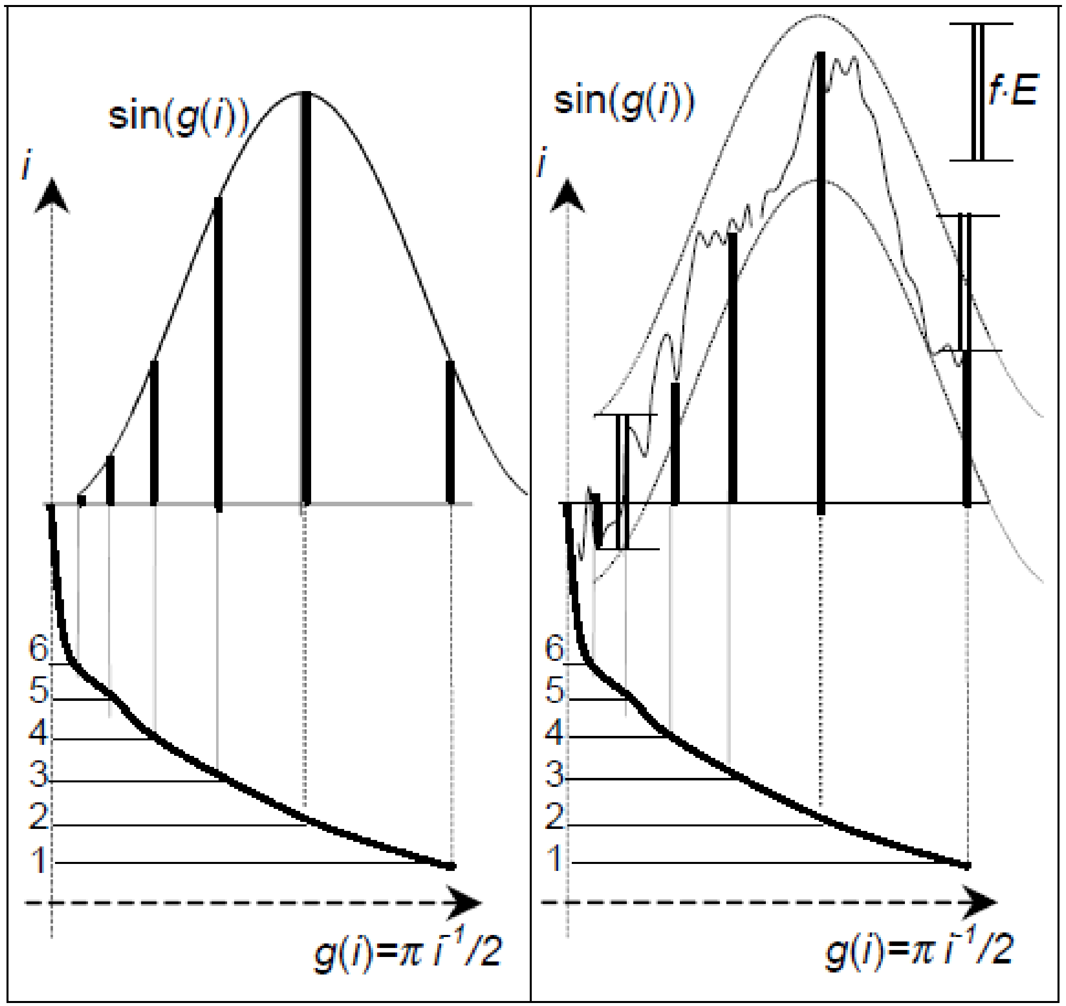


Fig. 4 Process of roundness error evaluation with the proposed system

Lobe Filtering



(a) (b)

Figure 2: Sinusoidal filtering (a) and lobe filtering (b).

Exponential distribution with initial point γ

$$D(\gamma, i) = \gamma + (\pi \cdot i^{-1})/2, \quad i = 2,..,n_2 \qquad (5)$$

This distribution is exponential because the distance between the starting point and the i^{th} location decreases in accordance with i^{-1} (i.e. the period of the Fourier series). If z_i denotes the measurements at the locations

Modello di rumore

E max rumore, $f \in [0,1]$

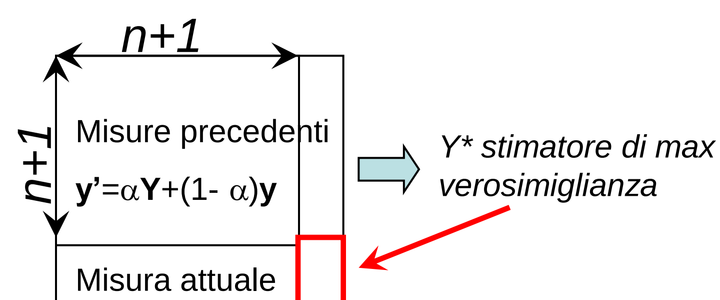
$$y_i - y_{i-1} \leq f \cdot E, \quad i = 3,..,n_2 + 2 \qquad (7)$$

where $f{\cdot}E$ is a non-negligible percentage of roundness error [5].

Modified IPR for noisy filtering

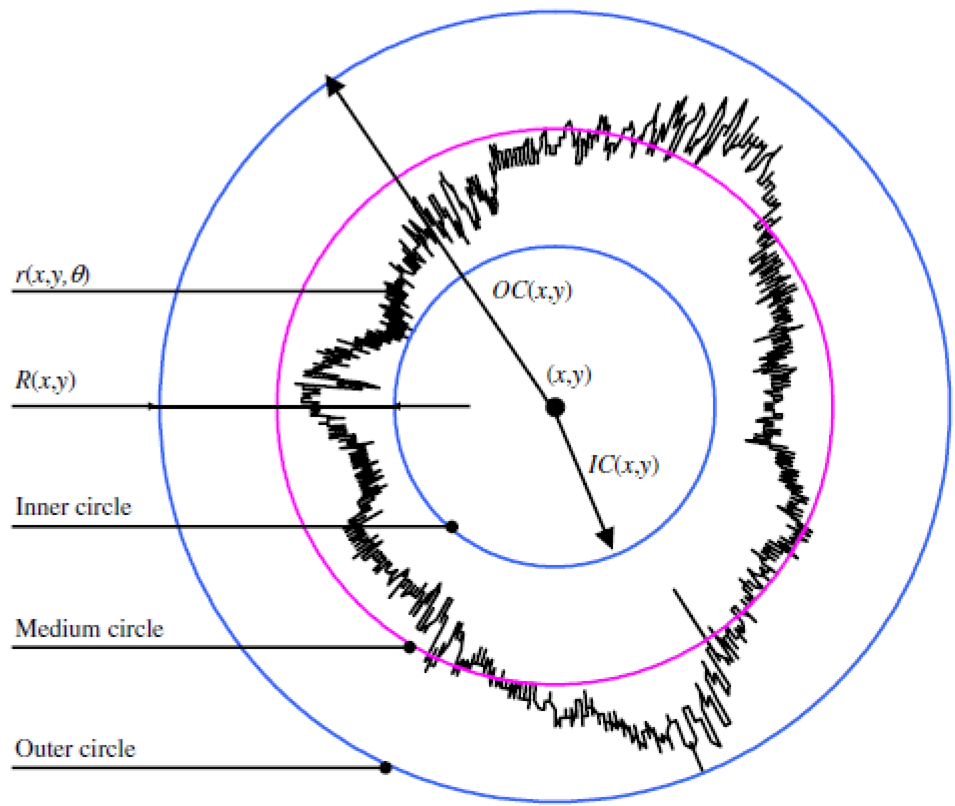
As the IPR gives a prediction based on past data, this algorithm can be used to smooth the noise by means of a linear combination between the predicted value Y_i and the obtained measurement y_i, like the following:

$$y'_i = \alpha Y_i + (1-\alpha) y_i, i = s,..,n_2 + 2, \alpha \in [0,1] \qquad (8)$$



The Minimum Zone Roundness problem (MZR)

- Find a point (x, y) such that the distance between the blue line and the pink line is minimal (the minimal circular ring enclosing the cloud).



Deviations type

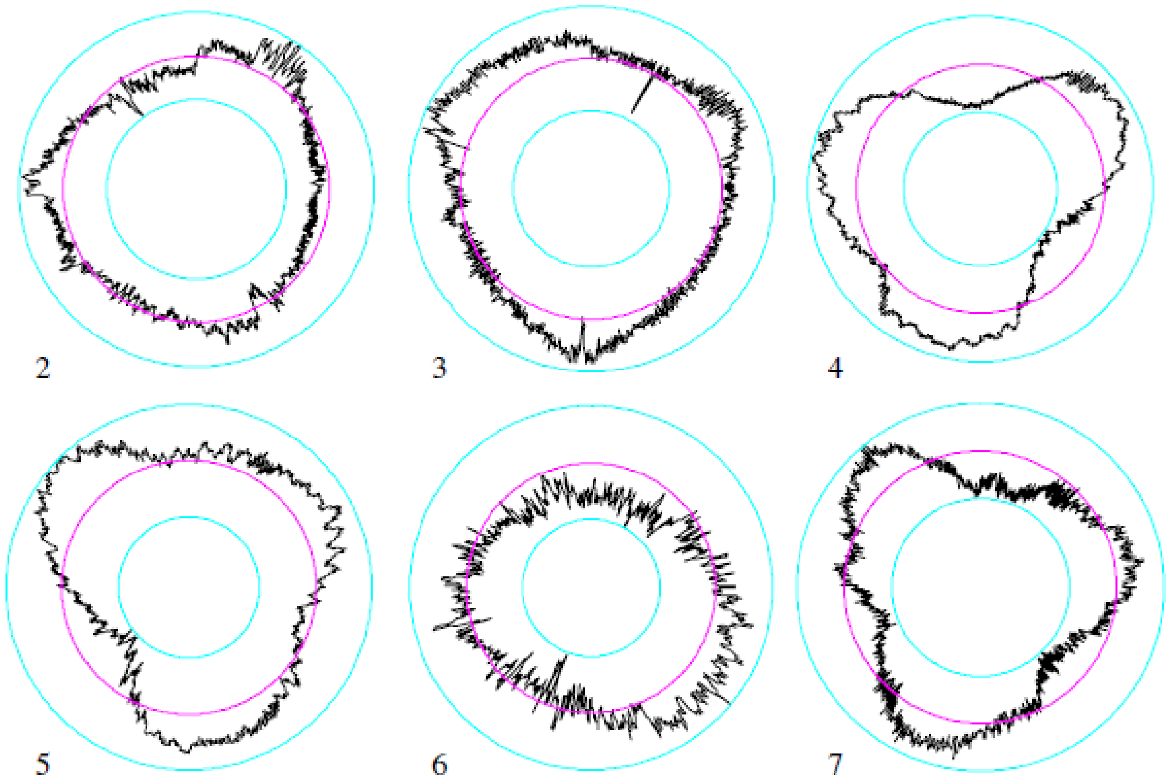


Fig. 3. Roundness deviations of samples no. 2–7 of Table 2 with the reference circles in Fig. 1.

Table 2
Experimental set [24].

Dataset	Diameter (mm)	Process	Material
1	10	Drilling	Aluminum alloy
2	10	Milling	Steel
3	14	Turning	Steel
4	17	Drilling	Marble
5	23	Turning	Steel
6	25	Turning	Aluminum alloy
7	39	Turning	Steel

Genetic algorithms for the MZT

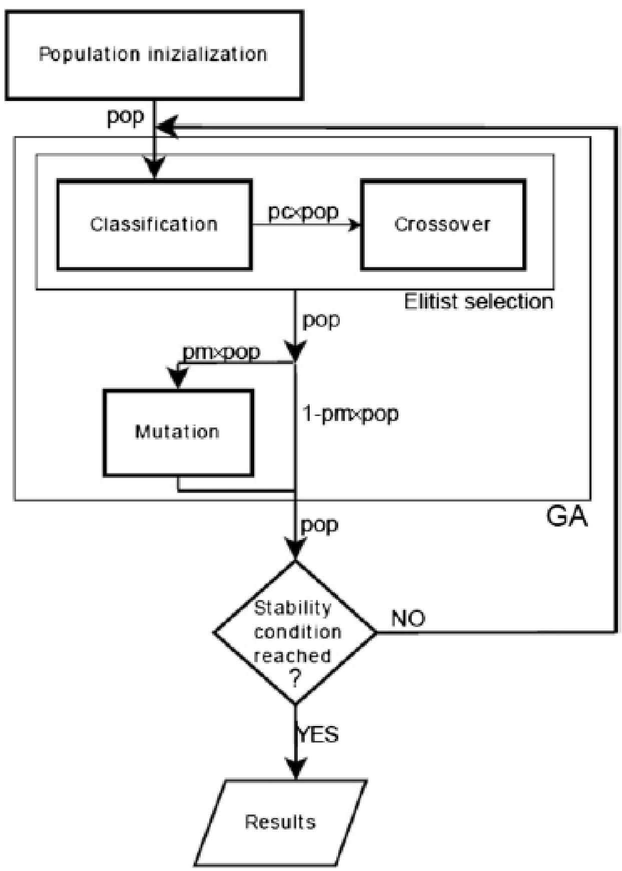


Fig. 2. Standard GA scheme.

Table 1
Genetic operators, their parameters and mechanisms.

Genetic operator	Parameter	Remark
–	*pop*	Population size
Selection	–	Elitist selection
Crossover	*pc*	One point crossover of the $pc \times pop$ parents' genes (i.e. coordinates) at each generation
Mutation	*pm*	$pm \times pop$ individuals are modified by changing one gene (i.e. coordinate) with a random value
Stop criterion	*N*	The algorithm computes *N* generations after the last best roundness error evaluated rounded off to the fourth decimal digit (0.1 μm)
Search space	*E*	Initial population randomly selected within

GA time reduction

- 1. reduction of population, *pop*
- 2. reduction of crossover prob., *pc*
- 3. stop the algorithm as earlier as possible, *N*
- 4. Concentrate the population, *E*

Reduction of the population (*pop*)

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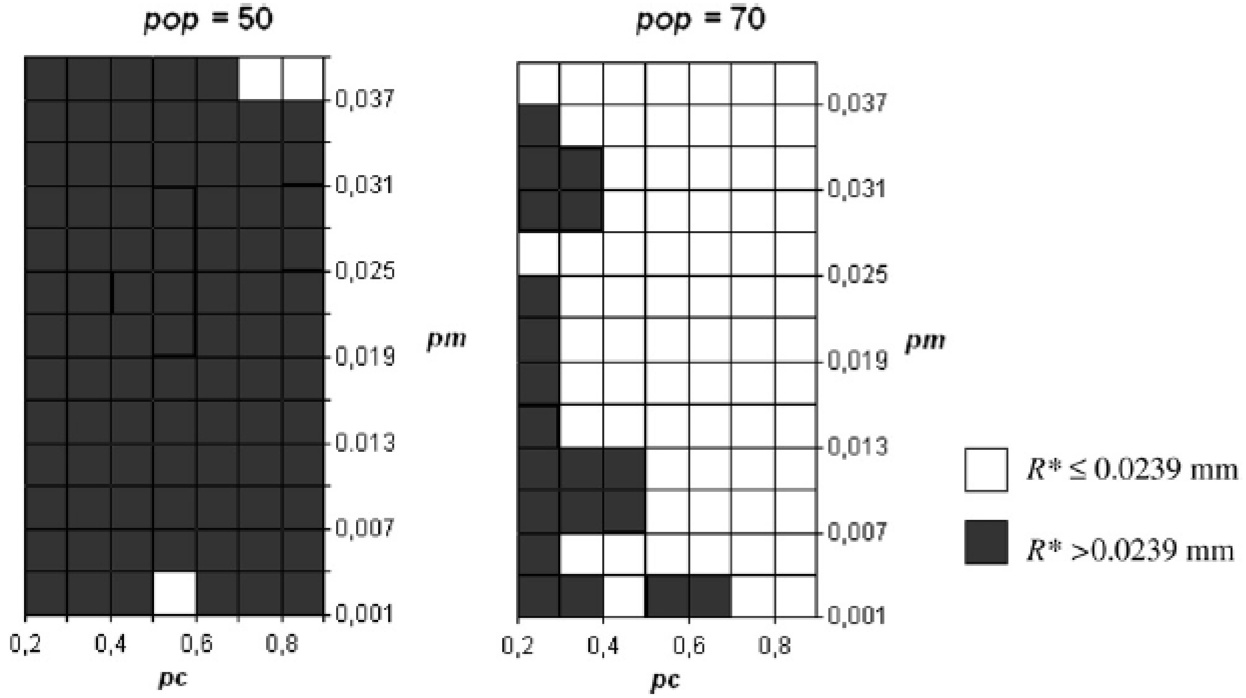

Fig. 5. GA parameters exploration: target roundness error R^* on dataset no. 1 of Table 2 as a function of *pc* and *pm* for two different values of *pop* upon an area of promising configuration (from Fig. 4) of *pc* and *pm*.

Combined optimization of parametes *pc* e *pm*

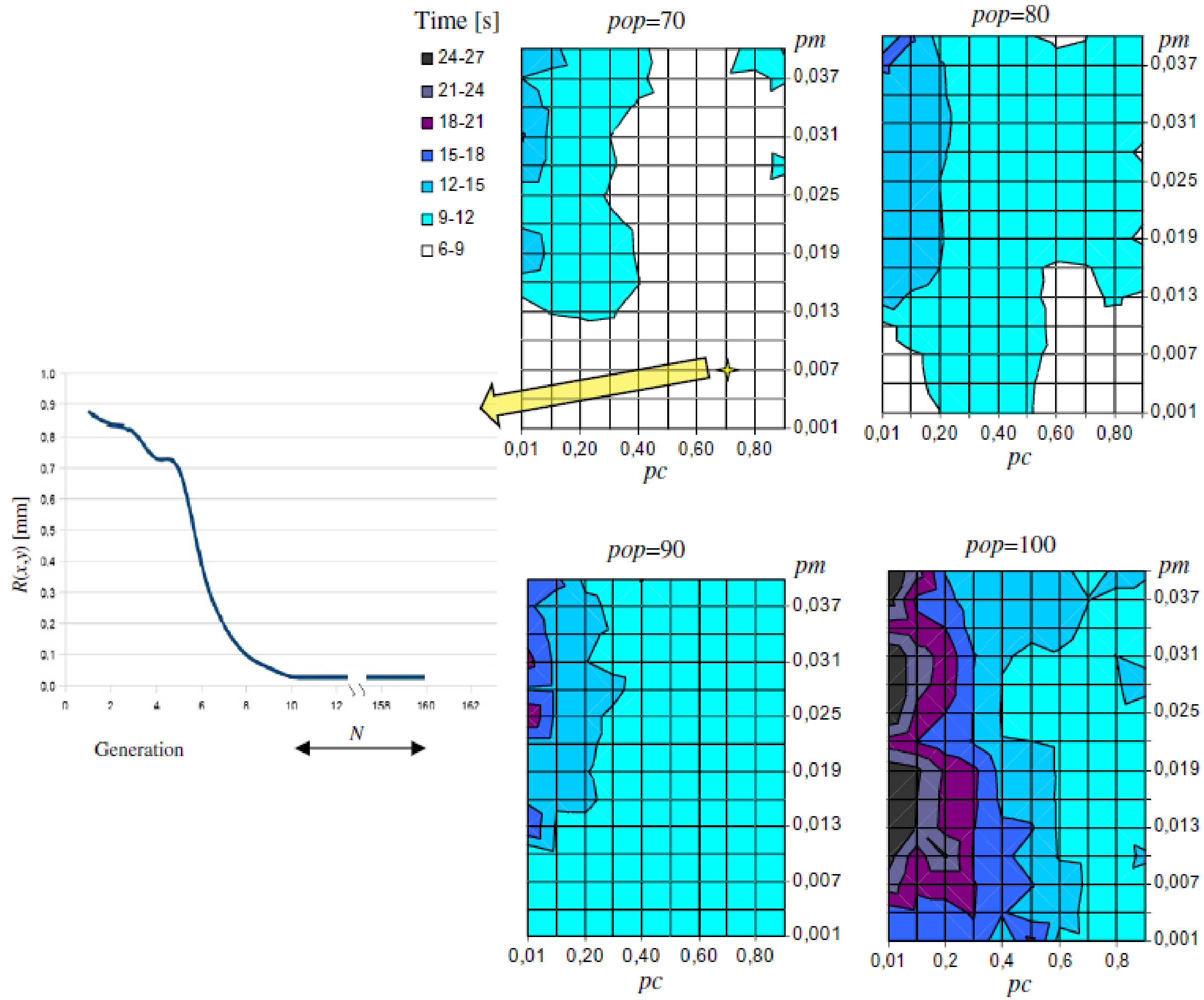

Fig. 6. GA parameters optimization: average computation time on the samples of Table 2 as a function of *pc* and *pm* for four different values of *pop* and convergence of the average roundness error for the selected parameters (left inset).

Computation time by GA

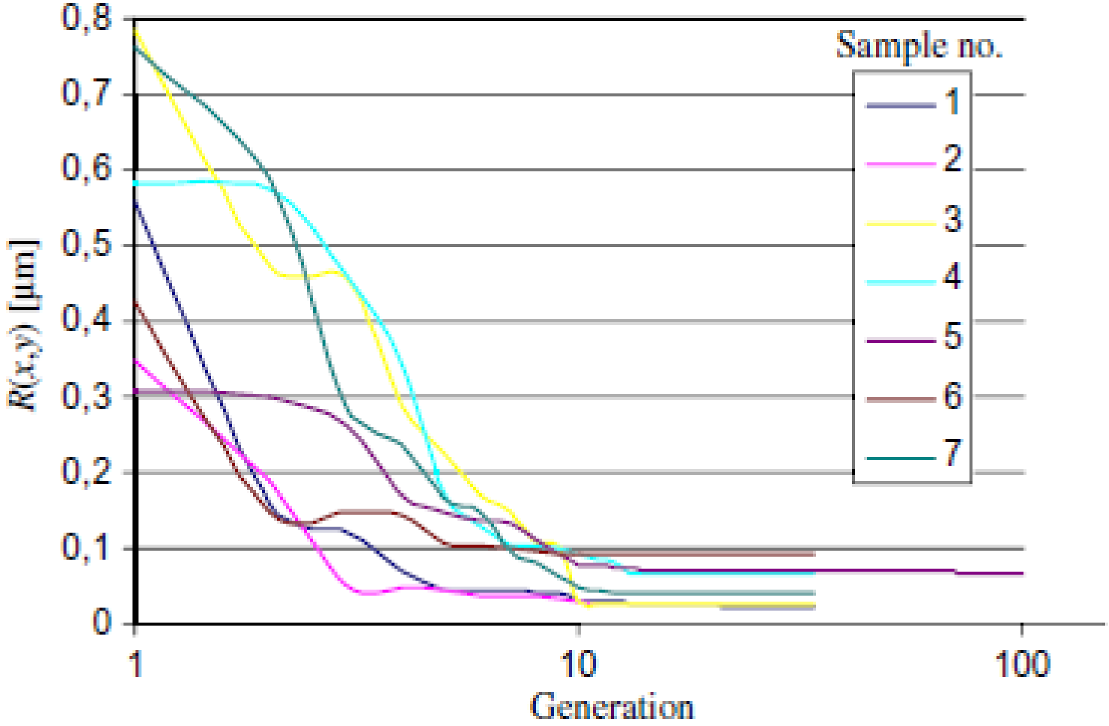

Fig. 7. Convergence of MZT for the seven samples of Table 2 with the selected values of the optimal parameters in Table 4.