

## **SURFACE FINISH ENHANCEMENT IN BALL BURNISHED AL6082 COMPONENTS USING BACTERIAL FORAGING OPTIMIZATION**

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### **ABSTRACT:**

Surface enhancement technique like burnishing improves the surface finish of the component besides surface properties of the component. Burnishing is a cost effective process, mostly used in mechanical industries to improve reliability and performance of the component. In burnishing process, surface roughness depends on factors like burnishing process parameters, tool, and material to be burnished. The major driving forces for development of new production technologies and material development are strength to weight ratio of materials, performance and reliability improvement. The availability of appropriate manufacturing methods plays a vital role with respect to both material properties, cost. Authors tried to investigate the effect of various parameters of ball burnishing on Aluminium AL6082 to optimize the surface finish enhancement using biologically inspired Bacterial foraging optimization technique.

Keywords: Burnishing Tool, Surface Integrity, Optimization, Burnishing Process Parameters

### **INTRODUCTION**

A major concern in the current scenario, in industry, is to manufacture all machine components with complete reliability, maximum safety and predictable performance of the component. Demands lead to development and deployment of predictive analytical models for various manufacturing processes and optimized processes parameters that predict various surface characteristics of the component.

Process of Burnishing employed technique where material surface is plastically deformed to produce highly finished surface. Being, non- material removal process; surface finish is obtained due to plastic deformation of the material. It is a chip-less process. This offers many advantages over other finishing processes like honing, lapping and grinding. Due to chip-less surface finishing processes, cold working of material is done at relatively high force. The applied force slightly exceeds the yield strength of the material and plastic deformation takes place. Due to plastic deformation of material along with a surface finish of the component, wear resistance, fatigue strength, foreign object property and surface microhardness of the component gets improved.

### **BURNISHING MECHANISM**

All machined surfaces consist of series of peaks and valleys of irregular height and spacing. As a result of uneven surface and high pressure, finishing process at the beginning of operation is extremely intensive but gradually slackens off. In burnishing, the motion of ball or roller deforms the peaks into the valleys, thus makes the surface of component finished one. In certain cases, burnishing is the only method to by which technical requirements of the surface can be satisfied.

The effectiveness of burnishing process in the improvement of surface integrity has attracted researchers and engineers. In this paper, work done by researchers on the effect of various burnishing process parameters on surface roughness of AL6082 specimens is presented

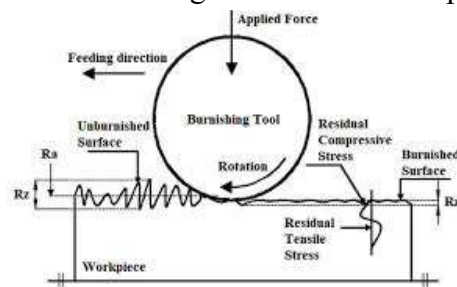


Figure 1. Burnishing Mechanism [1]

## LITERATURE REVIEW

Many researchers have attempted to study the parametric effect in ball, roller and other forms of burnishing and considered variety of work materials like Brass and Cast Al-Cu alloy, EN series material, Aluminium alloys, Titanium alloy, Mild steel etc. The current study deals with Aluminium alloy, thus, focussed on the work in the same domain.

Lv Jinlong and Luo Hongyun [1] investigated the impact of burnishing on 2024-T3 aluminium alloy grain texture and oxidative behaviour. Using a cylindrical-ended PCD (Polycrystalline diamond) burnishing tool, the authors achieved a burnishing depth of 20 nm at a tool speed of 3000 rpm. The EBSD scans were used to assess the electro-chemical condition of the surface after burnishing. Grain alteration of burnished surfaces resulted in an improved corrosion resistance. The surface quality and tribological behaviour of Aluminium 6061 were examined in relation to roller contact width and burnishing orientation throughout the investigation. El-Tayeb et al. [2] A 40 percent improvement in surface roughness may be achieved by burnishing with a reduced roller contact width. A 35 percent reduction in surface roughness can be achieved by burning with a force greater than 220 N. The use of lubricant instead of dry burnishing resulted in a better output. This study shows a negative influence on the wear resistance of burnished 6061 aluminium surfaces caused by increasing the burnishing force. U.M. Shirsat and B. B. Ahuja [3] On aluminium alloy, a parametric study of the combined turning and ball burnishing process was carried out.... A certain amount of force was shown to improve micro hardness, but only to a certain level. P N. Patel et al. [4] used the Taguchi approach to find the best parameters to increase the surface hardness of Al 6061. They found that a burnishing speed of 250 rpm and feed rates of 0.06 mm/rev, force of 8 Kgf, and the number of passes of 5 were the best parameters for hardness, and they came to the conclusion that speed promotes surface hardness. Decreases in hardness as speed increases. Fathi Gharbi et al. [5] a novel ball burnishing tool was used to improve the ductility of aluminium 1050A rolled sheet. As burnishing speed, feed, or force are increased, they found that the mean roughness decreased until it reached a minimal value, after which it began to rise as the burnishing parameters were raised. Amit Patel et al. [6] Response surface approach was used to examine the impact of the roller burnishing procedure on the surface roughness of 6061 - T6

aluminium alloy. As feed rate rises, so does the utility of roller burnishing. Passes enhance surface roughness; the greatest results were achieved with a reduced feed rate of 0.06 mm/rev, an applied force of 15-20 kgf, and four passes. El-Axir, Othman and Abodiena [7] A decrease in beyond-roundness, but no change in surface micro hardness was found when RSM was used in internal ball burnishing of Al 2014 utilising C-Cr steel balls, employing RSM as the basis for the study. There was a significant decrease in beyond-roundness and an increase in surface micro hardness after using a range of burnishing feed rates (from 0.2 to 0.35 mm/rev). Maheshwari and Gawande [8] The surface micro hardness of AA6351 was examined in relation to the impact of a newly developed burnishing tool. Researchers found that depth of penetration was the most important element in enhancing surface micro hardness, with a contribution of 64.52 percent followed by the number of passes. Stalin John & Vinayagam [9] RSM was used to conduct roller burnishing on Al6340 utilising a specially developed and constructed tool with replaceable springs for the procedure. Burnishing force was 1200 N, feed was 200 mm/s, and there were two passes, resulting in a surface roughness of 0.141 m and a hardness of 44 HRB for the finished product. Dadmal and Kurkute [10] showed how the roller burnishing process's transient structural analysis was used to construct a 2D FEA model. Experimental and FEA findings were determined to have an error margin of less than 10%, according to the study's authors. D. M. Mate and P. S. Chaudhari [11] The Al-2014 spherical surface burnishing tool was used to construct a mathematical model of the material. The author's LPP is based on the calculated findings, which give useful guidance for reducing E, Ra, and t in order to achieve greater performances.

## METHODOLOGY FOR EXPERIMENTATION

Parameters in Ball Burnishing have a significant impact on the surface roughness of aluminium Al6082 specimens, as shown in this work. On a Kirloskar Turmaster T 40 lathe, a specifically developed ball burnishing tool was used to perform the experiment (Fig 1). Roughness (Ra) of the burnished surface was tested using the Surftest 211 series (Mitutoyo Japan make). Perpendicular to the burnishing path, a surface roughness traverse was taken with a cut-off value of 0.25 millimetres.

A Carbide insert 16T304 is employed as a tool. Cylindrical Al6082 specimens were premachined to 30mm in diameter (Widia make). From 0.55 to 0.78 m, the surface roughness may be measured; (Ra). With various diameters, hardness, and pressures, the surface was simultaneously burnished with a variety of balls. As seen in Table 1 Uses 6.30 kg/mm flat-ended spring to produce the appropriate compression force for burnishing. With the help of the push rod and locking screw, the ball in the cap is kept firmly in place by bearing no. 608k. (Fig 2). Machine speed is 400 rpm, and the feed rate is 1/16th of an inch per minute for this investigation. Cutting Depth (for turning): 0.2 mm. Feed 0.045mm/rev.

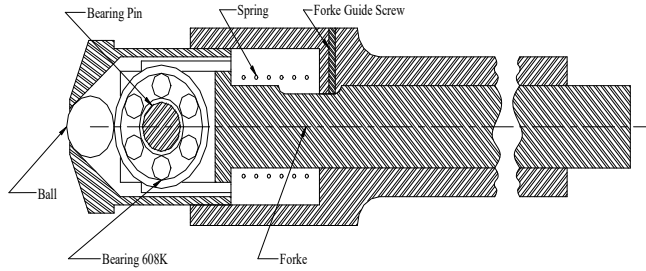


Fig. 2. Burnishing Tool Assembly

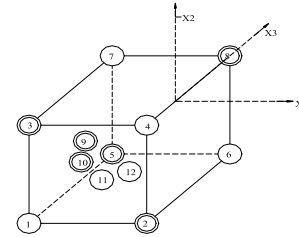


Fig. 3. Trial Numbers of Composite Design

### MODIFIED FACTORIAL DESIGN

Factorial design as a statistical technique, is frequently used in engineering analysis and has several benefits over the classic one variable at a time approach in terms of ease and convenience. In 1951, GEP Box [12] proposed it as part of a chemical process engineering optimization research. M. A. Baradie [13] employees it in developing model for turning Grey Cast Iron. As well S. M. Wu [14], U. M. Shirsat [3] successfully implemented this methodology on tool life testing and burnishing.

For present work, the range of parameters for work material Aluminium AL 6082 is

- i) Ball Materials- High Carbon High Chromium steel HCHCr (783VHN),  
Titanium Nitride Coated bearing steel (2300VHN),  
Titanium Aluminium Nitride coated bearing steel (3000VHN)
- ii) Ball Diameters – 10.9 mm, 13.9 mm and 16.1 mm
- iii) Burnishing Force- 15 kgf, 25 kgf, 40 kgf

Table 1. Experimental Parameters

WORK MATERIAL – Aluminium AL 6082						
Level	Ball Diameter mm	Ball Material Hardness VHN	Burnishing Force Kgf	Coding levels		
				X1	X2	X3
High	16.1	3000	40	+1	+1	+1
Centre	13.9	2300	25	0	0	0
Low	10.9	783	15	-1	-1	-1

#### 1. Development of Mathematical Model

In the modified factorial Design technique, the burnishing operation's reaction surface roughness and the examined independent variables are linked by an equation

$$Ra = C * D^k * M^l * F^m$$

Where Ra is the surface finish in micrometres, D is Ball Diameter (mm); M indicates Ball Material (VHN) and F is Burnishing force (kgf).

## 2. Experimental observations and analysis

The output response of the experimentation carried out are noted and tabulated as shown.

Table 2. Experimental Observations-Aluminium AL 6082

Trial No.	Diameter mm	Ball Material VHN	Burnishing Kgf	Surface Finish (Ra) $\mu\text{m}$		
				Turning	Burnishing 1st pass	Burnishing 2nd pass
1	-1	-1	-1	0.74	0.11	0.13
2	+1	-1	-1	0.54	0.08	0.05
3	-1	+1	-1	0.64	0.09	0.08
4	+1	+1	-1	0.65	0.11	0.22
5	-1	-1	+1	0.78	0.13	0.18
6	+1	-1	+1	0.74	0.07	0.14
7	-1	+1	+1	0.73	0.25	0.88
8	+1	+1	+1	0.65	0.26	0.28
9	0	0	0	0.55	0.19	0.36
10	0	0	0	0.68	0.20	0.29
11	0	0	0	0.56	0.16	0.32
12	0	0	0	0.63	0.18	0.30

The outcome of experimentation is analysed by dividing set of observations into three blocks

- First block (trial nos. 2,3,5,8,9,10),
- Second block (trial nos. 1,4,6,7,11,12) and
- Combined block (trial nos. 1 to 12).

The modified fractional method, Fig 3, is adopted [12]. Computations performed for analysis purpose resulted into the postulated model and regression coefficient (R2) for each block as below

After second pass,

Table 3. AL6082 postulated models for three blocks (2nd pass)

Block	Postulated Model	Regression coefficient R2
First	$Y1 = -4.8912 - 0.0392 \ln D + 0.3394 \ln M + 1.5622 \ln F$	0.6766
Second	$Y1 = -1.5224 - 1.8257 \ln D + 0.8801 \ln M + 0.9004 \ln F$	0.9648
Third	$Y1 = -3.2068 - 0.9324 \ln D + 0.6098 \ln M + 1.2313 \ln F$	0.6586

Therefore, the best model or surface roughness predicting equation for burnishing Al 6082 is

$$Y1 = -1.5224 - 1.8257 \ln D + 0.8801 \ln M + 0.9004 \ln F$$

Or In terms of surface finish

$$Ra = 0.002182 * D^{-1.8257} * M^{0.8801} * F^{0.9004}$$

Adequacy of the postulated model is checked by making analysis of Variance table.

## OPTIMIZATION OF BURNISHING PARAMETERS USING BACTERIAL FORAGING

Evolutionary optimization algorithms are now days extensively used in engineering design problems where the emphasis is on maximizing or minimizing a certain goal. For over the last half century, optimization algorithms like Genetic Algorithms (GAs), Evolutionary Programming (EP), Evolutionary Strategies (ES), which draw their inspiration from evolution and natural genetics, have been dominating the realm of optimization algorithms. Bacteria Foraging Optimization Algorithm (BFO), proposed in 2002 by Passino [15], is a new comer to the family of nature-inspired optimization algorithms besides Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO).

BFO uses foraging strategies of the E. coli bacterium cells. It follows chemotaxis (swimming and tumbling), swarming, reproduction and elimination, dispersal events. In chemotaxis, the flagellum is a left-handed helix configured so that, as the base of the flagellum rotates counter clockwise, it produces force against the bacterium and pushes the cell. Otherwise, each flagellum operates relatively independent of the others; rotates clockwise and the bacterium tumbles. During swarming, the bacteria move out from their respective places in a ring of cells by moving up the mean square error to the minimal value. During reproduction, the least healthy bacteria die and others split into two, are placed in the same location. This causes the population of bacteria to remain constant. The elimination and dispersal events are based on population level long-distance motile behaviour. They assist nearest required values.

The BFO algorithm is presented below.

**Bacterial Foraging Optimization Algorithm**

For initialization, you must choose  $p, S, N_i, N_e, N_r, N_c, N_p, N_s, p_{ed}$ , and the  $C(i), i = 1, 2, \dots, S$ . If you use swarming, you will also have to pick the parameters of the cell-to-cell attractant functions; here we will use the parameters given above. Also, initial values for the  $\theta^i, i = 1, 2, \dots, S$ , must be chosen. Choosing these to be in areas where an optimum value is likely to exist is a good choice. Alternatively, you may want to simply randomly distribute them across the domain of the optimization problem. The algorithm that models bacterial population chemotaxis, swarming, reproduction, elimination, and dispersal is given here (initially,  $j = k = l = 0$ ). For the algorithm, note that updates to the  $\theta^i$  automatically result in updates to  $P$ . Clearly, we could have added a more sophisticated termination test than simply specifying a maximum number of iterations.

- 1) Elimination-dispersal loop:  $i = i + 1$
- 2) Reproduction loop:  $k = k + 1$
- 3) Chemotaxis loop:  $j = j + 1$ 
  - a) For  $i = 1, 2, \dots, S$ , take a chemotactic step for bacterium  $i$  as follows.
  - b) Compute  $J(i, j, k, l)$ . Let  $J(i, j, k, l) = J(i, j, k, l) + J_c(\theta^i(j, k, l), P(j, k, l))$  (i.e., add on the cell-to-cell attractant effect to the nutrient concentration).
  - c) Let  $J_{min} = J(i, j, k, l)$  to save this value since we may find a better cost via a run.
  - d) Tumble: Generate a random vector  $\Delta(i) \in \mathbb{R}^p$  with each element  $\Delta_m(i), m = 1, 2, \dots, p$ , a random number on  $[-1, 1]$ .
  - e) Move: Let
 
$$\theta^i(j+1, k, l) = \theta^i(j, k, l) + C(i) \frac{\Delta(i)}{\sqrt{S(i)\Delta(i)}}$$
 This results in a step of size  $C(i)$  in the direction of the tumble for bacterium  $i$ .
  - f) Compute  $J(i, j+1, k, l)$ , and then let  $J(i, j+1, k, l) = J(i, j+1, k, l) + J_c(\theta^i(j+1, k, l), P(j+1, k, l))$ .
  - g) Swim (note that we use an approximation since we decide swimming behavior of each cell as if the bacteria numbered  $\{1, 2, \dots, j\}$  have moved and  $\{j+1, j+2, \dots, S\}$  have not; this is much simpler to simulate than simultaneous decisions about swimming and tumbling by all bacteria at the same time):
    - i) Let  $m = 0$  (counter for swim length)
    - ii) While  $m < N_i$  (if have not climbed down too long)
      - Let  $m = m + 1$
      - If  $J(i, j+1, k, l) < J_{min}$  (if doing better), let  $J_{min} = J(i, j+1, k, l)$  and let
 
$$\theta^i(j+1, k, l) = \theta^i(j+1, k, l) + C(i) \frac{\Delta(i)}{\sqrt{S(i)\Delta(i)}}$$
 and use this  $\theta^i(j+1, k, l)$  to compute the new  $J(i, j+1, k, l)$  as we did in f).
      - Else, let  $m = N_i$ . This is the end of the while statement.
    - h) Go to next bacterium ( $i + 1$ ) if  $i \neq S$  (i.e., go to b) to process the next bacterium).
- 4) If  $j < N_e$ , go to step 3. In this case, continue chemotaxis, since the life of the bacteria is not over.
- 5) Reproduction:
  - a) For the given  $k$  and  $l$ , and for each  $i = 1, 2, \dots, S$ , let
 
$$J_{min}^i = \sum_{j=1}^{S-1} J(i, j, k, l)$$
 be the health of bacterium  $i$  (a measure of how many nutrients it got over its lifetime and how successful it was at avoiding noxious substances). Sort bacteria and chemotactic parameters  $C(i)$  in order of ascending cost  $J_{min}^i$  (higher cost means lower health).
    - b) The  $S_i$  bacteria with the highest  $J_{min}^i$  values die and the other  $S_i$  bacteria with the best values split (and the copies that are made are placed at the same location as their parent).
  - b) If  $k < N_r$ , go to step 2. In this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.
- 7) Elimination-dispersal: For  $i = 1, 2, \dots, S$ , with probability  $p_{ed}$ , eliminate and disperse each bacterium (this keeps the number of bacteria in the population constant). To do this, if you eliminate a bacterium, simply disperse one to a random location on the optimization domain.
- 8) If  $i < N_e$ , then go to step 1, otherwise end.

**Fig. 4. General Code for Bacterial Foraging [15]**

## ADAPTATION OF BFO MODEL

In this approach following parameters are selected for BFO simulations.

- i) Number of BFO Estimators,  $N_e = 10$
- ii) Number of Rounds,  $N_r = 10$ ,
- iii) Number of Communicating Foraging Bacteria,  $N_c = 10$
- iv) Number of Particles,  $N_p = 10$
- v) Number of Solutions,  $N_s = 10$
- vi) Incremental Factor,  $D = 10$
- vii) Learning Rate,  $C = 0.01$
- vi) Probability of Elimination and Dispersal,  $P_{ed} = 0.9$

## OUTPUT OF BFO

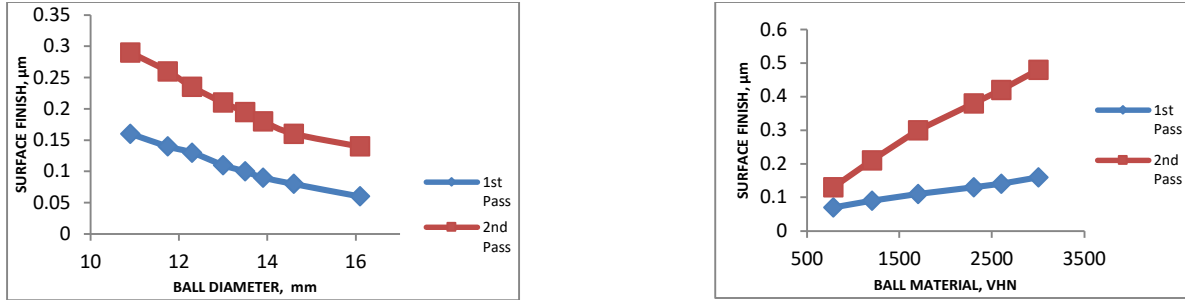
The output of optimum values obtained after the simulations are

$$D = 16.99, M = 1464.5, F = 29.4 \text{ For } Ra = 0.09 \mu m$$

These values being in fractions, are rounded off to the nearest possible parametric values for testing experimentally.

## RESULT AND CONCLUSION

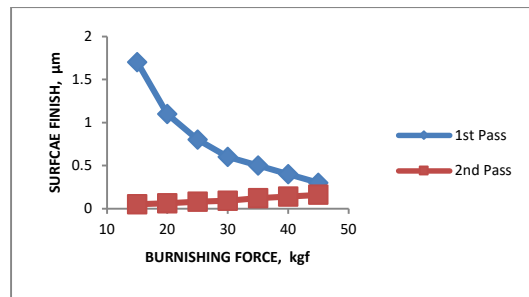
The outcome values of the surface finish obtained at different levels of ball burnishing parameters are noted and indicated in graphical form as under.



(i)

(ii)

**Fig. 6. Relationship between i) Ball Diameter & Surface Hardness ii) Ball Material & Surface Finish**



**Fig. 7. Relationship between Burnishing Force and Surface Hardness**

Analysis of results after SECOND PASS, indicates that, increase in diameter improves surface finish whereas increase in burnishing force, decreases finish. As well, with increase in ball hardness, finish gets deteriorated.

The experimental verification of the optimum values suggested by BFO lead to confirmation of 97.5%. This effect is observed due to the rounding of the values to the available parametric range as.

**D = 16 mm, M = 2300 VHN, F = 25 kgf to obtain Ra = 0.095 µm**

## REFERENCES

1. Lv Jinlong, Luo Hongyun, "Effect of surface burnishing on texture and corrosion on behaviour of 2024 aluminium alloy", *Surface & Coatings Technology* 235 (2013) 513–520(2013)
2. El-Tayeb, K.O. Low and P.V. Brevern, "Influence of roller burnishing contact width and burnishing orientation on surface quality and tribological behaviour of Aluminium 6061", *Journal of Materials Processing Technology* 186 272-278 (2007)
3. U.M. Shirsat, B.B. Ahuja, "Parametric Analysis of combined turning and ball burnishing process", *International journal of Engineering and Material science*, Vol. 11, PP-391-396 (2004).
4. P. N. Patel, N. B. Patel, T. M. Patel, " Parametric Optimization of Ball Burnishing Process Parameter for Hardness of Aluminium Alloy 6061", *ISOR Journal of Engineering*, vol. 4, Issue 08 ISSN(e):2250-3021, ISSN(p): 2278-8719(2014).



5. Fathi Gharbi, Salem Sghaier, Hedi Hamdi, Tarek Benameur, "Ductility improvement of aluminium 1050A rolled sheet by a newly designed ball burnishing tool device", Int J Adv Manuf Technology DOI 10.1007/500170-011-3598-6(2011).
6. Amit Patel, D. K. Patel, Kapil Banker "Effect Evaluation of Roller Burnishing Process on Surface Roughness Of 6061 T6 Al Alloy Using Response Surface Methodology", International Journal of Research and development, vol. 2, Issue 08, ISSN: 2321-0613(2014),
7. El-Axir, Othman, Abodiena, "Improvements in out-of-roundness and micro hardness of inner surfaces by internal ball burnishing process", Journal of Materials Processing Technology 196 120-128(2008).
8. A. S. Maheshwari and R. R. Gawande, "Improving surface quality of AA 6351 by the stiff burnishing technique," Jordan J. Mech. Ind. Eng., vol. 10, no. 4, pp. 245–251 (2016).
9. M. R. Stalin John & B. K. Vinayagam, "Investigation of roller burnishing process on Al 63400 material", Australian J of Mechanical Engineering, 8:1, 47-54 (2011).
10. Shailesh Dadmal, Vijay Kurkute, "Finite Element Analysis of Roller Burnishing Process", Int Research J of Engg. And Technology vol. 4 Issue 6 (2017).
11. D. M. Mate and P. S. Chaudhari (2014), "formulation of experimental data based on mathematical model for Al-2014 with spherical surface burnishing tool", Int J of Research in mechanical engineering, vol. 2(2014).
12. G.E.P. Box and Wilson, K.B. "Experimental attainment of optimum conditions". Journal of the Royal Statistical Society 13, 1-45(1951).
13. Baradie M. A. El, "Surface Roughness Model for Turning Grey Cast Iron", Proceedings of Institution of Mechanical Engineering, Vol 207 (1981).
14. S. M. Wu, "Tool Life Testing by Response Surface Methodology Part I and II", ASME Journal of Engineering for Industry, May 64, pp 105-115 (1964).
15. Passino, K.M. "Biomimicry of Bacterial Foraging for Distributed Optimization and Control". IEEE Control Systems Magazine, 52–67 (2002)

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