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# PARAMETRIC OPTIMIZATION AND INDIRECT MONITORING OF FLANK WEAR IN TURNING –A CUTTING TOOL CHATTER APPROACH

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## ABSTRACT

The chatter in machining is an important topic in engineering, because its occurrence results in increasing flank wear, specific energy and surface roughness. The implementation issues and spindle system responses for cutting speed, feed rate, depth of cut, material hardness and non stop duration of machining are investigated in this analysis. This study analyzes the relation between the chatter frequency in machining and the weighted combined objective of the process which is used for implementing the monitoring of flank wear from the experimentally observed chatter frequency. The optimization techniques such as Design of Experiments (DoE), Adaptive Genetic Algorithm (AGA), Simulated Annealing Algorithm (SAA) and Memetic Algorithm (MA) are used in this analysis . The optimized combined objective values of different test conditions are correlated with the experimentally observed chatter frequency values of the corresponding test conditions, and it is well known that the monitoring of flank wear in machining is possible from the experimentally observed chatter frequency by considering surface roughness as constraint.

**Keywords:** *Turning, Chatter, Taguchi's Design of Experiment, Adaptive Genetic Algorithm, Simulated Annealing Algorithm and Memetic Algorithm.*

## 1. Introduction to Wear

The performance of a machining operation depends on the dynamic relationship between the workpiece and cutting tool. The relative motion of the cutting tool results in a large amplitude of vibration. The chatter or vibration shows a significant effect on flank wear and surface roughness as presented by Abu-Zahra H et al [1]. By understanding and controlling the chatter in the cutting zone as indicated by Nejat Olgac et al [2], the cost of production is possible to be reduced. The phenomenon, dynamic instability is commonly referred to as cutting tool chatter. If large tool-work engagements are attempted, oscillations are suddenly built up in the tools which result in poor surface finish, cutting edge damage and abnormal noise. The dynamic interaction of workpiece and cutting tool is the result of chatter. In metal cutting, a force is generated between tool and workpiece and the magnitude of this force is due to the tool-work engagement and cutting parameters. The force causes the tool to strain elastically and hence a relative displacement of tool is caused. The instability of chatter vibrations is caused by material characteristics , tool geometry and the machining parameters.

The machining parameters selected in this analysis are, cutting speed, feed rate, depth of cut, material hardness and non stop duration of machining.

All the selected five parameters are varied to 4 levels. For controlling vibrations in metal cutting, the ratio between Length and Diameter of workpiece (L/D ratio) is not permitted to be higher than 4 as indicated by Tamizharasan T et al [3]. Hence, the length and diameter of the workpieces are taken as 200mm and 50mm respectively. Based on the number of parameters and levels, the required orthogonal array and the values of levels of the corresponding parameters are selected as given by Tamizharasan T et al [4], Karthikeyan R, [5].

Cemented carbide cutting inserts of specifications: CNMG 120408 with 0° side clearance angle, -5° rake angle and 10° cutting edge angle are used with a tool holder of PCLNR 2525M12 model to machine the specimen. The hmt T5 CNC lathe machine of specifications; 4500 rpm max. Speed, 330 mm max. Swing, 41mm bore capacity, 230mm X axis travel, 230mm Z axis travel and 152mm chuck size is selected to perform the machining operations on the heat treated EN 8 specimen of composition: 0.95%C, 0.3%Si, 1.2%Mn,0.5%Cr, 0.5%W and 0.1%V (at 25 HRC).

The vibration analyzer of specifications: Syscon make, Displacement range of 0.1 to 1000 microns, Velocity of 0.01 to 100 mm/sec., Frequency of 10 to 10000 Hz, Electromagnetic type is incorporated in the CNC lathe machine to measure the frequency of chatter.

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The non-traditional techniques such as AGA, SAA and MA as discussed by Dereli.T et al [6] are also applied to optimize the machining parameters in order to minimize the combined objective or flank wear and specific energy by maintaining the value of surface roughness (constraint) below 3.00 microns.

By repeating the evolutionary cycle of reproduction, crossover and mutation, the genetic search process in AGA can progressively lead to new populations of candidate solutions as given by Dongcheolkim et al [7]. The search process is terminated when a predefined number of iterations are reached. The best solution over the time will be consequently adopted as the final solution for machining operations.

Simulated annealing is a point by point method. The algorithm begins with an initial point and a high temperature 'T'. In SAA, the initial temperature (T) and decrement factor (df) are the two important parameters which govern the successful working of the simulated annealing procedure. If a larger initial value of 'T' (or)'df' is chosen, it takes more number of iterations for convergence. On the other hand, if a small value of initial temperature 'T' is chosen, the search is not adequate to thoroughly investigate the search space before converging to the true optimum. Unfortunately, there are no unique values of the initial temperature (T), decrement factor (df) and number of iterations (n) that work for every problem. However, an estimate of the initial temperature can be obtained by calculating the average of the function values at a number of random points in the search space. A suitable value of 'n' can be chosen depending on the convergence criteria.

The combination of a local search operator with a global search technique provides a very good result in some of the problems. The resulting algorithm from such an approach is termed as Memetic Algorithm (MA). In this paper, the above global search technique (AGA) is combined with the local search operator (SAA).The Memetic approach takes the concept of evolution as employed in Adaptive Genetic algorithm and combines with an element of local search. In this work, AGA employs the basic operational steps of population initialization and the three genetic operations of reproduction, crossover and mutation. An additional component of the algorithm shows that each individual is readily improved. This is accomplished by a local search using SAA in the neighborhood of every updated population before its insertion into the new population.

## 2. Experimental Details

In this analysis, five parameters at four levels each are considered for parametric optimization. The various levels (1, 2, 3 and 4) of parameters selected are,

| | |
|---|---|
| Cutting speed | 50(1), 75(2), 100(3), 125(4) m/min |
| Feed rate | 0.1(1), 0.2(2),0.3(3), 0.4(4) mm/rev |
| Depth of cut | 0.2(1), 0.4(2), 0.6(3), 0.8(4) mm |
| Material hardness | 10(1), 15(2), 20(3), 25(4) HRC |
| Machining time | 10(1), 15(2), 20(3), 25(4) min |

As per the Taguchi's Design of Experiments, the minimum number of experiments to be conducted for parametric optimization is calculated as,

$$\text{Minimum number of experiments} = [(L-1) \times P] + 1 \qquad (1)$$
$$= [(4-1) \times 5] + 1 = 16$$

The 16 dry turning experiments are conducted with out affecting the orthogonality.

After the completion of each experiment, the flank wear of cutting inserts is measured with a Tool maker's microscope of specifications: 1395 A model, 30 X magnification, 2X objective, WF 15X with cross reticule of eye piece and 0.0025mm least count , electrical energy consumption is measured with a three phase energy meter of specifications: SIMCO make, BV 4 model, 100 rev./kWh, 3x240 V and the surface roughness is measured with a surface tester of specifications: Surtronic 3+ model, 1mm/sec traverse speed, LCD matrix 2 lines x 16 channels alpha numeric display, Ra, Rq, Rz, Ry, Sm parameters and .less than reversal time for calculation.The arithmetic average surface roughness values recorded are less than 3 microns. The average values of flank wear for all the parameters and their levels are calculated to draw a graph for the identification of best levels of various machining parameters based on flank wear.

Similarly, average values of chatter frequency for all the parameters and their levels are calculated. From the calculated average values, the required curves are drawn for the identification of best levels of selected machining parameters based on chatter frequency.The statistical measure of performance called Signal-to-Noise (S/N) ratio developed by Dr. Taguchi is applied to identify the best levels of parameters and to determine the effects of various machining parameters on the combined objective (70% weightage for flank wear and 30% weightage for specific energy).

The S/N equation depends on the criterion for the quality characteristics to be optimized. In this study, both the flank wear and specific energy are to be minimized and hence, lower- is- better formula for S/N ratio is selected in order to form the weighted combined objective.

S/N ratio for weighted combined objective

$$= -10 \log_{10}\left(\text{weightedCO}\right) \qquad (2)$$

where,

$$\text{Objective for minimization} = \frac{1}{n_t}\sum \bar{y}^2 \qquad (3)$$

Weighted combined objective
=Addition of weighted objectives of FW and SE

$n_t$ is the number of trials of experiments and $\overline{y}$ is the value observed data.

By using the above formulae, the S/N ratio for the weighted combined objective (S/N CO) and chatter frequency (S/N CF) are calculated and tabulated. The best parameter levels based on the S/N values of weighted combined objective (since the S/N ratio is used, the maximum values of levels are identified as best levels of the corresponding parameters) and chatter frequency are identified by using Taguchi's DoE.

With the identified best levels of parameters, a validation experiment is conducted and the objectives such as flank wear, specific energy and chatter frequency are recorded. The validated results of CO and CF are further confirmed statistically by calculating Confidence Interval (CI).

The experimental setup used in this analysis for machining is shown in figure 1.

Figure 2 shows the complete experimental setup used for measuring arithmetic average surface roughness.

The experimental test conditions, observed data, weighted data and S/N values of objectives are shown in table 1.

**Fig. 1 Experimental Setup of Machining Centre**

**Fig. 2 Experimental Setup of Surface Roughness Tester**

**Table 1: Experimental Test Conditions, Observed Data, Weighted Data and S/N Values**

| Test condition number | Cutting speed (V) n m/min | Feed rate (f) in mm/rev | Depth of cut (d) in mm | Material hardness (H) in | Machining time (T) in min | Frequency (F) in Hz | Flank wear (FW) in mm | Specific energy (SE) in W/cm3/min | Weighted FW (70 %) | Weighted SE (30 %) | Weighted CO (100 %) | S/N CO | S/N CF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50 | 0.1 | 0.2 | 10 | 10 | 208 | 0.28 | 23.21 | 0.05488 | 0.00016 | 0.05504 | 12.59 | 13.64 |
| 2 | 50 | 0.2 | 0.4 | 15 | 15 | 300 | 0.29 | 46.75 | 0.05887 | 0.00066 | 0.05953 | 12.25 | 10.46 |
| 3 | 50 | 0.3 | 0.6 | 20 | 20 | 415 | 0.47 | 71.29 | 0.15463 | 0.00152 | 0.15615 | 8.14 | 7.63 |
| 4 | 50 | 0.4 | 0.8 | 25 | 25 | 524 | 0.63 | 94.83 | 0.27783 | 0.00270 | 0.28053 | 5.48 | 5.61 |
| 5 | 75 | 0.1 | 0.4 | 20 | 25 | 509 | 0.46 | 79.57 | 0.14812 | 0.00190 | 0.15002 | 8.18 | 5.86 |
| 6 | 75 | 0.2 | 0.2 | 25 | 20 | 408 | 0.52 | 77.94 | 0.18928 | 0.00182 | 0.19110 | 7.21 | 7.79 |
| 7 | 75 | 0.3 | 0.8 | 10 | 15 | 312 | 0.34 | 37.12 | 0.08092 | 0.00041 | 0.08133 | 10.90 | 10.12 |
| 8 | 75 | 0.4 | 0.6 | 15 | 10 | 216 | 0.31 | 35.37 | 0.06727 | 0.00038 | 0.06765 | 11.70 | 13.31 |
| 9 | 100 | 0.1 | 0.6 | 25 | 15 | 320 | 0.48 | 57.76 | 0.16128 | 0.00100 | 0.16228 | 7.83 | 9.89 |
| 10 | 100 | 0.2 | 0.8 | 20 | 10 | 214 | 0.40 | 37.48 | 0.11200 | 0.00042 | 0.11242 | 9.59 | 13.39 |
| 11 | 100 | 0.3 | 0.2 | 15 | 25 | 510 | 0.44 | 70.36 | 0.13552 | 0.00149 | 0.13701 | 8.63 | 5.85 |
| 12 | 100 | 0.4 | 0.4 | 10 | 20 | 410 | 0.43 | 48.08 | 0.12943 | 0.00069 | 0.13012 | 8.86 | 7.74 |
| 13 | 125 | 0.1 | 0.8 | 15 | 20 | 408 | 0.39 | 55.10 | 0.10647 | 0.00091 | 0.10738 | 9.69 | 7.78 |
| 14 | 125 | 0.2 | 0.6 | 10 | 25 | 511 | 0.39 | 60.90 | 0.10647 | 0.00111 | 0.10758 | 9.68 | 5.83 |
| 15 | 125 | 0.3 | 0.4 | 25 | 10 | 229 | 0.51 | 51.85 | 0.18207 | 0.00081 | 0.18288 | 7.44 | 12.80 |
| 16 | 125 | 0.4 | 0.2 | 20 | 15 | 344 | 0.49 | 57.64 | 0.16807 | 0.0010 | 0.16907 | 7.74 | 9.27 |

## 3. Results and Discussion

The identified best levels of machining parameters based on S/N CO match more or less with the identified best levels of parameters based on S/N CF, which are shown in figures 3 and 4.

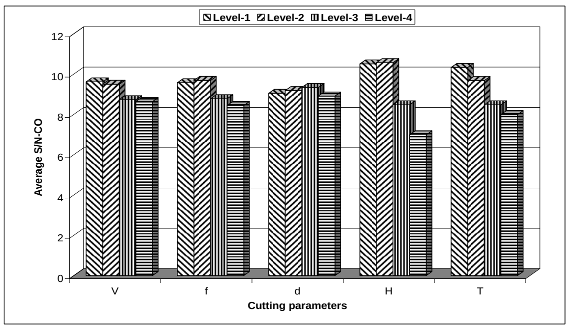


**Fig. 3 Best values of Machining Parameters Based on S/N-CO**

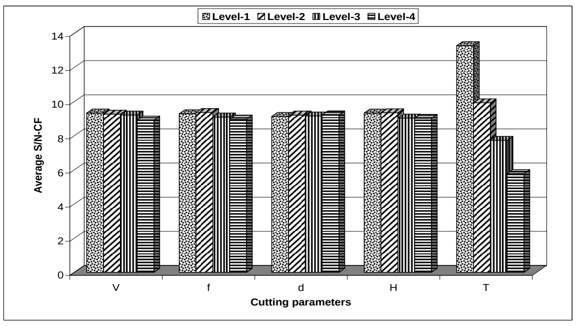


**Fig 4: Best Values of Machining Parameters Based on S/N-CF**

This best correlation shows that the flank wear and specific energy or the weighted combined objective is possible to be calculated from the experimentally measured values of chatter frequency in turning. Since this is one of the monitoring methods for flank wear, specific energy or weighted combined objective, this minimizes the cost of production to a great extent.

Since this study focuses on chatter frequency, the best values of parameters on the basis of chatter frequency are selected and the validation experiment is conducted. The raw results of validation experiment are considerably lower than that of the corresponding raw values shown in table 1.

| | |
|---|---|
| Flank wear | = 0.25mm, |
| Specific energy | = 20.20W/cm$^3$/min, |
| S/N CO | = 13.58, |
| Chatter frequency | = 196 Hz, |
| S/N-CF | = 14.15. |

For verifying the validated result of CO, the estimated mean is calculated as,

$$CO_{em}=V_{1m}+f_{2m}+d_{3m}+H_{2m}+T_{1m}-4CO_m \qquad (4)$$

where,

$CO_{em}$ = Estimated mean of CO
$V_{1m}$ = Mean of CO corresponding to cutting speed, $V_1$
$f_{2m}$ =Mean of CO corresponding to feed rate, $f_2$
$d_{3m}$ = Mean of CO corresponding to depth of cut, $d_3$
$H_{2m}$ = Mean of CO corresponding to material hardness, $H_2$
$T_{1m}$ =Mean of CO corresponding to machining time, $T_1$
$CO_m$= Overall mean of CO

From table 1, the mean values for the above parameters are calculated and substituting in equation (4),

$CO_{em}$ = 9.62 + 9.69 + 9.34 + 10.57 + 10.334 x 9.12
= 13.07

The statistical data such as error degree of freedom and error variance based on the combined objective required for the calculation of CI are generated by using regression analysis.

A confidence interval for the prediction of mean of combined objective is calculated as,

$$CI=\sqrt{F_{0.05}(4, f_e)V_e\left[\frac{1}{n_e}+\frac{1}{R}\right]} \qquad (5)$$

where,

$f_e$ - Error degrees of freedom(10) from regression table which is not shown
$F_{0.05}(4, f_e)$ - F ratio required for risk (4, 10) = 3.48 from standard "F" table
-Error variance (0.574) from regression table which is not shown
R -Number of repetitions for confirmation test (3)
N -Total number of experiments ($n_r$ x number of experiments) = 1 x 16 = 16

where $n_r$ - Number of replications of experiments (1)

Effective number of replications ($n_e$)
=N / [1+degrees of freedom associated with CO]
= 16 / (1 + 15) = 1

From the above relations, the value of Confidence Interval (CI) is calculated as,

CI = {3.48 x 0.574 [(1 / 1) + (1 / 3)]}$^{1/}$
= 1.63.

The 95% confidence interval of the optimal value of S/N CO in confirmation test is,

$$(CO_{em} – CI) < CO_{con} < (CO_{em} + CI) \qquad (6)$$

The result of confirmation test shows that the value of S/N CO is 13.58 which is in between

$(CO_{em} – CI)$ and $(CO_{em} + CI)$

That is, 13.58 is in between 11.44 and 14.70. The validated S/N CO is thus confirmed by the above calculations.

Similarly, the validated S/N CF is also confirmed as 14.15 by the similar calculations

The trend between the values of S/N CO and S/N CF is shown in figure 5.

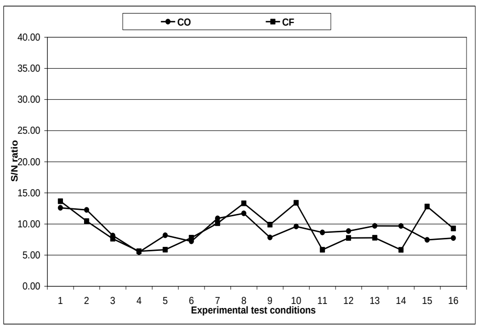


**Fig. 5 S/N CO and S/N CF at all the test conditions**

For running AGA programme, the population size is selected by trial and error and hence different population sizes have been considered for identifying the best results of combined objective and chatter frequency. These population sizes are selected by running the programme at different population sizes ranging from 10- 50 at an interval of 5. Almost all the possible population sizes have been tried out and 45 and 30 are identified as best population sizes for S/N CO and S/N CF. The convergences for S/N CO and S/N CF start occurring at iteration numbers 132 and 154 respectively and hence, the maximum iteration number for both the cases is selected as 200.The cross over probability, mutation probability and bit length for combined objective and chatter frequency are taken as 0.8, 0.05 and 10 respectively.

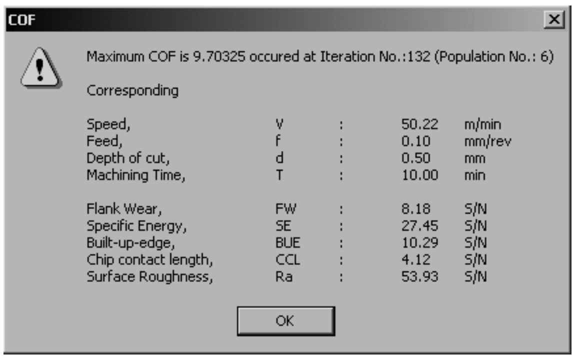
Before running the SAA programme, the decrement factor is left to the choice of the user. However the initial temperature and subsequent cooling schedule require some trial and error efforts. Hence, different combinations of these two parameters have been analyzed and the best results are obtained with the following combinations as,

Number of iterations, n = 200 (convergences occur at iteration numbers 73 and 57 respectively)

For CO, T = 1000° C, df = 0.7 and for CF, T = 1000° C, df = 0.8.

For running MA programme, the identified best population size, number of iterations, cross over probability, mutation probability, bit length, initial temperature and decrement factor are, 20, 100, 0.8, 0.005, 10, 1000°C and 0.994 respectively. The convergences for S/N CO and S/N CF based on MA start at iteration numbers 85 and 89 respectively.

**Table 2: Outputs of AGA (a), SAA (b) and MA (c) based on S/N-CO**



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Maximum COF is 9.70325 occured at Iteration No.:132 (Population No.: 6)

Corresponding

Speed,                  V     :     50.22   m/min
Feed,                   f     :     0.10    mm/rev
Depth of cut,           d     :     0.50    mm
Machining Time,         T     :     10.00   min

Flank Wear,             FW    :     8.18    S/N
Specific Energy,        SE    :     27.45   S/N
Built-up-edge,          BUE   :     10.29   S/N
Chip contact length,    CCL   :     4.12    S/N
Surface Roughness,      Ra    :     53.93   S/N
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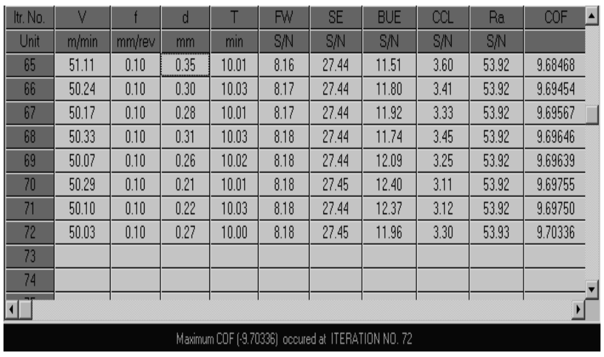
(a)



| Itr. No. | V | f | d | T | FW | SE | BUE | CCL | Ra | COF |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit | m/min | mm/rev | mm | min | S/N | S/N | S/N | S/N | S/N | |
| 65 | 51.11 | 0.10 | 0.35 | 10.01 | 8.16 | 27.44 | 11.51 | 3.60 | 53.92 | 9.68468 |
| 66 | 50.24 | 0.10 | 0.30 | 10.03 | 8.17 | 27.44 | 11.80 | 3.41 | 53.92 | 9.69454 |
| 67 | 50.17 | 0.10 | 0.28 | 10.01 | 8.17 | 27.44 | 11.92 | 3.33 | 53.92 | 9.69567 |
| 68 | 50.33 | 0.10 | 0.31 | 10.03 | 8.18 | 27.44 | 11.74 | 3.45 | 53.92 | 9.69646 |
| 69 | 50.07 | 0.10 | 0.26 | 10.02 | 8.18 | 27.44 | 12.09 | 3.25 | 53.92 | 9.69639 |
| 70 | 50.29 | 0.10 | 0.21 | 10.01 | 8.18 | 27.45 | 12.40 | 3.11 | 53.92 | 9.69755 |
| 71 | 50.10 | 0.10 | 0.22 | 10.03 | 8.18 | 27.44 | 12.37 | 3.12 | 53.92 | 9.69750 |
| 72 | 50.03 | 0.10 | 0.27 | 10.00 | 8.18 | 27.45 | 11.96 | 3.30 | 53.93 | 9.70336 |
| 73 | | | | | | | | | | |
| 74 | | | | | | | | | | |

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Maximum COF (-9.70336)  occured at  ITERATION NO. 72
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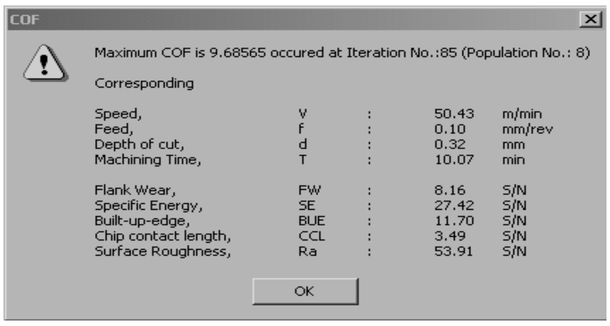
(b)



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Maximum COF is 9.68565 occured at Iteration No.:85 (Population No.: 8)

Corresponding

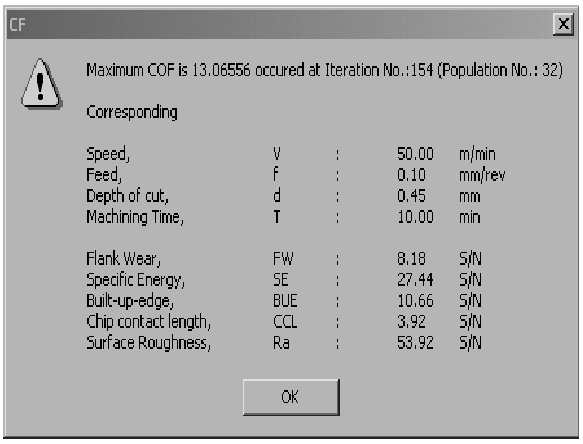
Speed,                  V     :     50.43   m/min
Feed,                   f     :     0.10    mm/rev
Depth of cut,           d     :     0.32    mm
Machining Time,         T     :     10.07   min

Flank Wear,             FW    :     8.16    S/N
Specific Energy,        SE    :     27.42   S/N
Built-up-edge,          BUE   :     11.70   S/N
Chip contact length,    CCL   :     3.49    S/N
Surface Roughness,      Ra    :     53.91   S/N
```

(c)

The output values obtained from SAA, AGA and MA based on S/N CO and S/N CF are shown in tables 2 (a,b and c) and 3 (a,b and c) respectively.

**Table 3: Outputs of AGA (a), SAA (b) and MA (c) based on S/N-CF**



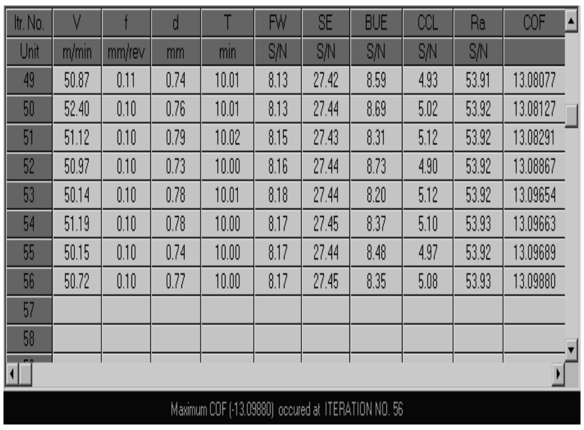
Maximum COF is 13.06556 occured at Iteration No.:154 (Population No.: 32)

Corresponding

Speed, V : 50.00 m/min
Feed, f : 0.10 mm/rev
Depth of cut, d : 0.45 mm
Machining Time, T : 10.00 min

Flank Wear, FW : 8.18 S/N
Specific Energy, SE : 27.44 S/N
Built-up-edge, BUE : 10.66 S/N
Chip contact length, CCL : 3.92 S/N
Surface Roughness, Ra : 53.92 S/N

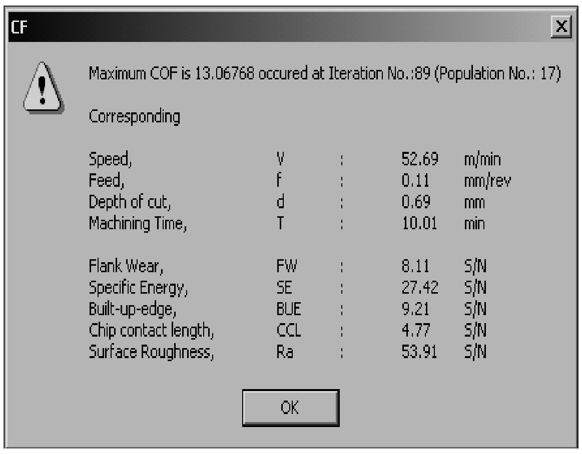
(a)



| Itr. No. | V | f | d | T | FW | SE | BUE | CCL | Ra | COF |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit | m/min | mm/rev | mm | min | S/N | S/N | S/N | S/N | S/N | |
| 49 | 50.87 | 0.11 | 0.74 | 10.01 | 8.13 | 27.42 | 8.59 | 4.93 | 53.91 | 13.08077 |
| 50 | 52.40 | 0.10 | 0.76 | 10.01 | 8.13 | 27.44 | 8.69 | 5.02 | 53.92 | 13.08127 |
| 51 | 51.12 | 0.10 | 0.79 | 10.02 | 8.15 | 27.43 | 8.31 | 5.12 | 53.92 | 13.08291 |
| 52 | 50.97 | 0.10 | 0.73 | 10.00 | 8.16 | 27.44 | 8.73 | 4.90 | 53.92 | 13.08867 |
| 53 | 50.14 | 0.10 | 0.78 | 10.01 | 8.18 | 27.44 | 8.20 | 5.12 | 53.92 | 13.09654 |
| 54 | 51.19 | 0.10 | 0.78 | 10.00 | 8.17 | 27.45 | 8.37 | 5.10 | 53.93 | 13.09663 |
| 55 | 50.15 | 0.10 | 0.74 | 10.00 | 8.17 | 27.44 | 8.48 | 4.97 | 53.92 | 13.09689 |
| 56 | 50.72 | 0.10 | 0.77 | 10.00 | 8.17 | 27.45 | 8.35 | 5.08 | 53.93 | 13.09880 |
| 57 | | | | | | | | | | |
| 58 | | | | | | | | | | |

Maximum COF (-13.09880) occured at ITERATION NO. 56

(b)



Maximum COF is 13.06768 occured at Iteration No.:89 (Population No.: 17)

Corresponding

Speed, V : 52.69 m/min
Feed, f : 0.11 mm/rev
Depth of cut, d : 0.69 mm
Machining Time, T : 10.01 min

Flank Wear, FW : 8.11 S/N
Specific Energy, SE : 27.42 S/N
Built-up-edge, BUE : 9.21 S/N
Chip contact length, CCL : 4.77 S/N
Surface Roughness, Ra : 53.91 S/N

(c)

Since the non-traditional optimization techniques show better results, the values of S/N CO and S/N CF obtained from AGA, SAA and MA at various iterations are shown in figures 6 and 7 respectively.

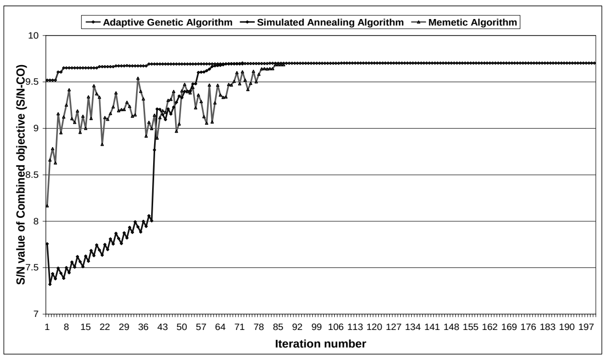


**Fig. 6 S/N-CO Obtained From AGA, SAA and MA at Various Iterations**

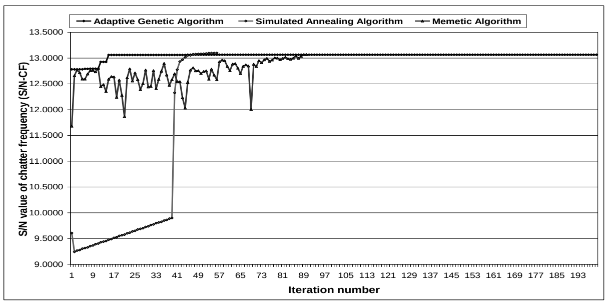


**Fig. 7 S/N-CF Obtained From AGA, SAA and MA at Various Iterations**

It is understood that the figures 6 and 7 are identical which confirms that the combined objective (flank wear and specific energy) in the turning operation is possible to be monitored from the experimentally measured chatter frequency.

## 4. Conclusion

This paper analyzes the effectiveness of various optimization techniques such as Design of experiments, Adaptive Genetic Algorithm, Simulated Annealing Algorithm and Memetic Algorithm for optimizing the machining parameters based on S/N CO and S/N CF.

These techniques aid to minimize the combined objective and also for the selection of best values of various machining parameters. It is concluded that these optimization techniques are well suited for all the experimental test conditions.

From the correlation between S/N CO and S/N CF values shown by various optimization techniques at all iterations, it is concluded that it is possible for monitoring of flank wear from the experimentally observed chatter frequency.

## References

1. *Abu-Zahra H and Lango J H(2002), "Tool Chatter Monitoring in Turning Operations using Wavelet Analysis of Ultrasound Waves", International Journal of Advanced Manufacturing Technology, Vol.20,248-254.*

2. *Nejat Olgac and Martin Hosek (2000), "A New Machine Tool Chatter", Technical paper submitted in the Department of Mechanical Engineering, University of Connecticut, Storrs, Connecticut, 1-6.*

3. *Tamizharasan T and Kingston Barnabas J (2009), "Analysis of the Effects of Convective Heat Transfer on Cutting Tool Wear in Hard Turning", ICAMB 2009 International Conference, VIT University, Vellore, India, 743-750.*

4. *Tamizharasan T and Kingston Barnabas J (2009), "Determination of Flank Wear in Turning – An Acoustic Emission Approach", 2nd International Conference of Recent Advances in Materials Processing Technology, SME, India, 738-746.*

5. *Karthikeyan R (1999), "Analysis and Optimization of Machining Characteristics of Al/SiC Particulate Composites", Ph.D Thesis, Department of Production Engineering, Annamalai University, Tamil nadu, India, 1-320.*

6. *Dereli T, Filish I H and Baykasoglu A (2001), "Optimizing Cutting Parameters in Process Planning of Prismatic Parts by using Genetic Algorithm", International Journal of Production Research, Vol.39(15), 3303-3328.*

7. *Dongcheolkim, Sehunrhee and Hyunsung park (2002), "Modeling and Optimization of a GMA Welding Process by Genetic Algorithm and Response Surface Methodology", International Journal of Production Research, Vol.40(7), 1699-1711.*