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Application of dragonfly algorithm for optimal performance analysis of process parameters in turn-mill operations- A case study

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Abstract. Meta-heuristic multi-response optimization methods are widely in use to solve multi-objective problems to obtain Pareto optimal solutions during optimization. This work focuses on optimal multi-response evaluation of process parameters in generating responses like surface roughness (R_a), surface hardness (H) and tool vibration displacement amplitude (Vib) while performing operations like tangential and orthogonal turn-mill processes on A-axis Computer Numerical Control vertical milling center. Process parameters like tool speed, feed rate and depth of cut are considered as process parameters machined over brass material under dry condition with high speed steel end milling cutters using Taguchi design of experiments (DOE). Meta-heuristic like Dragonfly algorithm is used to optimize the multi-objectives like 'R_a', 'H' and 'Vib' to identify the optimal multi-response process parameters combination. Later, the results thus obtained from multi-objective dragonfly algorithm (MODA) are compared with another multi-response optimization technique Viz. Grey relational analysis (GRA).

1. Introduction to dragonfly algorithm

Meta-heuristic methods like genetic algorithm (GA), particle swarm optimization (PSO), Ant colony optimization (ACO), Simulated annealing (SA), Artificial bee colony (ABC) etc are much in wide usage for optimization of processes parameters problems having an objective function and constraints, but very few are capable for multi-response problems making the need of much more new heuristic methods basing on swarm intelligence [1-3].

Dragonfly algorithm (DA) is a novel swam intelligence optimization technique originating from natural behaviour of dragonflies, which depends on exploration and exploitation. The two aspects of the dragonflies for navigating, searching food and survival from enemies by creating sub-warms over different areas is used for convergence towards pareto optimal solutions and coverage of optimal solution along the objectives. The ultimate goal for a multi-response optimization method is to determine most accurate approximation of true Pareto optimal solution with uniform coverage across all objectives. The phenomena of dragonfly behaviour is well suited for designing modelling for generating optimal solutions for multi-response optimization problems [1].

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2. Introduction to turn-mill processes and experimental setup

Turn-mill processes which have additional mechanism having capabilities of simultaneous tool and workpiece rotary system are adoptable in par with multi-axis machine tools. The rotary tool axis may be tangential or coaxial to the workpiece axis [4,5]. Two turn-mill processes viz. Tangential turn-mill process (i.e. rotating cylindrical workpiece and rotary cutting tool machining with its helical edge) while orthogonal turn-mill process (i.e. rotating cylindrical workpiece and rotary cutting tool machining with its bottom tip) were been studied by Ratnam et al.[6]. Extruded brass (leaded) work material with High speed steel (HSS) cutters based on Taguchi L_{16} experimental runs under dry conditions, as given in Table 1a were adopted for experimentation and the responses thus generated as shown in Table 1b are been considered for study in this work. The experimental setup and used instruments with specifications are shown in figure 1.

(a) CNC VMC-1050 with A-axis attachment and Poly-Tech 100 Laser Doppler Vibrometer (LDV)

(b) Surface Roughness Tester of MITUTOYO Surface Test SJ-301

Figure 1. Experimental setup and instruments used

Universal Hardness Testing machine of REICHERTER STIEFELMAYER, Germany-make, UH-3 model with load range of 1 to 250kg, measuring Vickers Hardness values as per ASTM E92 was used for measuring Surface Hardness (H).

Table 1a. Taguchi DOE of L_{16} based on orthogonal array.

Exp. No.	Machining Parameters			Actual setting values		
	A	B	C	A: Tool Speed (rpm)	B: Feed Rate (mm/min)	C: Depth of cut (mm)
1	1	1	1	2400	3.27	0.25
2	1	2	2	2400	5.05	0.50
3	1	3	3	2400	8.76	0.75
4	1	4	4	2400	10.0	1.00
5	2	1	2	2650	3.27	0.50
6	2	2	1	2650	5.05	0.25
7	2	3	4	2650	8.76	1.00
8	2	4	3	2650	10.0	0.75
9	3	1	3	2900	3.27	0.75
10	3	2	4	2900	5.05	1.00
11	3	3	1	2900	8.76	0.25
12	3	4	2	2900	10.0	0.50
13	4	1	4	3150	3.27	1.00
14	4	2	3	3150	5.05	0.75
15	4	3	2	3150	8.76	0.50
16	4	4	1	3150	10.0	0.25

3. Experimentation methodology

The maximum and minimum ranges of the process parameters (say: Tool speed (N) between 2400 rpm to 3150 rpm, feed rate (f) between 3.27 mm/min to 10.0 mm/min and depth of cut (DOC) between 0.25 to 1.00 mm), as shown in Table 1b are used as constraints and are taken from Ratnam et al.[6]. The experimental responses and the regression equations of the responses thus generated are utilized for multi-response optimization using MODA and GRA.

For MODA, the non-linear regression equations of the responses (i.e. surface roughness (R_a), surface hardness (H) and tool vibration displacement amplitude (Vib)) generated by Ratnam et al.[6] in both the turn-mill processes, as shown in Table 2 are been considered as objective functions for determining multi-objective optimization of responses using Matlab code of multi-objective Dragonfly algorithm (MODA) developed from Seyedali [1].

On the other hand, Grey relational analysis (GRA) is used for multi-objective optimization with the 4 levels for each of the three process parameters and their corresponding response values, as shown in Table 1b [6] are considered for study. The multi-response results generated using MODA and GRA are compared thereon and concluded.

3.1. Experimentation methodology of multi-objective dragonfly algorithm (MODA)

Multi-objective dragonfly algorithm (MODA) process flow chart is shown in figure 2. The MODA depends on static and dynamic swarming capabilities like separation, alignment, cohesion, attraction towards food source (i.e. towards optimality), distraction outwards enemies (i.e. non-movement towards non-optimality) using the below given formulae considered from Seyedali [1].

Separation is calculated as: $S_i = -\sum_{j=1}^{N} (X - X_j)$ (1)

Alignment is calculated as: $A_i = \frac{\sum_{j=1}^{N} V_j}{N}$ (2)

Cohesion is calculated as: $C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X$ (3)

Attraction towards a food source is calculated as: $F_i = X^+ - X$ (4)

Distraction outwards an enemy is calculated as: $E_i = X^- + X$ (5)

where X is the position of the current individual, X_j shows the position j^{th} neighbouring individual, V_j shows the velocity of j^{th} neighbouring individual, N is the number of neighbouring individuals, X^+ shows the position of the food source and X^- shows the position of the enemy.

The step vector shows the direction of the movement of the dragonflies:

$\Delta X_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_t$ (6)

The position vectors are calculated as: $X_{t+1} = X_i + \Delta X_{t+1}$ (7)

Pareto dominance is determined as: $\forall_i \in \{1,2,\ldots,k\}, [f(x_i) \geq f(y_i)]^\wedge[\exists i \in 1,2,\ldots.k\colon f(x_i)]$ (8)

Pareto optimality is determined as: $\nexists \vec{y} \in X : F(\vec{y}) > F(\vec{x})$ (9)

Pareto optimal set is determined as: $P_s = \{x, y \in X : \exists F(y) > F(x)\}$ (10)

Pareto optimal objective front/set is determined as: $P_f = \{x \in P_s : F(x)\}$ (11)

where t is the current iteration, and s, a, c, f, and e are weights of separation, alignment, cohesion, food and enemy factors respectively, w is inertia weight (w=0.9-iteration*((0.9-0.2)/max_iter)) and radius within a dragonfly flies r= (ub-lb)/4+((ub-lb)*(iteration/max_iter)*2) [1].

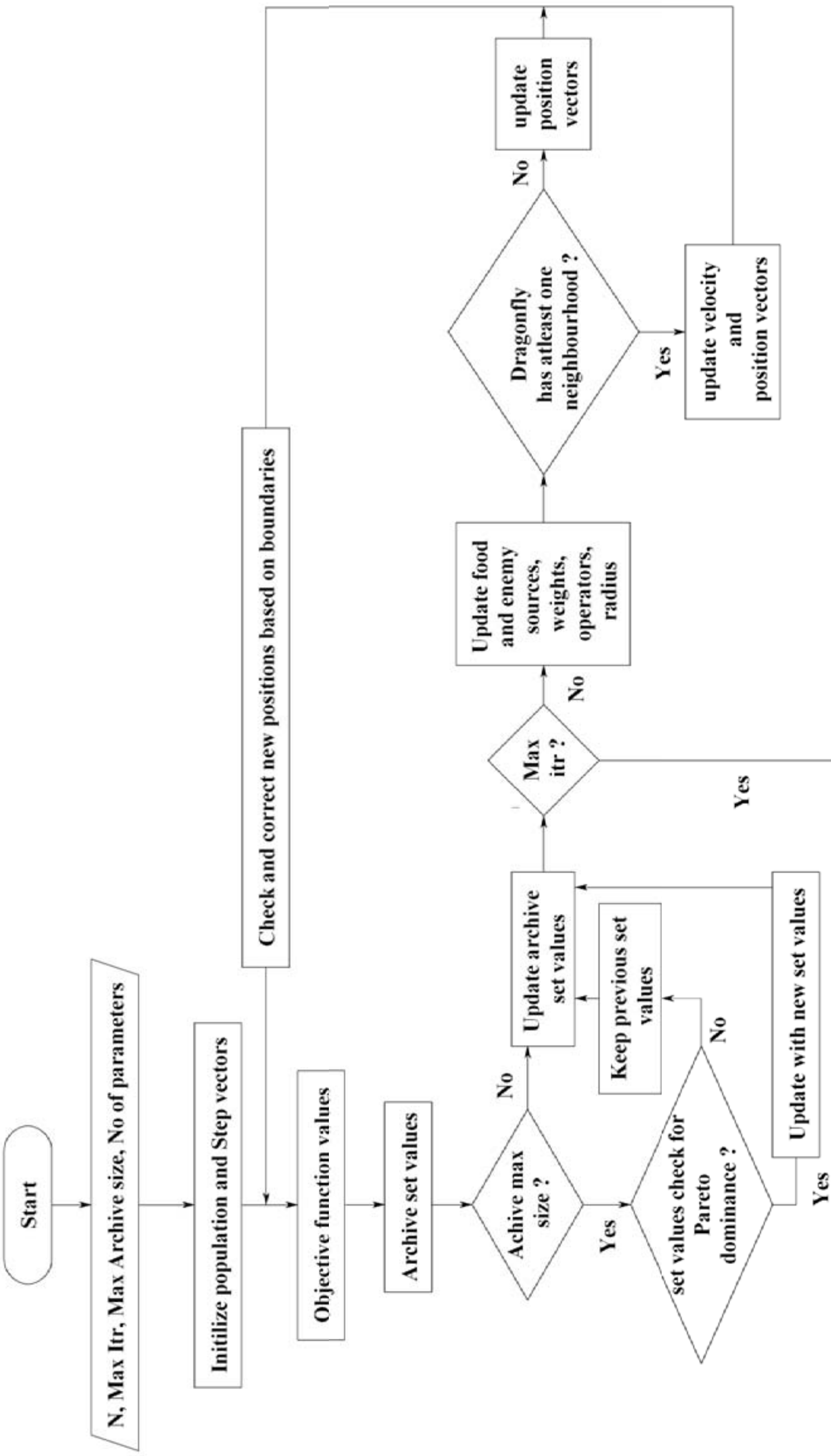

Figure 2. Process flow diagram of MODA

Table 1b. Experimental values recorded in tangential turn-milling process [6].

Exp No.	Tool Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	Tangential turn-mill process			Orthogonal turn-mill process		
				R_a (μm)	H (VHN)	Vib (μm)	R_a (μm)	H (VHN)	Vib (μm)
1	2400	3.27	0.25	0.78	142.3	27.64	4.82	120.0	39.14
2	2400	5.05	0.50	1.11	145.9	29.90	5.65	134.0	54.49
3	2400	8.76	0.75	1.83	151.3	36.60	6.50	143.7	71.30
4	2400	10.0	1.00	2.30	151.5	47.10	7.30	148.0	80.21
5	2650	3.27	0.50	0.56	156.7	23.09	4.41	134.7	40.20
6	2650	5.05	0.25	0.73	153.3	21.50	5.35	127.3	32.30
7	2650	8.76	1.00	1.80	163.0	31.20	5.93	154.0	71.64
8	2650	10.0	0.75	1.88	158.4	34.85	7.12	145.0	52.50
9	2900	3.27	0.75	0.50	170.0	22.54	2.95	148.7	49.20
10	2900	5.05	1.00	0.77	172.3	23.56	4.10	156.7	65.50
11	2900	8.76	0.25	1.08	161.0	19.91	5.50	125.0	31.50
12	2900	10.0	0.50	1.50	162.3	29.48	6.18	136.0	38.90
13	3150	3.27	1.00	0.34	177.3	21.11	1.89	163.0	46.82
14	3150	5.05	0.75	0.42	175.4	16.40	2.74	151.3	39.60
15	3150	8.76	0.50	0.84	167.7	14.72	4.65	141.7	36.70
16	3150	10.0	0.25	1.01	162.3	18.50	5.70	128.3	22.30

Average surface roughness- R_a; Average surface hardness-H and Tool vibration displacement amplitude-Vib

Table 2. Non-linear regression equations generated in both the turn-milling process [6].

Exp No.	Tool Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	Non-linear Regression equations in Tangential turn-mill process	Non-linear Regression equations in Orthogonal turn-mill process
1	2400	3.27	0.25	$(R_a)_{Tan} = e^{17.3} B^{1.00} C^{0.128} A^{-2.41}$ and $(H)_{Tan} = e^{0.92} B^{-0.01} C^{0.05} A^{0.53}$ and $(Vib)_{Tan} = e^{21.2} B^{0.224} C^{0.213} A^{-2.3}$	$(R_a)_{Ortho} = e^{14.2} B^{0.542} C^{-0.135} A^{-1.73}$ and $(H)_{ortho} = e^{3.2} B^{-0.01} C^{0.16} A^{0.24}$ and $(Vib)_{ortho} = e^{17.78} B^{0.0291} C^{0.551} A^{-1.7269}$
2	2400	5.05	0.50		
3	2400	8.76	0.75		
4	2400	10.0	1.00		
5	2650	3.27	0.50		
6	2650	5.05	0.25		
7	2650	8.76	1.00		
8	2650	10.0	0.75		
9	2900	3.27	0.75		
10	2900	5.05	1.00		
11	2900	8.76	0.25		
12	2900	10.0	0.50		
13	3150	3.27	1.00		
14	3150	5.05	0.75		
15	3150	8.76	0.50		
16	3150	10.0	0.25		

3.2. Grey relational analysis

Grey relational analysis (GRA) depends on the response values generated for the problem under consideration (here machining responses like R_a, H and Vib in both the turn-mill processes) and determine the combined optimal combination of process parameters with only the set of process parameters levels considered.

GRA firstly convert the response values which are incomparable to each other to a comparable values using concept of normalizing using larger-to-better or smaller-is-better equations. Then the converted and comparable response data are used to determine process parameters combination of the multi-response (I.e. R_a, H and Vib) [7-10] as shown in figure 3 and respective formulae utilization.

Step 1: convert response values to a sequence of comparable data by **normalizing** using Eq-12:

For Lower-is-Better (LB): $x_i^*(j) = \frac{[max\ (x_i(j)) - x_i(j)]}{[max\ (x_i(j)) - min(x_i(j))]}$ (12a)

For Higher-is-Better (HB): $x_i^*(j) = \frac{[x_i(j) - min\ (x_i(j))]}{[max\ (x_i(j)) - min(x_i(j))]}$ (12b)

where $X_i(j)$ is value of response of i^{th} experiment, $max(x_i(j))$ and $min(x_i(j))$ are the smallest and largest values of $X_i(j)$ respectively.

Step 2: determine **deviation sequence** $\Delta_{oi}(k)$ of each response normalized values and is given as:

$$\Delta_{oi}(k) = \|X_o(k) - X_i(k)\| \quad (13)$$

Step 3: Correlated of responses by giving some due weight age to determine **grey relational coefficient** as given in equation-14.

$$\gamma_i = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (14)$$

where Δ_{min} is smallest value of the normalized values, Δ_{max} is maximum value of the normalized values, ζ is distinguishing coefficient and ranges from 0 to 1 and had been assumed as 0.5 [9].

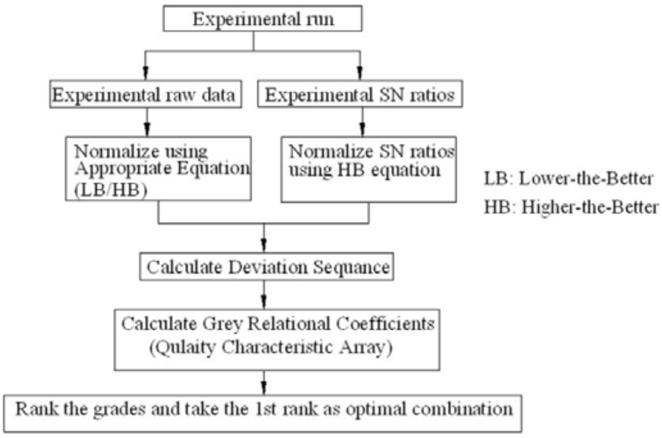

Figure 3. Process flow diagram of GRA

Step 4: Grading each combination of process parameters using Grey Relational Grade as given in equation-15. $\alpha_i = \frac{1}{n}\sum_{k=1}^{n}\gamma_i(k)$ (15)

where "n_r" is total number of responses.

Basing on the grey relational grade, the ranking has to be given in descending order. The combination of process parameters which has highest rank is considered to be optimal.

4. Computations and results

Data assumed for processing of MODA in MATLAB:

a. Number of process parameters=3 (tool speed, feed rate and depth of cut) and non-linear objective functions of tangential and orthogonal turn-mill operations from Ratnam et al. [6].

b. Lower bound (lb)=[2400 rpm, 3.27 mm/min and 0.25 mm] and Upper bound (ub)=[3150 rpm, 10 mm/min and 1.0 mm] for tool speed, feed rate and depth of cut respectively.

c. Number of artificial dragon flies (N) = 500

d. Maximum iterations (Max_iter) = 500

e. Maximum archive size (Max_arch) = 50

f. Number of objectives = 3

4.1. Computations and results using MODA

Executing the MODA code in MATLAB, the optimal non-dominated combination of processes parameters obtained and their response values for tangential turn-mill and orthogonal turn-mill are shown in figure 4a and figure 4b. The optimal surface roughness (R_a), surface hardness (H) and tool vibration displacement amplitude (Vib) are generated as 0.3931 µm, 176.8 VHN and 18.71 µm respectively in tangential turn-mill at tool speed 3150 rpm, feed rate 3.27 mm/min and 0.957 mm depth of cut.

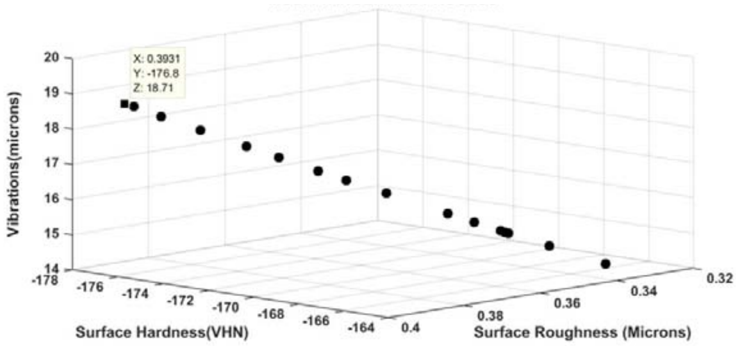

Figure 4a. MODA results for responses in tangential turn-mill

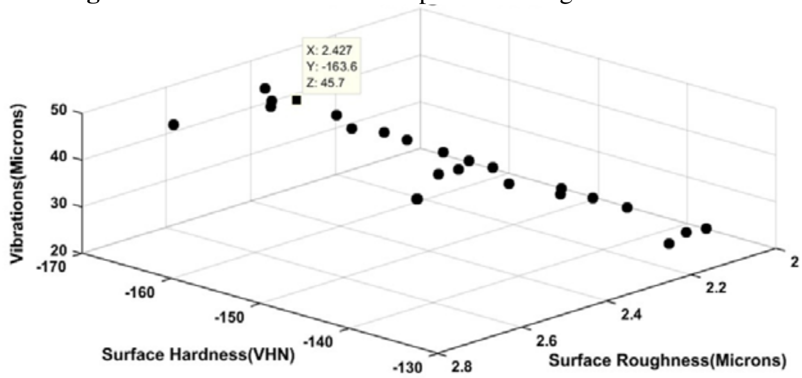

Figure 4b. MODA results for responses in orthogonal turn-mill

The optimal surface roughness (R_a), surface hardness (H) and tool vibration displacement amplitude (Vib) are generated as 2.427 µm, 163.6 VHN and 45.7 µm respectively in orthogonal turn-mill at tool speed 3150 rpm, feed rate 3.27 mm/min and 0.86 mm depth of cut.

(Note: The negative sign for surface hardness values indicate that the objective function which should be of maximization has been considered as minimization for running the MODA)

4.2. Computations and results using GRA

Sample calculations of experimental run 1 of surface roughness in tangential turn-mill:

The GRA method procedure has been adopted to calculate optimal combination of responses using GRA in both the turn-mill processes and is listed in Table 3.

For Normalization R_a, Lower-is-Better (LB) and using the Eq. 12a, we get

For Lower-is-Better (LB): $x_i^*(j) = \frac{[\max(x_i(j)) - x_i(j)]}{[\max(x_i(j)) - \min(x_i(j))]}$ = [(2.3-0.78/(2.3-0.34)] = 0.7755

The deviation sequence using Eq. 13: $\Delta_{oi}(k) = \|X_o(k) - X_i(k)\|$ = |0.7755-1|=0.2245

Grey relational coefficient is calculated using Eq. 14 as γ_i = ((0+0.5*1)/((0.2245+(0.5*1)))=0.690

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Table 3. Grey Relational Coefficients in both the turn-mill processes.

Exp. No	Grey Relational Coefficients						Grade	Rank	Grade	Rank
	Tangential turn-mill process			Orthogonal turn-mill process			Tangential		Orthogonal	
	Ra (µm)	H (VHN)	Vib (µm)	Ra (µm)	H (VHN)	Vib (µm)				
1	0.690	0.333	0.556	0.480	0.333	0.632	0.527		0.482	
2	0.560	0.358	0.516	0.418	0.426	0.474	0.478		0.439	
3	0.397	0.402	0.425	0.370	0.527	0.371	0.408		0.423	
4	0.333	0.404	0.333	0.333	0.589	0.333	0.357		0.419	
5	0.817	0.459	0.659	0.518	0.432	0.618	0.645		0.522	
6	0.715	0.422	0.705	0.439	0.376	0.743	0.614		0.519	
7	0.402	0.550	0.496	0.401	0.705	0.370	0.483		0.492	
8	0.389	0.481	0.446	0.341	0.544	0.489	0.438		0.458	
9	0.860	0.706	0.674	0.718	0.601	0.518	0.747		0.612	
10	0.695	0.778	0.647	0.550	0.773	0.401	0.707		0.575	
11	0.570	0.518	0.757	0.428	0.361	0.759	0.615		0.516	
12	0.458	0.538	0.523	0.387	0.443	0.636	0.507		0.489	
13	1.000	1.000	0.717	1.000	1.000	0.541	0.906		0.847	1
14	0.925	0.902	0.906	0.761	0.648	0.626	0.911	1	0.678	
15	0.662	0.646	1.000	0.495	0.502	0.668	0.769		0.555	
16	0.594	0.538	0.811	0.415	0.383	1.000	0.648		0.599	

The optimal evaluation of responses using DA and GRA are compared in Table 4.

Table 4. Comparison of results generated using DA and GRA in both the turn-mill processes

Optimal process parameters combination	R_a (µm)	H (VHN)	Vib (µm)
Using MODA algorithm for tangential turn-mill process Tool speed: 3142.7 rpm; Feed rate: 3.27 mm/min; Depth of cut: 0.25 mm	0.333	165.1	14.13
Using MODA algorithm for orthogonal turn-mill process Tool speed: 2789.9 rpm; Feed rate: 3.27 mm/min; Depth of cut: 0.31 mm	3.58	134.9	32.01
Using GRA for tangential turn-milling process Tool speed: 3150 rpm; Feed rate: 5.05 mm/min; Depth of cut: 0.75 mm	0.42	175.4	16.40
Using GRA for orthogonal turn-milling process Tool speed: 3150 rpm; Feed rate: 3.27 mm/min; Depth of cut: 1.00 mm	1.89	163.0	46.82

5. Results and Discussions

Observing Table 4, we it is clear that the MODA search in between the parameter levels and generate non-dominant optimal results which do not give a combined combination of process parameters for optimizing all the responses simultaneously and so one has to choose the result basing on the priority of the response they require. But on the other hand, observing Table 3 and Table 1b, it is clear that the GRA generates results only one combination of parameters which gives simultaneous optimal result of all the responses but restricts to only the levels that exist in the design of experiments.

6. Conclusions

Multi-objective dragonfly algorithm (MODA) relays on the objective functions and constraints of a given problem and so it is preferred where intermediate combination of process parameter for optimality is required to evaluate, which is not possible in case of GRA. While Grey relational analysis can be of more useful when need to analyze the process in working stage to generate a multi-objective optimality.

MODA approach is adoptable where we have clarity of priority among the responses when compared to GRA, but if optimization of all the responses simultaneously is required then GRA is preferable. As the MODA algorithm depends on updating of archived data, it generates a random of different optimal solutions when executed every time, whereas GRA generates only one definite solution for a problem.

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