**Coupled Systems Mechanics,** *Vol. 13, No. 3 (2024) 219-229*
https://doi.org/10.12989/csm.2024.13.3.219

# Design optimization of turning machine process

T. Jagan[1,2a] and S. Elizabeth Amudhini Stephen[*1]

[1]*Department of Mathematics, Karunya Institute of Technology and Sciences,*
*Coimbatore, Tamil Nadu, 641114, India*
[2]*Department of Mathematics, KG College of Arts and Science, Coimbatore, Tamil Nadu, 641035, India*

*(Received April 9, 2022, Revised March 25, 2024, Accepted March 26, 2024)*

**Abstract.** By introducing optimization algorithms into the machining process, product quality can be improved, time saved, and costs reduced. The cutting speed and feed can be handled by the turning machine. The approach of optimizing is used to manage pyrotechnics, Lawler's, greedy, bacterial colony, elephant herding, ant lion, spiral, auction, and pattern search for these ten odd ways. Ten artificial optimization methodologies were used to investigate the time and cost of a turning machine. It has been discovered how to create the optimal turning machine procedure. The best solution approach for the turning machine process problem is found, and the results are verified using ANSYS.

**Keywords:** ANSYS; optimization techniques; simulation; tuning machine process

## 1. Introduction

A Turning machine, usually a non-rotary device bit, specifies a helix tool route by transmitting more or less linearly while the workpiece spins. Optimization algorithms are used in the machining process to increase product quality while lowering cost and time. Turning machine technology allows for lower speeds and feed rates. (Amudhini *et al.* 2015). Jagan and Elizabeth Amudhini Stephen (2021) solved the Turning machining process to improve product quality while reducing costs and time. They described eleven non-traditional approaches for optimizing machining processes. In this research, they determine which strategy provides a superior answer for the turning machine operation.

Pavan Kumar and Basavaraj (2021) presented that the turning process in a valve company plays a significant role in the manufacturing department, which adds to the industry's profits. To acquire the best results from the machining process, it is critical to understand the contribution level of various cutting parameters such as spindle speed, feed rate, and depth of cut to the machine. In this study, several levels of process parameters are optimised using the Taguchi-Super Ranking approach, resulting in optimum outcomes and increased machine life.

---

[*]Corresponding author, Professor, E-mail: elizi.felix@gmail.com
[a]Assistant Professor, E-mail: jagan.t@kgcas.com

http://www.techno-press.org/?journal=csm&subpage=8 ISSN: 2234-2184 (Print), 2234-2192 (Online)

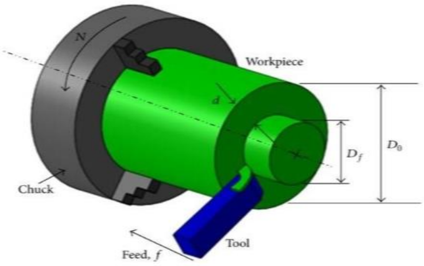


Fig. 1 Turning machine process design

Ganesan and Mohankumar (2011) described One of the most significant aspects of metal component process planning is optimizing cutting settings. The machining parameters used in multipass turning include depth of cut, cutting speed, and feed. In this study, the ideal machining parameters for continuous profile machining are found in terms of the shortest production time while keeping a set of practical restrictions in mind, including cutting force, power, dimensional accuracy, and surface polish. Due to the difficulty of this machining optimization issue, a genetic algorithm (GA) and Particle Swarm Optimization (PSO) are used to solve it, and the outcomes of GA and PSO are compared.

Cutting speed, feed, depth of cut, and passes are all characteristics in machining, as are outputs like production cost, tool life, production time, cutting force, cutting temperature, and power consumption. It is vital to select the appropriate cutting data. The quality of the product as well as the cost of processing are both influenced. The three parameters are feed (*f*), cutting speed (*Vc*), and cut depth (*Dc*).

Optimizing machining process conditions is required to solve the multi-pass turning parameter selection problem. Several authors tried to handle the same problem with different methods. Chen presented a hybrid strategy for lowering production costs based on simulation algorithms and pattern search.

Optimization technique the genetic algorithm that was retrieved is the basis for this. Pattern search not only solves difficult optimization problems but also attracts fresh researchers. To make the same model, combine a hybrid algorithm and a genetic algorithm. The lathe process, according to the literature review, is a difficult problem that can be handled by utilizing a range of optimization strategies. A pattern search is being developed for this operation to lower manufacturing unit costs. By contrasting the acquired results, the proposed optimization strategy is highlighted. Fig. 1 shows the Turning machine process design (Millie and Radha 2009).

Most of the engineering components such as gears, bearings, clutches, tools, screws and nuts etc. need dimensional and form accuracy and a good surface finish for serving their purposes. Performing like casting, forging etc. generally cannot provide the desired accuracy and finish. For that such preformed parts, called blanks, need semi-finishing and finishing and it is done by machining and grinding. Machining is an essential process of finishing by which jobs are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s).

The basic principle of machining is typically illustrated.

A metal rod of irregular shape, size and surface is converted into a finished rod of desired dimension and surface by machining by proper relative motions of the tool-work pair.

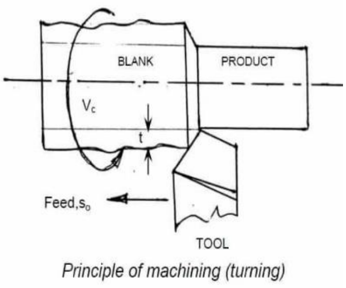


Fig. 2 Principle of machining turning

*Machining operations*

There are many kinds of machining operations, each of which is capable of generating a certain part geometry and surface texture. In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. The primary motion is provided by rotating the workpiece, and the feed motion is achieved by moving the cutting tool slowly in a direction parallel to the axis of rotation of the workpiece.

## 2. Mathematical modelling of machining cost

Machining optimum provides the nearest optimum solution in the actual cutting process. There are two types of optimization. The first part is mathematical formulation and the second part is finding a global optimum solution (Mohan and Kiran 2017).

*C*-Cost of Machining; *Vc*-cutting speed; *f*-feed; *Cr*-Labor plus overhead cost; *tL*-Non-productive time; *ap*-depth of a cut; *tm*-Machining time; *T*-Tool life; *td*-tool changing time; *Ca*-tool cost per cutting edge; *D*-Work piece diameter; *L*-Length of turning; *CT*, *p*, *q*, *r*-empirical constants
Cost of Machining:

Cost of machining $C=C_rt_L+C_rt_m+\underline{tm}\,(Cr.\ td + Ca)$

Machining time in turning process

$$t_m = \frac{\pi.D.L}{1000.Vc.f}$$

Tool life

$$T = C_r/v_c^p.f_q.a_p^r$$

Cost of machining

$$C = C_1 + C_2.V_C^{-1}.f^{-1} + C_3.V_C^{p-1}.f^{q-1}$$

Where:

$$C_1 = C_r.t_L$$
$$C_2 = \frac{\pi.F.L.Cr}{1000}$$
$$C_3 = \frac{\pi.D.L.arp(Cr.td+Ca)}{1000\times Cr}$$

Constraints functions;

a. constrains on the cutting tool ability:

$$V_c.f^y \leq \frac{Cv.Kv}{Tm.ap}$$

b. Machine tool power force constraints:

$$V_c.f^{y1} \leq \frac{6120.Pm.\eta}{Ck1.kf.ap}$$

c. strength tool constraints:

$$f^{y1} \leq \frac{Rsd}{Ck1.C0.kf.ap}$$

d. Stiffness work piece constraints:

$$f^{y1} \leq \frac{\delta.E.I}{0.8.Ck1.l1.kf.ap}$$

e. Constraints on the minimal spindle speed:

$$V_c \geq \frac{\pi.D.n\ \mathrm{min}}{1000}$$

f. Constraints on the maximal spindle speed:

$$V_c \leq \frac{\pi.\mathrm{D.n\ max}}{1000}$$

g. Constraints on the minimal feed:

$$f \geq f_{\mathrm{min}}$$

h. Constraints on the maximal feed:

$$f \leq f_{\mathrm{max}}$$

*The Mathematical model of the objective function is represented as:*
Objective function:

$$\min C=0.30+\frac{4.60}{Vc.f}+1.72.10^{-11}.V_c^{4.55}f^{0.67}$$

Constraint functions:

a. $Vc\,f^{0.30} \leq 91.57$
b. $Vc\,f^{0.75} \leq 74.80$
c. $f^{0.75} \leq 6.48$
d. $Vc \geq 5.03$
e. $Vc \leq 502.65$
f. $f \geq 0.04$
g. $f \leq 9$

The above problem is solved using all ten non-traditional optimization methods. Each method is run for 20 trials and the average values are taken for $Vc$, $f$ and the cost (Pavan 2020).

## 3. Comparative results

The comparative results of turning machining parameters using 10 non-traditional optimization algorithms were tabulated in Table 1. Every problem is run for 20 trials since the non-traditional optimization methods give the global optimum solution (Jagan and Elizabeth Amudhini Stephen 2021).

## 4. Simulation for validating optimized results

The Turning machine tool spindle provides the relative motion between the cutting tool and the

Table 1 Comparative results of non-traditional optimization methods

| Trial No. | ABC | AUCT | ANT | ELE | SPIRAL | BACT | GREEDY | LAWLERS | FIRE | PATT |
|---|---|---|---|---|---|---|---|---|---|---|
| Objective | 0.3454 | 0.3455 | 0.33998 | 0.3462 | 0.3461 | 0.3655 | 0.3458 | 0.3553 | 0.3445 | **0.32561** |
| *t* (Sec) | 1.6376 | 1.6736 | 1.584 | 1.6613 | 1.6615 | 1.5962 | 1.6541 | 1.6508 | 1.5879 | **1.561** |
| Feed(mm) | 6.1541 | 6.1408 | 6.1354 | 6.3149 | 6.1374 | 6.1474 | 6.1395 | 6.1555 | 6.3619 | **6.1246** |
| *Vc* (mins) | 14.8174 | 14.5211 | 14.7 | 14.8915 | 14.8873 | 14.7739 | 15.023 | 15.152 | 14.714 | **13.995** |

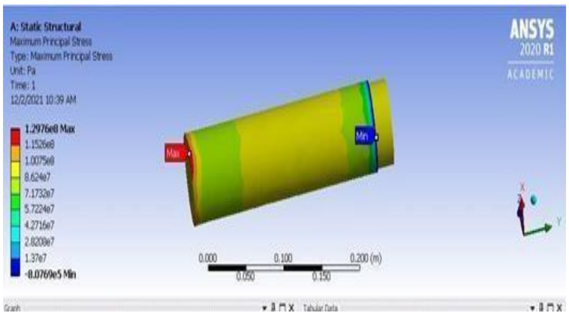


Fig. 3 Meshed structure of turning machine

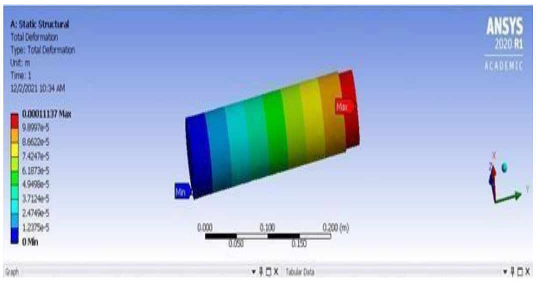


Fig. 4 Upper boundary geometry turning machine

workpiece which is necessary to perform a material removal operation. In turning, while in processes like milling, drilling or grinding. This work deals with the design and analysis of the spindle in which material is used for the alloy steel. The Meshed structure of the turning machine is shown in Fig. 3.

### *4.1 Upper boundary results*

The upper boundary geometry turning machine is given in Fig. 4. The turning machine was subjected to a uniform pressure of 100 MPa. The upper bound details that were incorporated in ANSYS are the rotational velocity of 502.65 rad/s at a point of 90 mm in the feed.

### *4.2 Deformation for upper boundary*

The Deformation for the Upper Boundary Turning machine is shown in Fig. 5. The maximum deflection that was in the upper bound is 0.09 mm in the upper bound limits under the pressure of 100 MPa. The least deflection value is 0.01 mm when the upper boundary limits were applied.

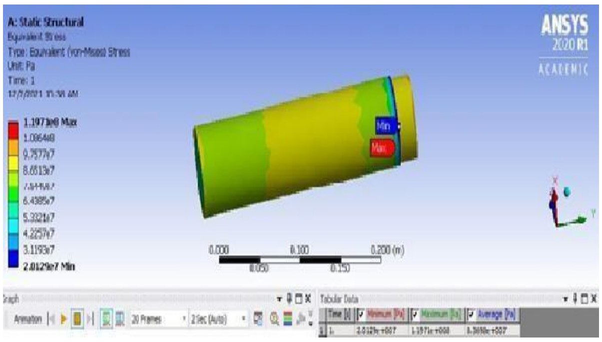


Fig. 5 Deformation for upper boundary turning machine

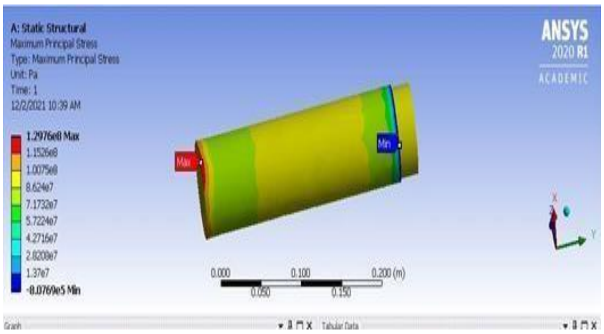


Fig. 6 Equivalent stress for upper bound turning machine

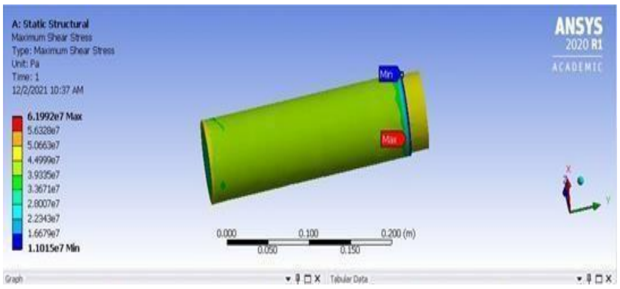


Fig. 7 Maximum principle stress for upper boundary turning machine

### 4.3 Equivalent stress for upper boundary

The Equivalent Stress for Upper Bound Turning machine is given in Fig. 6. The maximum equivalent stress attained is 119.7 MPa when the upper bound limits were applied. The minimum equivalent stress attained is 20.13 MPa when the upper bound limits were applied.

### 4.4 Maximum principle stress for upper boundary

The Maximum Principle Stress for the Upper Boundary Turning machine is shown in Fig. 7. The maximum principle stress attained is 129.76 MPa when the upper bound limits were applied. The range of the maximum principle stress is from 0.81 MPa to 129.76 MPa.

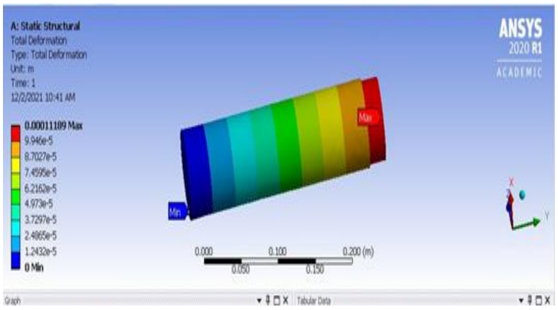


Fig. 8 Lower boundary turning machine

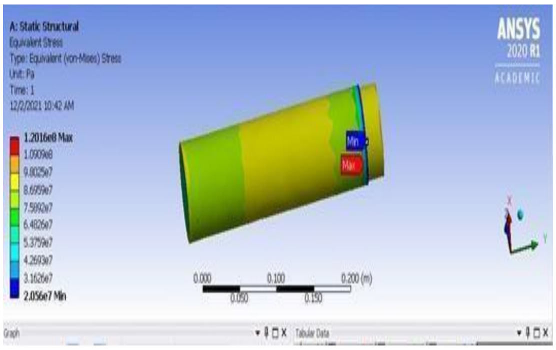


Fig. 9 Deformation for lower boundary turning machine

### 4.5 Maximum shear stress for upper boundary

The maximum shear stress attained was 61.99 MPa when the upper bound limits were applied. The range of the maximum shear stress is from 11.02 MPa to 61.99 MPa.

### 4.6 Lower boundary results

The Lower Boundary Turning machine is given in Fig. 8. The turning machine was subjected to a uniform pressure of 100 MPa. The lower bound details that were incorporated in ANSYS are the rotational velocity of 5.03 rad/s at a point of 0.4 mm in the feed.

### 4.7 Deformation for lower boundary

The Deformation for the Lower Boundary Turning machine is shown in Fig. 9. The maximum deflection that was in the lower bound is 0.11 mm in the lower bound limits under the pressure of 100 MPa. The least deflection value is 0.02 mm when the lower boundary limits were applied.

### 4.8 Equivalent stress for lower boundary

The Equivalent Stress for the Lower Boundary Turning machine is shown in Fig. 10. The maximum equivalent stress attained is 120.16 MPa when the lower bound limits were applied. The minimum equivalent stress attained is 20.56 MPa when the lower bound limits were applied.

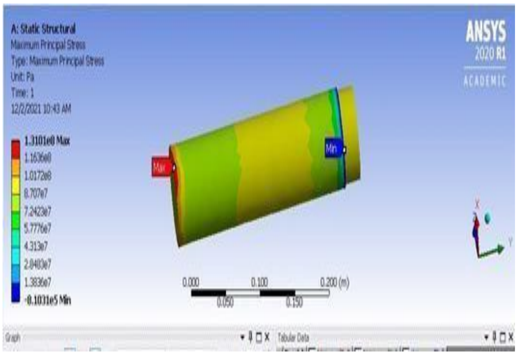


Fig. 10 Equivalent stress for lower boundary turning machine

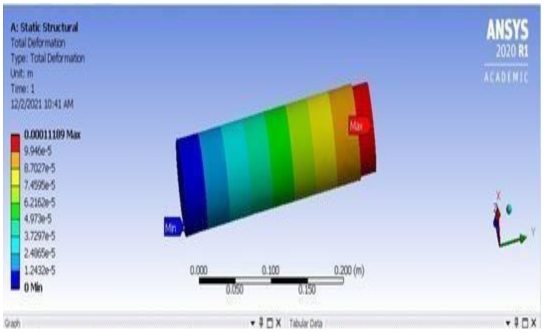


Fig. 11 Maximum principle stress for lower boundary

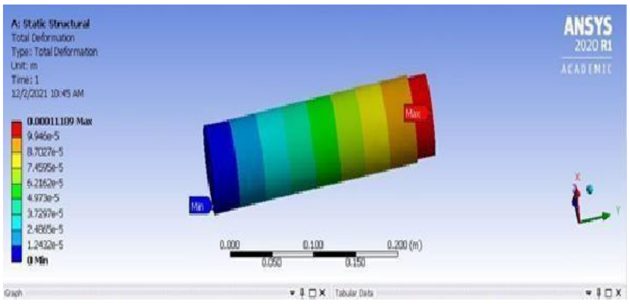


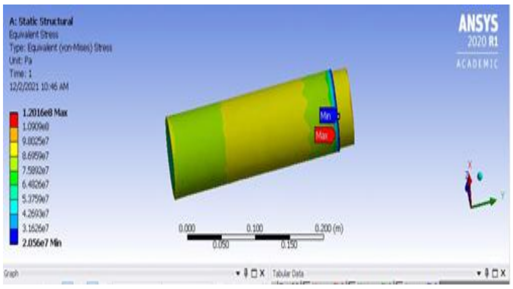
Fig. 12 Optimum boundary geometry turning machine

### *4.9 Maximum principle stress for lower boundary*

The Maximum Principle Stress for the Lower Boundary Turning machine is shown in Fig. 11. The maximum principle stress attained is 131.01 MPa when the lower bound limits were applied. The range of the maximum principle stress is from 0.81 MPa to 131.01 MPa.

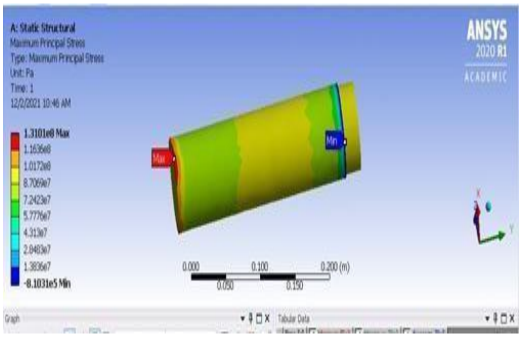
### *4.10 Maximum shear stress for lower boundary*

The maximum shear stress attained was 62.31 MPa when the lower bound limits were applied. The range of the maximum shear stress is from 11.25 MPa to 62.31 MPa.



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
12/2/2021 10:46 AM

Fig. 13 Deformation for optimum boundary turning machine



A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
12/2/2021 10:46 AM

Fig. 14 Equivalent stress for optimum boundary turning machine

### 4.11 Optimum boundary

The Optimum boundary geometry Turning machine is shown in Fig. 12. The turning machine was subjected to a uniform pressure of 100 MPa. The optimum details that were incorporated in ANSYS are the rotational velocity of 13.995 rad/s at a point of 61.2 mm in the feed.

### 4.12 Deformation for optimum boundary

The Deformation for the Optimum boundary-turning machine is shown in Fig. 13. The maximum deflection that was in the optimum is 0.11 mm in the optimum limits under the pressure of 100 MPa. The least deflection value is 0.01 mm when the optimum limits were applied.

### 4.13 Equivalent stress for optimum boundary

The Equivalent Stress for the Optimum boundary-turning machine is shown in Fig. 14. The maximum equivalent stress attained is 120.16 MPa when the optimum limits were applied. The minimum equivalent stress attained is 20.56 MPa when the optimum limits were applied.

### 4.14 Maximum principle stress for optimum boundary

The Maximum Principle Stress for the Optimum boundary-turning machine is shown in Fig. 15. The maximum principle stress attained is 131.01 MPa when the optimum limits were applied. The range of the maximum principle stress is from 0.81 MPa to 131.01 MPa.

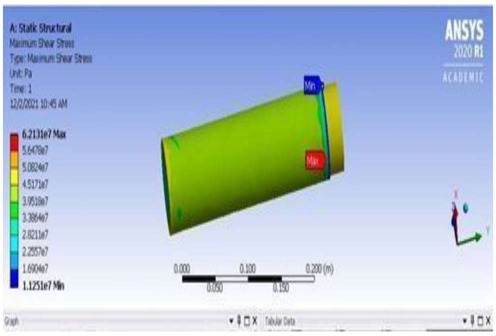


Fig. 15 Maximum principle stress for optimum boundary turning machine

## 5. Conclusion for simulation

The maximum shear stress attained is 62.13 MPa when the optimum limits were applied. The range of the maximum shear stress is from 11.25 MPa to 62.13 MPa.

In the case of the optimal limits turning machine, the deformation, equivalent stress, maximum principle stress and the maximum shear stress value under constant pressure of 100 MPa at a rotational velocity of 13.995 rad/sat 61.2 mm in the feed are compared with the upper bound limits of rotational velocity of 502.6 rad/sat 90 mm in the feed and the lower bound limits of rotational velocity of 5.03 rad/sat 0.4 mm in the feed

## 6. Conclusions

The cost minimization of the turning machine process problem is solved by ten non-traditional methods in optimization. The ten algorithms are implemented by using MATLAB. The problem is made by 20 trials. From Table 1, we observe that time is minimal in the pattern search method (1.561 sec) followed by Ant lion (1.584 sec). The cutting speed *Vc* is minimum in the pattern search method (13.995 mins) followed by the Auction algorithm (14.5211 mins). The Feed also minimum in the pattern search method (6.1246 mm) followed by the Ant lion algorithm (6.1354 mm). From the above result, we conclude that the pattern search algorithm has minimum evaluation. The result derived can be given to turning machine manufacturing industries for further processing.

## References

Amudhini, E.S., Joe, A. and Susmitha, K. (2015), “Cost minimization of turning machining process using cuckoo search, pattern search, firefly and flower pollination”, *Int. J. Mech. Eng. Tech.*, **9**(3), 1.

Gadekula, R.K., Potta, M., Kamisetty, D., Yarava, U.K., Anand, P. and Dondapati, R.S. (2018), “Investigation on parametric process optimization of HCHCR in CNC turning machine using Taguchi technique”, *Mater. Today: Proc.*, **5**(14), 28446-28453. https://doi.org/10.1016/j.matpr.2018.10.131.

Ganesan, H. and Mohankumar, G. (2011), “Optimization of machining parameters in turning process using genetic algorithm and particle swarm optimization with experimental verification”, *Int. J. Eng. Sci. Technol.*, **3**(2), 1.

Jagan, T. and Stephen, S.E.A. (2021), "Cost minimization of turning machining process with materials using Abc, Auction, Ant Lion, Elephant, Spiral, Bacterial, Greedy, Lawlers fireworks and pattern search", *IOP Conf. Ser.: Mater. Sci. Eng.*, **1126**(1), 012056. https://doi.org/10.1088/1757-899X/1126/1/012056.

Kumar, B.P., Basavaraj, Y., Sandeep, M.J. and Kumar, N.K. (2021), "Optimization of process parameters for turning machine using Taguchi super ranking method: A case study in valve industry", *Mater. Today: Proc.*, **47**, 2505-2508. https://doi.org/10.1016/j.matpr.2021.05.043.

Kumar, S., Rizvi, Y. and Kumar, R. (2018), "A review of modelling and optimization techniques in turning processes", *Int. J. Mech. Eng. Technol.*, **9**(3), 1146-1156.

Kumar, S.M. and Kumar, K.K. (2017), "Optimization techniques in turning operation by using Taguchi method", *Int. J. Eng. Adv. Technol.*, **6**(6), 57-64.

Madić, M. and Radovanović, M. (2014), "Optimization of machining processes using pattern search algorithm", *Int. J. Indus. Eng. Comput.*, **5**(2), 223-234. https://doi.org/10.5267/j.ijiec.2014.1.002.

Pant, M., Thangaraj, R. and Singh, V.P. (2009), "Optimization of mechanical design problems using improved differential evolution algorithm", *Int. J. Recent Trend. Eng.*, **1**(5), 21.

Rana, P.B., Patel, J.L. and Lalwani, D.I. (2019), "Parametric optimization of turning process using evolutionary optimization techniques-A review (2000-2016)", *Soft Computing for Problem Solving: SocProS 2017*, **2**, 165-180. https://doi.org/10.1007/978-981-13-1595-4_13.

*CC*