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Review on Optimization of Hole-Making Operations for Injection Mould Using Non-Traditional Algorithms

A.M. Dalavi
Assistant Professor, Department of Mechanical Engineering, Symbiosis Institute of Technology, Symbiosis International University, Gram Lavale, Mulshi, Pune, India 412115, amol.dalavi83@gmail.com

P. J. Pawar
Professor, Department of Production Engineering, K. K. Wagh Institute of Engineering Education and Research, Nashik, India

T.P.Singh
Director and Professor, Department of Mechanical Engineering, Symbiosis Institute of Technology, Symbiosis International University, Gram Lavale, Mulshi, Pune, India 412115

A.S.Warke
Professor, Department of Applied sciences, Symbiosis Institute of Technology, Symbiosis International University, Gram Lavale, Mulshi, Pune, India 412115

P.D.Paliwal
Professor, Department of Applied sciences, Symbiosis Institute of Technology, Symbiosis International University, Gram Lavale, Mulshi, Pune, India 412115

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Abstract

Optimization of hole-making operations plays a crucial role in which tool travel and tool switch scheduling are the two major issues. Industrial products such as moulds, dies, engine block etc. consists of large number of holes having different diameters, depths and surface finish. This requiers large number of machining operations like drilling, reaming or tapping to achieve the final size of individual hole. This gives rise to large number of possible sequences to achieve final size of the hole. Optimal sequence of operations which reduces the overall processing cost of these hole-making operations are essential. Hence it is necessary to use non-traditional optimization techniques which are strong enough to handle these complex problems as well which gives optimal results. This paper reviews about the various non-traditional optimization techniques which are already implemented to solve optimization of hole-making operation problems.

Key words: *Hole-making operations, non-traditional optimization algorithms*

1. INTRODUCTION

In machining process of many industrial parts such as dies and moulds, operations like drilling, reaming or tapping account for a large segment of process. Generally, a part, for e.g. a plastic injection mould may have many holes of different diameters, surface finish, and maybe different depths.

If the diameter of hole is relatively large, a pilot hole may have to be drilled first using a tool of smaller diameter and then enlarge it to its final size with a larger tool, followed by reaming or tapping whenever essential. For hole H_3, as shown in fig. 1, there could be four different combinations of tools: (A,B,C), (A,C), (B,C), and (C) The selection of tool combinations for each hole directly affects the optimum cutting speeds, required number of tools switches, and tool travel distance [1].

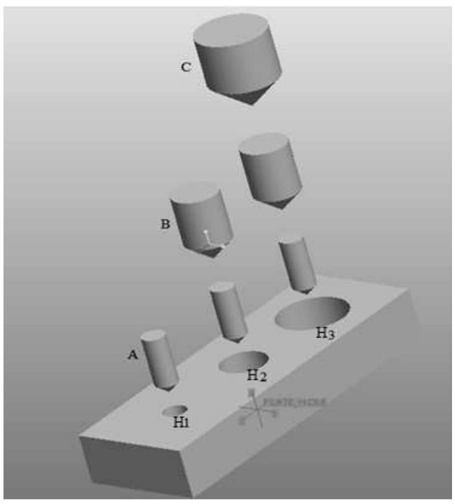

Figure 1. Image showing various tool combinations required to drill a hole on workpiece.

2. LITERATURE REVIEW

Tool switch and tool travel from one position to another takes a large amount of machining time in machining processes. Usually 70% of the overall time in machining processes is spent on movements of tools and part [2]. To reduce the tool travel, the spindle is not moved until a hole is completely drilled by using several tools of different diameters, thereby increasing tool switching cost. On the other hand, to reduce tool switching cost, the tool may be used to drill all possible holes which in turn increases the tool travel cost. Luong and Spedding [3] addressed the process planning and cost estimation of hole-making operations by developing a generic knowledge based procedure.

Castelino et al. [4] reports an algorithm for minimizing airtime for milling by optimally connecting various tool path segments. In their work, problem was formulated as a generalized travelling salesmen problem and was solved using a heuristic method. Kolahan and Liang [1] introduced a tabu search (TS) approach to reduce the overall processing cost of hole-making operations. Overall processing cost consists of tooling & machining costs, non-productive tool travel cost and tool switch cost. A case study of injection mould is considered which involving total 56 machining operations. Fred Glover proposed tabu search in a paper that dates back to the mid-1980s, the optimum in tabu search is approached iteratively [5]. Alam et al. [6] presented a practical application of computer-aided process planning (CAPP) system, to reduce the overall processing time of injection moulds. Genetic algorithm (GA) was used for optimizing the selection of machine tools, cutting tools, and cutting conditions for different processes. Qudeiri and Yamamoto [7] used genetic algorithm to find the optimal sequence of operations which gives the shortest cutting tool travel path (CTTP). Tool travel time and tool switch time is crucial in finding the shorting cutting tool path.

Shi et al. [8] presented a novel particle swarm optimization (PSO) based algorithm for solving the travelling salesman problem (TSP). They compared their proposed algorithm with existing algorithms and found that PSO can be used for solving large size problems. Guo et al. [9] developed a problem on integration of process planning, scheduling of manufacturing field using particle swarm optimization algorithm. Shao et al. [10] used a modified genetic algorithm based approach to integrate the process planning and scheduling of manufacturing systems in order to achieve an improved performance. Ghaiebi & Solimanpur [11] applied proposed ant colony optimization (ACO) algorithm for optimizing the sequence of hole-making operations of industrial part. Also, six bench mark problems of hole-making operations were considered.

Results of ACO were compared with dynamic programming and particle swarm optimization. Injection mould application considered for proposed ACO algorithm and its results of tool travel and tool switch time were compared with Dynamic programming and PSO, it is observed from the results that ACO results are better than other two. Ant colony optimization (ACO) algorithm is a metaheuristic developed by Marco Dorigo, which was motivated by colonies of real ants, which deposit a chemical substance on the ground called pheromone [12-15]. Hsieh et al. [16] used immune based evolutionary approach (IA) to find the optimal sequence of hole-making operations. Six bench mark problems of hole-making operations were considered and compared with dynamic programming, PSO and ACO. A case study of injection mould is attempted for finding minimum tool travel and tool switch time. It is observed that IA results are better than dynamic programming, PSO and ACO. Bersini and Varela [17] are considered to be first to apply immune algorithms to problem solving in the early 1990s.

Tamjidy et al. [18] presented an evolutionary algorithm to reduce the tool travel and tool switching time during hole-making operations based on geographic distribution of biological organism i.e. biogeography based optimization (BBO) algorithm.Guo et al. [19] presented a case study of five-axis prismatic parts for sequencing the operations using particle swarm optimization approach. Kiani et al. [20] put forward the ant colony algorithm to get the best order of operations that achieve concise cutting trajectory in computer numerical control machine. Nassehi et al. [21] used evolutionary algorithms for generation and optimization of tool path. Jiang et al. [22] compared the performance of ant colony optimization and genetic algorithm for replugging tour planning of seedling transplanter. Srivatsava et al. [23] presented firefly algorithm (FA) for achieving optimal test sequence generation. Marinakis Y and Marinaki M [24] used bumble bees mating optimization (BBMO) algorithm for the open vehicle routing problem. Narooei et al. [25] used ACO algorithm for optimizing the tool path of case study involving multiple holes. Oscar et al. [26] presented a methodology to optimize the manufacturing time using ACO. Liu et al. [27] used ACO algorithm for process planning optimization of hole-making operations. Lim et al. [28] used a hybrid cuckoo search-genetic algorithm (CS-GA) for hole-making sequence optimization. Lim et al. [29] used Cuckoo Search (CS) algorithm for optimization of sequence in PCB Holes drilling process. Liu et al. [30] used ACO algorithm for process planning optimization. Ismail et al. [31] used firefly algorithm for path optimization in PCB holes drilling process.

Liyun et al. [32] presented process planning optimization by using an improved genetic simulated annealing algorithm. Nicholas C. Metropolis [33] developed simulated annealing which a stochastic search algorithm based on the concept called “annealing”.

It is understood from the literature discussed here that most of the researchers have worked in the area of minimization of non-productive tool travel time and tool switching time. Kolahan and Liang [1] has considered three elements of total processing costs, tooling & machining cost, non-productive tool travel cost and tool switching cost.It is also found in the literature related to this area that the non-traditional optimization methods such as tabu search, genetic algorithm, particle swarm optimization, ant colony algorithm, immune algorithm, cuckoo search, firefly algorithm, bumble bees mating optimization algorithm and biogeography based optimization (BBO) algorithm etc. has been used to solve the problem of optimization of hole-making operations.

Tabu search that uses only one solution can easily neglect some promising areas of the search space also they may not find optimal solution or exact solution. Most widely used advanced optimization technique is the genetic algorithm. Genetic algorithm gives near optimal solution for complex problems [34]. Also GA requires more parameters [35]. In ACO algorithm, convergence is slow due to pheromone evaporation and CPU time requirement is more [35]. Immune based evolutionary approach requires more parameters.

PSO algorithm was usually found to perform better than other algorithms in terms of success rate and solution quality ([35]. Problem solving success of the cuckoo search and differential evolution algorithms are relatively better than the PSO [36]. Basic cuckoo search algorithm may easily fall into local optimum solution [37].

Firefly algorithm (FA) has limitations like it gets trapped into several local optima. Also FA does not memorize or remember any history of better situation for each firefly [38]. Honey bees mating optimization algorithm may miss the optimum and provide a near optimum solution in a limited runtime period [39]. Biogeography-based optimization (BBO) is poor in exploiting the solutions. Also there is no provision for selecting the best members from each generation [40]. From the literature, it is also found that recently developed optimization algorithm known as particle swarm optimization could be attempted due to its simplicity, easy implementation and high convergence rate [41].Hence next section discusses about the particle swarm optimization algorithm.

3. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

Particle swarm optimization is an evolutionary computation technique developed by Kennedy and Eberhart(1995) [37]. The particle swarm thought was originated as a simulation of a simplified social system. This technique starts with initialization of population of random solutions called "particles".

This algorithm consists of two "best" values. First one is the "p_{best}" best fitness values of individual particles achieved so far. Second is the "g_{best}" which one is the best values among all the particles. Velocity and position of individual particles are obtained and updated using the following Eqs. (1)- (2) [37].

Each particle updates its velocity and position through the problem space by comparing its current position and velocity with the optimal solution. In PSO, velocity of particles is changed at every generation towards the "p_{best}" and "g_{best}".

$$V_{i+1} = w \times V_i + C_1 \times r_1 \times (p_{besti} - X_i) + C_2 \times r_2 \times (g_{besti} - X_i) \quad (1)$$

$$X_{i+1} = X_i + V_{i+1} \quad (2)$$

Where,

V_{i+1} = New velocity of each particle,

w = Inertia weight

V_i =Previous velocity of particle,

r_1 & r_2 =random numbers between 0 to 1

C_1 & C_2 =acceleration constants or Cognitive and social constants

X_i = Previous position of particle

Eq.(1)-(2) carried out until the convergence criteria is not satisfied.

Next section discuss about selected application examples of injection mould attempted using noo-tradtional optimization algorithms in order to minimize the total processing cost of hole-making operations.

4. APPLICATION EXAMPLE ATTEMPTED USING NON- TRADITIONAL OPTIMIZATION ALGORITHMS

Following section discusses about the various non-traditional optimization techniques used for optimization of hole-making of operations of industrial parts.

Kolahan and Liang [1] used tabu-search algorithm to determine the optimal sequence of operations and corresponding cutting speeds of the upper holder of plastic injection mould as shown in Figure 2. Overall processing cost consists of tooling & machining costs, non-productive tool travel cost and tool switch cost.Injection mould case study considered which involving total 56 machining operations.This mould consists of a total 32 holes namely GP1, GP2, GP3, GP4, GE1-GE4, PR1-PR4, C1-C4, C1"-C4", P1-P4, EB1-EB6, ES1-ES2. Hole-making operations such drilling, enlargement and reaming or tapping are used for mould as shown in figure 2. Figure 2 also shows data related to the distances between the holes, type of operations required, and the depth of each hole. Obtained results of tabu-search for sequence has a total processing cost of \$60.2 from which \$45.2 is the tool cost and machining cost, \$10.1 tool switch cost, and \$4.9 tool travel cost.

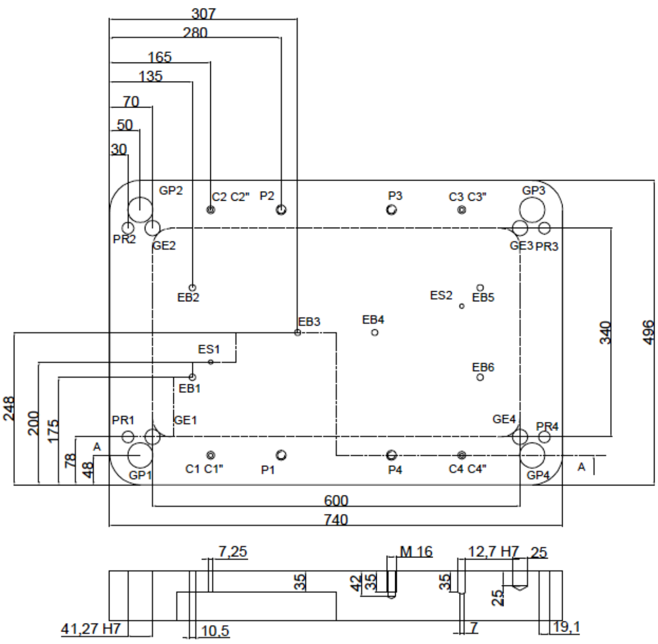

Figure 2. Upper holder of the plastic injection mould [1].

Ghaiebi and Solimanpur [11] used ant colony optimization technique for optimization of hole-making operations of industrial component. This paper deals with the optimization of hole-making operations in conditions where a hole may need several tools to get completed. The objective of interest in the considered problem is to minimize the summation of tool travel time and tool switch time.

The paper includes an illustrative example which shows the application of the proposed algorithm to optimizing the sequence of hole-making operations in a typical industrial part shown in figure 3. It consists of total 12 holes involving drilling, enlargement and reaming operations. Details of diameters and distance between holes are given figure 3.Numbering of hole in application examples is shown in figure 4. The computational experiments conducted in their research indicate that the proposed method is both effective and efficient. Next section summarizes the various non-traditional optimization algorithms which were already used for optimization of hole-making operations.

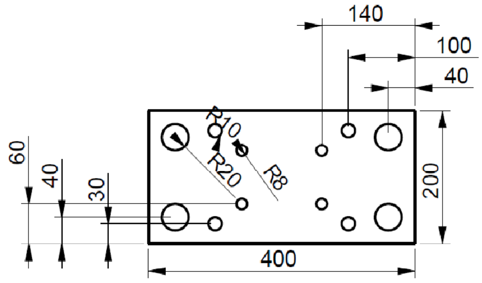

Figure 3. Top view of example part [11].

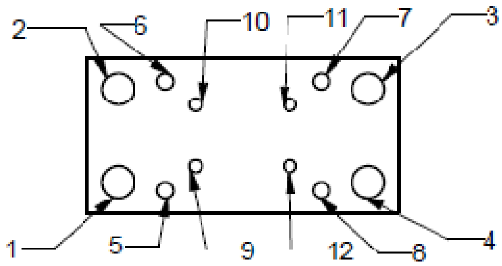

Figure 4. Hole numbering of example part [11].

5. NON-TRADITIONAL OPTIMIZATION METHOD USED BY VARIOUS AUTHORS FOR OPTIMIZATION OF HOLE-MAKING OPERATIONS

Table 1. Summary of non-traditional optimization which used for optimization of hole-making operations

Method → / Author ↓	TS	GA-SA	GA	PSO	ACO	BBO	IA	FA	BBMO	CS	CS-GA
Kolahan & Liang	Yes	---	---	---	---	---	---	---	---	---	---
Qudeiri and Hidehiko	----	---	Yes	---	---	---	---	---	---	---	---
Guo et al.	----	---	---	Yes	---	---	---	---	---	---	---
Shao et al.	----	---	Yes		---	---	---	---	---	---	---
Ghaiebi & Solimanpur	----	---	----	---	Yes	---	---	---	---	---	---
Hsieh et al.	----	---	----	---	---		Yes	---	---	---	---
Tamjidy et al.	----	---	----	---	---	Yes	---	---	---	---	---
Guo et al.	----	---		Yes	---	---	---	---	---	---	---
Kiani et al.	----	---	----	---	---	---	---	---	---	---	---
Srivatsava et al.	----	---	----	---	---	---	---	Yes	---	---	---
Marinakis &Marinaki	----	---	----	---	---	---	---	---	Yes	---	---
Narooei et al.	----	---	----	---	Yes	---	---	---	---	---	---
Oscar et al.	----	---	----	---	Yes	---	---	---	---	---	---
Lim et al.	----	---	----	---	---	---	---	---	---	Yes	---
Lim et al.	----	---	----	---	---	---	---	---	---		Yes
Liu et al.	----	---	----	---	Yes	---	---	---	---	---	---
Ismail et al.	----	---	----	---	---	---	---	Yes	---	---	---
Liyun et al.	---	Yes	----	---	---	---	---	---	---	---	---

6. CONCLUSION

Optimization of hole-making operations involves large number of hole-making operations sequences due to the location of hole and tool sequence constraint. To achieve this, proper determination operations sequence and associated cutting speeds which reduce the overall processing cost of hole-making operations are essential. Hence it is necessary to use non-traditional optimization techniques which are enough strong to handle these complex problems as well which gives optimal results. This paper reviews the various non-traditional optimization techniques such as tabu-search, simulated annealing, genetic algorithm, ant colony optimization algorithm, particle swarm optimization algorithm, immune algorithm, BBO algorithm, CS and hybrid CS etc..which are already implemented to solve optimization of hole-making operations problems. Advantages and limitations of these algorithms are discussed in the literature review. Results of optimizaton of hole-making operations, attempted by various researchers shows the potential of non-traditional optimization to handle large scale industrial problems of optimization of hole-making operations.

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Osvrt na optimizaciju operacija perforacije injekcionih modula upotrebom nekonvencionalnih algoritama

A.M. Dalavi, P. J. Pawar, T.P.Singh, A.S.Warke

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Apstrakt

Optimizacija operacija perforiranja ima ključnu ulogu pri određivanju i planiranju angažovanja pokretnih alata i alata prekidača u prvom planu. Industrijske aplikacije kao što su kalupi, alati, blok motori, itd., sastoje se od velikog broja perforiranih otvora koje karakterišu različiti prečnici, dubine i površine. Ovo rezultira pojavom deformacija kod velikog broja mašinskih operacija kao što je bušenje tokom procesa postizanja konačnog broja individualnih otvora. Takođe, dolazi do nastajanja velikog broja mogućih sekvenci za postizanje finalnih veličina pojedinih otvora. Ono što je od suštinskog značaja jeste činjenica da optimalan redosled operacija i brzina rezanja utiče na smanjenje ukupnih troškove obrade. U ovom radu razmatraju se različite tehnike ne-tradicionalne optimizacije koji su do sada implementirani u rešavanju problema optimizacije operacija perforiranja.

Ključne reči: *Operacije perforiranja, nekonvencionalne tehnike optimizacije algoritma*