Intelligent Sequencing of Working Steps Using Genetic Algorithm

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Abstract. There are many factors that need to be considered in the operation sequencing, and there are mutual relations among them, so it has become a hot topic worthy of study. In this paper, based on the parallel consideration of process constraint and minimum manufacturing cost, the concepts of working steps sequence matrix and process constraint matrix are proposed. The process constraint matrix is used to ensure that the working steps sequences conform to the precedence relation constraint, and the genetic algorithm is used to ensure the minimum manufacturing cost. Finally, the optimal solution of the working steps sequence is obtained. The connecting rod of marine diesel engine is taken as an example to verify.

1. Introduction
As a bridge between part design and manufacturing, process planning has been regarded as a research hotspot in the field of machining. First of all, for the more complex parts, there are many machining features and different machining methods corresponding to each feature, so the arrangement of processes has more flexibility. Secondly, the operation sequencing needs to meet all the precedence constraints and minimal manufacturing cost, which makes the operation sequencing becomes a problem has complex precedence relations.

More and more scholars use various algorithms to study the operation sequencing. Hu, Qiao, and Peng[1] proposed a novel modified ant colony optimization algorithm for the operation sequencing. Li et al.[2] presented an ant colony algorithm based cooperative optimization for machining scheme selection and operation sequencing of engine cylinder. A novel discrete particle swarm optimization (DPSO) approach is proposed to solve the operation sequencing problems in CAPP[3]. Dou, Li and Su[4] proposed a novel discrete particle swarm optimisation (DPSO) named feasible sequence oriented DPSO (FSDPSO) to solve the operation sequencing problems in CAPP. Nallakumarasamy et al.[5] used meta-heuristic simulated annealing technique (SAT) to generate the feasible sequences of operations based on the precedence cost matrix and reward-penalty matrix. Qiao, Hu and Zhang[6] conducted an algorithm to generate optimal machining sequence of the distributed holes in a machined part by using simulated annealing. Phung et al.[7] presented a method for optimizing operation sequence using modified clustering algorithm. Sundstrom et al.[8] showed how the sequence planner language (SPL) model can be converted into a constraint programming model for optimization. Fok, Thimm and Britton[9] presented the use of datum hierarchy trees, back propagation neural network and evolutionary algorithm in operation sequencing.

Among them, the most studied is the application of genetic algorithm in operation sequencing. Dou, Zhao and Su[10] developed an improved genetic algorithm (IGA) to minimize the total cost, which
includes feasible operation sequence (FOS) permutation coding method, fragment crossover and fragment mutation, as well as a new elitist-based crossover strategy. A new Feasible Operation Sequence Oriented Genetic Algorithm (FOSOGA) was developed to solve the operation sequencing problem. In the FOSOGA, the crossover with adaptive crossover probability and the mutation with adaptive mutation probability were designed[11]. Liu and Qiao[12] provided feature constraint matrix, the operation constraint matrix and an iterative genetic algorithm to simplify process constraint aggregations. Su et al.[13] presented a modified GA that use an edge selection based chromosome encoding approach to make sure all the precedence constraints are met in every step. Su et al.[14] offered an edge selection strategy based on GA to improve GA’s converging efficiency. An improved genetic algorithm to optimize worksteps sequence was proposed for mill/turn machining center[15]. However, these studies do not link and optimize the two requirements of the precedence constraints and minimal manufacturing cost in a unified way. At the same time, the genetic algorithm has the advantages of small correlation with the initial conditions, parallel search for global optimal solution and good operability. Therefore, this paper proposes a workingsteps sequence optimization algorithm with the workingsteps sequence matrix as the constraint means and the genetic algorithm as the optimization idea.

2. Intelligent sequencing based on genetic algorithm

Traditional process planning usually determines the sequence of processing operations first, then the machine and tools. Although such a process can ensure the requirements of process constraints, it is not easy to meet the requirements of minimal manufacturing cost. So this paper considers these two requirements in parallel. Using the matrix to restrict the clear precedence relation, using genetic algorithm to comprehensively consider the influence of tools, machines and fixtures, and finally determine the order. The complete flow chart of the method is shown in figure 1.

2.1. Objective function and gene coding

In order to meet the requirements of the minimal manufacturing cost, it is necessary to ensure the minimum replacement of process resources. Therefore, this paper aims to reduce the replacement of tools, machines and fixtures.

The change factor $\beta = \frac{\text{real}(\text{the number of steps corresponding to the unchanged process resources})}{\text{max}(\text{the number of steps corresponding to the unchanged process resources})}$ is given to quantitatively express the influence of each optimization objective. The denominator Max represents the maximum value of the number of working steps corresponding to the unchanged process resources, that is, the difference of the total number of working steps minus the number of corresponding process resources required for processing. The molecular Real represents the actual
value of the number of working steps corresponding to the unchanged process resources, that is, the difference of the total number of working steps minus actual replacement times of corresponding process resources.

The change factors of tool, machine and fixture are set as $\beta_1$, $\beta_2$, and $\beta_3$ respectively. For comprehensive consideration, the objective function given is the weighted sum of three change factors, i.e. the objective function $\eta = \omega_1 \times \beta_1 + \omega_2 \times \beta_2 + \omega_3 \times \beta_3$, and each weight can be determined by the importance between the two elements by Analytical Hierarchy Process (AHP).

The natural digital chain gene coding is used to represent the working steps sequence which has many factors and mutual influence. In order to meet the minimum manufacturing cost constraint, it is necessary to consider the replacement times of tool, machine and fixture at the same time. Therefore, these three factors are directly displayed in each gene of chromosome, that is, gene is composed of four parts: working step number, machine number, fixture number and tool number. The examples of gene coding for working steps are shown in Figure 2.

The examples of gene coding for working steps

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| Workingsteps | Features | Machines | Fixtures | Tools | Genes   |
|--------------|----------|----------|----------|-------|---------|
| Step1        | A1       | M01      | F01      | T01   | 01010101|
| Step2        | A1       | M01      | F01      | T01   | 02010101|
| Step3        | B1       | M01      | F01      | T01   | 03010101|
| Step4        | B1       | M01      | F01      | T01   | 04010101|
| Step5        | C1       | M02      | F02      | T02   | 05020202|
| Step6        | C1       | M02      | F02      | T03   | 06020203|
| Step7        | C1       | M03      | F03      | T04   | 07030304|
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Figure 2. The examples of gene coding for working steps.

2.2. Working steps sequence matrix and process constraint matrix

It is necessary to consider not only the influence of minimum manufacturing cost, but also the constraint of precedence relation and process experience between machining features to ensure manufacturability. The precedence constraints between features mainly include two aspects: process constraints and geometric constraints. Among them, process constraints mainly include benchmark constraint, location constraint, clamping constraint and non-destructive constraint. Geometric constraints mainly include the topological relation constraint and subordination relation constraint. Furthermore, the process experience constraints include: machining faces before machining holes, rough machining before finish machining and main features before secondary features.

The discrete constraints can't restrict the working steps sequence clearly and intuitively, so the concept of working steps sequence matrix is put forward. An N-order matrix is established to quantify the order relations among N working steps. The value of each element is determined by the order of the working steps corresponding to the numbers of row and column. For example, the element $M_{ij}$ represents the sequence relation between step $i$ and step $j$. When the working step $i$ precedes the working step $j$, $M_{ij} = 1$. When the working step $i$ is after the working step $j$, $M_{ij} = 0$. When there is no clear sequence relation between the two working steps, $M_{ij} = 2$. Since the main diagonal element only represents the working step itself, it is set as the machining feature identification to avoid self-contradictory.

Process constraint matrix can be regarded as a special working steps sequence matrix. It takes the constraint rules as the premise input, obtains the precedence relation table according to the constraints, and determines the values of corresponding elements according to precedence relation table and the concept of working steps sequence matrix. The process constraint matrix is used to determine the
initial population and to screen the chromosomes after mutation. The chromosomes in the population are transformed into the corresponding working steps sequence matrix according to the order between the working steps, and then the chromosomes can be determined whether they meet the precedence constraints by comparing the element values with the process constraint matrix.

2.3. Chromosome selection and crossing
A set of initial population which meets the constraint requirements can be obtained by comparing the process constraint matrix. By calculating the objective function and combining with roulette selection method, the preliminary selection of working steps sequences can be completed. The chromosomes are crossed and mutated to obtain the global optimization results. The mutation operation is realized by the direct exchange of two random working steps, and the mutation probability is smaller. Compared with mutation operation, crossover operation has higher probability and more flexibility. In order to avoid repeatedly using the process constraint matrix for testing, Subtour Exchange Crossover is used for reference. As shown in figure 3, select a group of genes in parent 1, and then find these genes in parent 2. Keep the unselected genes in parent 1 unchanged, and replace the selected genes in parent 1 according to the sequence of these genes in parent 2 to get the offspring.

![Figure 3. The example of chromosome crossing.](image)

3. Case study
The marine diesel engine connecting rod is taken as the research object to prove the operability of the method in this paper. According to the coding rules and specific machine, fixture and tool for working steps, the gene coding of all the machining features of the connecting rod is given, as shown in figure 4.

![Figure 4. Gene coding of working steps of connecting rod.](image)
Using the genetic algorithm, the working steps sequence with the minimum objective function can be found. Taking the connecting rod as an example, the optimal working steps sequence is shown in figure 5. Among them, the number of machine replacement is 4, the number of fixture replacement is 7, and the number of tool replacement is 15.

![Diagram of connecting rod with working steps](image)

**Figure 5.** Optimal working steps sequence of connecting rod.

### 4. Conclusions

There are many factors that need to be considered in the operation sequencing, and there are mutual relations among them, so it has become a hot topic worthy of study. In this paper, based on the parallel consideration of process constraint and minimum manufacturing cost, the method of process constraint matrix combined with genetic algorithm is adopted to obtain the optimal solution of working steps.
sequence. And the connecting rod of marine diesel engine is taken as an example to verify. The result of the process sequence is basically consistent with the process sequence compiled by the factory based on many year experience.

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