Research on Assembly Sequence Planning of Marine Diesel Engine Based on Improved Genetic Algorithm

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Abstract. That genetic algorithm is applied to the assembly sequence planning of marine diesel engine can improve assembly planning efficiency a lot. The genetic algorithm crossover operator of genetic algorithm is improved. By combining the clashes matrix and priority relationship matrix, the relational-clashes matrix is established. In order to get the assembly sequence which can assembly safely and effectively, but conform to the actual assembly habits as well, the fitness function combines the feasibility of assembly sequence, the rationality of assembly sequence and the number of redirection. The evaluation method based on the general principle of assembly sequence was proposed for the first time. Priority of parts is evaluated according to their barycentric coordinates and precision level. The evaluation method can enrich the evaluation method of assembly sequences and expand the application of intelligent algorithms in the field. After some tests and analysis of the experimental results, the algorithm proved to be convergent and the results are effective.

1. Introduction
Assembly sequence planning (ASP) is a process that technologists establish a reasonable assembly sequence based on the constraint relationship between product parts. In the manufacturing industry, the assembly of manufactured products accounts for more than 50% of the total production time and 30-50% of the labor costs, which makes the ASP problem as one of the basic problems in the assembly process[1].

ASP is an important process in marine diesel engine assembly process planning stage, and it determines marine diesel engine’s production organization plan and the distribution of production resources. A reasonable assembly sequence can improve not only marine diesel engine production efficiency and reliability, but also production process management level, and it has important significance for saving assembly cost and production time. Scholars have done extensive works on it since the 1980s, and they have come up with a series of sequence planning methods and evaluation methods. Recently, intelligent algorithms have been rapidly developed, including the particle swarm optimization (PSO) algorithm, imperialist competitive algorithm (ICA), genetic algorithm (GA), and ant colony optimization (ACO) algorithm. That those intelligent algorithms are widely applied to ASP has opened up new ideas for assembly sequence planning [2]. Compared with the traditional algorithm, the genetic algorithm (GA) has stronger robustness and adaptability, and it can avoid the combined explosion well [3]. Therefore, that GA is applied to the ASP has great research significance and practical value in improving assembly sequence planning efficiency. This paper presents an application of the improved genetic algorithm in ASP according to the assembly characteristics of marine diesel engines.
2. Coding Method of Assembly Sequence
In order to carry on the assembly planning efficiently, the product assembly sequence and related operation should be expressed properly [4]. The specific gene coding method of this paper is as follows:

- Assign a decimal number to each part.
- An assembly sequence is represented by an array sequence containing \( n \) numbers. The length \( n \) of the array represents the length of the gene, and the order of the numbers in the array expresses the sequence of assembly.
- Because each part can only be assembled once in assembly process, each number in the array are not allowed to repeat.

The structure of low-speed diesel engine cylinder block assembly is shown in Figure 1. Encode the main components, and the codes is as flows: 0—cylinder block, 1—chain box, 2—cylinder liner assembly, 3—cylinder head assembly, 4—cylinder head bolt, 5—main fuel pipe, 6—fuel supply pump, 7—camshaft, 8—high pressure pump and valve driving mechanism, 9—scavenging box, 10—air cooler box. It is assumed that an assembly sequence is as follows: cylinder block -> chain box -> cylinder liner assembly -> cylinder head assembly -> cylinder head bolt -> main fuel pipe -> fuel supply pump -> camshaft -> high pressure pump and valve driving mechanism -> scavenging box -> air cooler box, and the gene of the assembly sequence is [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10].

3. Genetic algorithm operators

3.1. Selection operator
The roulette selection method is chosen, it is a kind of replay random sampling method. The probability that each individual is selected is equal to the ratio of its fitness value to the individual fitness value of the whole population. In short, the probability that an individual is selected is directly proportional to its fitness function value.

3.2. Crossover operator
One-point Crossover method is used as gene crossover operator. According to the traditional One-point Crossover method, some elements will be repeated in the gene sequence. The improved
crossover operator can carry on the processing of duplicate removal for the next generation individual gene sequence.

3.3. Mutation operator
In ASP, each part can only be assembled once and cannot be repeated. The improved mutation operator of ASP exchange the positions of the two numbers randomly in gene. It can avoid element duplication in a gene sequence.

4. Objective functions and fitness function
For the assembly of complex mechanical products such as low-speed diesel engines, there may be many assembly sequences, and the selection of the best assembly solution should be considered in many aspects. According to the characteristics of low-speed diesel engines, it is necessary to select appropriate objective function and fitness function to evaluate and screen the assembly sequence. The paper proposes the evaluation method of assembly sequence based on three aspects, which are the feasibility of assembly sequence, the rationality of assembly sequence and the number of redirection.

4.1. Objective function based on the feasibility of assembly
The feasibility of assembly is the most basic requirement in ASP, and it requires that assembly interference does not occur during assembly and maintains good assembly stability. Assembly stability means that there is no relative movement or fall between the assembled parts when a part is assembled, in addition, the overall can maintain stability [5].

Assembly clashes matrix is used to describe the clashes between each part and other parts during assembly (or disassembly) in one direction. The priority relationship matrix is used to describe the constraint priority relationship between the parts in the assembly process. By combining the clashes matrix and priority relationship matrix, the relational-clashes matrix is established. The relational-clashes matrix is shown as formula (1). In this matrix, if the part j clashes with the part i regardless of disassembling along the direction of +X, +Y, +Z, or the part i must be installed after part j, the value of \( r_{ij} \) is 1, otherwise 0.

\[
\begin{pmatrix}
\gamma_{11} & \cdots & \gamma_{1n} \\
\vdots & \ddots & \vdots \\
\gamma_{n1} & \cdots & \gamma_{nn}
\end{pmatrix}
\]  

A random assembly sequence S whose array is represented as \([S_1, S_2, S_3, \ldots S_n]\), and the objective function based on relational-clashes matrix is shown as formula (2).

\[
F_i = \sum_{i=1}^{n} \sum_{j=i+1}^{n} r_{ij} S_i S_j
\]

4.2. Objective function based on the rationality of assembly
In ASP problem, the rationality is mainly reflected in the priority order of the parts. Many scholars choose parts quality or volume as an important evaluation criterion. In the assembly process, it is not consistent with the assembly situation that the parts with smaller weight or smaller volume are arranged at the end of the sequence. Especially in the manual assembly, it may lead to leakage of tiny parts due to the visual influence of other parts [6]. The effect of parts quality or volume on the assembly sequence is indeterminate, and it may be an element which disturb the results. In order to get the assembly sequence which conform to the actual assembly habits, the chapter proposes an evaluation method based on the general principle of assembly sequence, and the evaluation method is used as an objective function of the genetic algorithm to evaluate the individuality of the population.
In the assembly process, the general principles of assembly sequence are listed as follow: assembly from the bottom up, assembly from interior to exterior, assembly from left to right (assemble along length direction), assembly order by general parts after precision parts.

The barycentric coordinates of each part in the assembly model can be got easily by using the weight attribute of CAD system, and the positional relationship between each part can be determined by comparing their barycentric coordinates. The parts of low-speed diesel engine was divided into level1 parts, level2 parts and level3 parts according to their machining precision, assembly precision and function. The specific classification standards are shown in Table 1.

Table 1. The specific classification standards of parts.

| Part Level | Standard |
|------------|----------|
| Level1 parts | The parts have strict requirements of machining precision and assembly precision either can directly affect the diesel engine working performance, such as crankshaft sets, piston sets, cylinder liners, camshafts, cylinder head bolts, etc. |
| Level2 parts | The parts have high requirements of machining precision and assembly precision, and they are the main component of diesel engine, such as high pressure pump and valve driving mechanism sets, fuel supply pump, main fuel pipe, etc. |
| Level3 parts | The parts have general requirements of machining precision and assembly precision, either are attached to the external parts of the diesel engine, such as various types of door, air cooler box, scavenging air boxes, etc. |

The objective function based on the rationality of the assembly can screened out the individuals who are inconsistent with the general principle of the assembly sequence, and its process is shown in Figure 2.

A random assembly sequence S whose array is represented as $[S_1, S_2, S_3, \ldots, S_n]$, and the objective function based on the rationality of the assembly sequence is shown as formula (3) and formula (4). In the formula (3), a, b, c, d are weights, and they are set to 2, 2, 1, 8.

$$F_2 = a \sum_{i=1}^{n-1} P_i + b \sum_{i=1}^{n-1} Q_i + c \sum_{i=1}^{n-1} R_i + d \sum_{i=1}^{n-1} T_i$$  \hspace{1cm} (3)

$$P_i / Q_i / R_i / T_i = \begin{cases} 1, & \text{The D/Z/Y/G of the part } i \text{ is larger than D/Z/Y/G of part } i+1 \\ 0, & \text{Other cases} \end{cases}$$  \hspace{1cm} (4)
4.3. Objective function based on the number of redirection
In the assembly process, in order to reduce the redundant operation of the assembly process and improve the assembly efficiency, the number of redirection should be reduced as much as possible [7]. According to this principle, the objective function based on the number of redirects is established, and it is shown as formula (5) and formula (6).

\[
F_3 = \sum_{i=1}^{n} D_i \tag{5}
\]

\[
D_i = \begin{cases} 
1, & \text{The part } i \text{ is assembled in the same direction as the part } i+1 \\
0, & \text{The part } i \text{ is not assembled in the same direction as the part } i+1 
\end{cases} \tag{6}
\]

4.4. Objective functions and fitness function
The objective function combination with the feasibility of assembly sequence, the rationality of assembly sequence and the number of redirection is shown as formula (7). In the formula, \( w_1, w_2, w_3 \) are weights. After many tests, they are set to 2, 0.1, 0.1.

\[
F = w_1 \cdot F_1 + w_2 \cdot F_2 + w_3 \cdot F_3 \tag{7}
\]

The fitness function is established as formula (8):

\[
G = \frac{1}{F} \tag{8}
\]

5. Case Study
The ASP method based on genetic algorithm is verified by testing the low-speed diesel engine cylinder block assembly. The structure of cylinder block assembly is shown in Figure 1. Assembly information such as relational-clashes matrix, barycentric coordinates and assembly direction of each component can be got by secondary programming of CAD system. Part Level is got by adding Part Level label to CAD model in the design stage. The components information of cylinder block assembly is shown in Table 2, and the relational-clashes matrix of cylinder block assembly is shown in figure 3.

| Part node | Parts                         | X-axis coordinates | Y-axis coordinates | Z-axis coordinates | Part Level | Assembly direction |
|-----------|-------------------------------|-------------------|-------------------|-------------------|------------|-------------------|
| 0         | cylinder block                | -3470.31          | 4036.87           | -3478.64          | 0          | Z                 |
| 1         | chain box                     | -2327.24          | 6510.67           | -3260.20          | 2          | X                 |
| 2         | cylinder liner assembly       | -3549.84          | 3858.68           | -2558.88          | 1          | Z                 |
| 3         | cylinder head assembly        | -3554.47          | 3858.22           | -1270.98          | 1          | Z                 |
| 4         | cylinder head bolt            | -3549.08          | 3858.69           | -1983.45          | 1          | Z                 |
| 5         | main fuel pipe                | -2579.21          | 3039.47           | -3317.87          | 2          | Z                 |
| 6         | fuel supply pump              | -3317.13          | 1202.68           | -2442.81          | 2          | Z                 |
| 7         | camshaft                      | -2600.71          | 4431.23           | -3108.37          | 1          | Z                 |
| 8         | high pressure pump and valve driving mechanism | -2656.99 | 3065.23 | -2497.99 | 2          | Z                 |
| 9         | scavenging box                | -5044.50          | 3751.74           | -3143.75          | 3          | X                 |
| 10        | air cooler box                | -3787.52          | 7641.19           | -3995.58          | 3          | Y                 |
The ASP method based on improved genetic algorithm is programmed in Python. The assembly information and relational-clashes matrix are stored in txt format. In the program, the initial population size, gene crossover probability, gene mutation probability and number of iterations were set to 500, 0.7, 0.01, 100.

After four texts, the optimal solutions of the four calculations are 

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0
\end{bmatrix}
\]

Figure 3. The relational-clashes matrix of the cylinder block assembly.

The optimal solutions of the four calculations are 

\[0, 7, 4, 2, 3, 5, 8, 1, 6, 9, 10\], 
\[0, 7, 4, 2, 3, 5, 1, 6, 8, 9, 10\], 
\[0, 7, 4, 2, 5, 8, 9, 3, 1, 6, 10\], 
\[0, 7, 4, 2, 3, 1, 5, 8, 8, 9, 10\],

and their fitness values are 0.32258, 0.32258, 0.30303, 0.32258. The optimal solutions of the third calculation is inferior to other calculations. The results of the other three calculations are different, but their fitness values are the same. The image of the four calculations is shown in Figure 4.

Figure 4. The image of the four calculations.

In the four calculations, the optimal assembly sequence can be got before the 40th generation, and the fitness value of the optimal assembly sequence is 0.32258. The optimal sequence got by the four calculations has no assembly clashes, and their assembly stability is good. Their assembly direction changes less frequently. In theory, all they can be used as the assembly sequence. In actual assembly, cylinder head bolt, cylinder liner assembly and cylinder head assembly are installed successively, so the third assembly sequence does not conform to the actual assembly process.
6. Conclusion
In this paper, the GA crossover operator based on genetic algorithm is improved. The fitness function based on three aspects, which are the feasibility of the assembly, the rationality of the assembly and the number of redirection is established. The paper proposes the evaluation method based on the general principle of assembly sequence for the first time. The method can get assembly sequences that conform to the assembly habits, and it can enrich the evaluation method of assembly sequences and expand the application of intelligent algorithms in the field.

The tests proved that the algorithm is converged and the results are effective. With the method based on improved genetic algorithm, the efficiency and quality of the assembly sequence planning of the marine diesel engine are improved a lot. It not only avoid the situation that some parts need to reinstalled due to unreasonable assembly sequence but reduces the number of redirections in the assembly process as well.

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