**Optimization Process Knowledge-Based Genetic Optimization Algorithm for Excavator Stick**

Yang-mei ZHANG\(^1,^*\), Shuan-qiang YANG\(^1\), Hai-yan HUA\(^2\) and Zhen-hui SHEN\(^1\)

\(^1\)Engineering College, FuJian JiangXia University, Fuzhou 350108, P.R. China
\(^2\)School of Mechanical & Automotive Engineering, FuJian University of Technology, Fuzhou 350108, P.R. China

*Corresponding author

**Keywords:** Excavator stick, GA, Optimization process knowledge, Structural optimization.

**Abstract.** In view of the deficiencies existing in current knowledge-based global numerical optimization for excavator stick such as the insufficiency acquiring and utilizing optimization process knowledge to guide the global numerical optimization for stick, the easily falling in local optimal solution and so on, the optimization process knowledge-based genetic optimization algorithm for excavator stick is proposed. By establishing the selecting operator, crossover operator and mutation operator based on optimization process knowledge to realize the sufficiency in utilizing optimization process knowledge to guide the genetic intelligent optimization algorithm for stick. The structural optimization of ear-plate stick for medium hydraulic excavator is taken as example, which demonstrates that the genetic optimization algorithm based on optimization process knowledge for stick is feasible and efficacious.

**Introduction**

Lightweight and high strength are two important but contradictory targets for mechanical design [1], which is difficult to be coordinated for complex component. In recent years, the numerical optimization methods of structural intelligent optimization are mostly researched through the angle of the pure numerical optimization algorithm combined with analysis software [2,3], or the numerical optimization algorithm combined with fuzzy expert system [4], or the numerical optimization based on static knowledge [5,6]. However, using the existing method, the global numerical algorithm fails to sufficiently utilize optimization process knowledge and easily fall in local optimal solution in the process. For complex component, it is necessary to seek a more effective method to complete the structural intelligent optimization. Therefore, the optimization process knowledge based genetic algorithm for excavator stick is proposed in this paper.

**Intelligent Genetic Optimization Algorithm for Stick**

Aimed at improving the efficiency of global optimization of genetic algorithm, selecting operator, crossover operator and mutation operator based on optimization process knowledge and judgment operator of individual comprehensive state are established to construct optimization process knowledge based intelligent genetic optimization algorithm for stick. The main steps of the intelligent genetic optimization algorithm are shown in Fig.1 and illustrated as follows.

**Selection Operator Based on Optimization Process Knowledge**

To improve the efficiency of coordinating the lightweight and structural performance, a calculation formula of individual fitness value based on the weight distribution of weight and stress is established. Calculating the individual fitness value to realize the reasonable choice of the excellent individual. The optimization population can be divided into excellent feasible individuals, feasible
individuals, excellent invalid individuals and invalid individuals, according to the individual fitness value.

In order to preserve the diversity of individual as much as possible, the excellent feasible individuals can genetic to the next generation directly, the feasible individuals and invalid individuals can be used as parent matching cross individuals, the excellent invalid individuals can be used as parent mutants.

![Figure 1. Intelligent genetic optimization algorithm based on optimization process knowledge.](image)

**Judgment Operator of Individual Comprehensive State**

The judgment operator is used to identify the stress state of individual each stress characteristic sections and extract the target sensitivity knowledge of individual each real number coding genes, to determine the expected search direction and reasonable adjustment step of parent individual genes.

The stress state of stress characteristic section refers to the relationship between the maximum stress of stress characteristic section and the allowable stress of structural material under the multi-working conditions, and coding the stress state. The coding string composed of the stress state codes of each stress characteristic sections can effectively represent the individual stress state.

The individual real number coding genes both are the global optimization variables. According to the coding string of parent individual stress state can query the expected search direction and reasonable adjustment step of each global optimization variables, so as to obtain the opcode of each parent individual genes.

**Crossover Operator Based on Optimization Process Knowledge**

In order to maximize the probability that offspring is better than the parent, establishing the crossover operator based on optimization process knowledge. Using the crossover operator can fully extract the parent individual objective knowledge and constraint knowledge to determine whether crossover operator is required of each genes of the parent cross-matching individual, and to determine the expected search direction and reasonable adjustment step of each genes.

**Mutation Operator Based on Optimization Process Knowledge**

In order to give full of each individual characteristics, establish the mutation operator based on optimization process knowledge to perform the different genes of mutants in different ways. After processing the geometry classification mode, the geometry of each individuals are reasonable. During the mutation operator, if the genes of individual geometry variables were mutated in a large interval, then, the individual may no longer belong to the original geometry classification class, or even become malformation, and resulting in individual worse. Therefore, the genes of individual geometry variables and the genes of individual non-geometry variables should perform in different ways. According to the geometry constraint knowledge, the first-order coding of the parent mutants can be extracted to obtain the upper limit value and lower limit value of the mesh interval matrix corresponding to the genes of the parent geometry. Limiting the genes of the parent geometry should be changed in the corresponding mesh interval, to ensure the geometry of offspring still satisfy the geometry classification constraint.
Intelligent Genetic Optimization Strategy for Stick

The intelligent optimization design process for excavator stick can be divided into structural scheme design stage, structural optimized pre-processing stage, numerical optimization stage and structural optimized post-processing stage. The main steps of the intelligent optimization design process are shown in Fig.2 and illustrated as follows.

Figure 2. Genetic optimization of excavator stick based on optimization process knowledge.

Step 1: Set GA parameters on software interface. Main parameters include population number \(N_p\), iteration times \(T_{\text{max}}\), volume weight \(W_v\), i.e., which are shown in Fig.3.

Step 2: Read-in optimized pre-processing result. The data include structural parameters, global optimization variables, the pre-processing results of non-optimized variables, optimization objective model, constraint systems model, the pre-processing results of interval constraint of variables.

Step 3: The initial optimization population(IOP) is taken by the method of Latin Hypercube Sampling based on structural design code knowledge. The number of optimization population is \(N_p\). Set current iteration times \(T = 1\).

Step 4: The constraints include geometry classification model, stress constraint model, natural frequency constraint model. After the constraints processing, the constraint knowledge of the current optimization population can be extracted and stored in the base of optimization process knowledge.

Step 5: The objective value of the current optimization population are calculated, then, the objective knowledge is extracted and stored in the base of objective knowledge.

Step 6: Calculating the individual fitness value of the population based on knowledge.

Step 7: Each individual is coded with real Numbers.

Step 8: The selection operator is used to classify the current optimization population based on optimization process knowledge. The number of excellent individuals is \(N_e\) who can inherit directly to the next generation, the number of cross individuals is \(2N_e\), the number of mutant is \(N_m N_m\).
Step 9: The crossover operator is used to pair the cross individuals \((2N_c)\) to obtain the new offspring \((2N_c)\) based on optimization process knowledge.

Step 10: The mutation operator is used to mutate the mutant \((N_m)\) to obtain the new offspring \((N_m)\) based on optimization process knowledge.

Step 11: Generating new optimization population (NOP), setting \(T = T + 1\).

Step 12: Judging the end condition of optimization. If \(T \geq T_{\text{max}}\) or the optimization group has satisfied the convergence conditions, then turn to step 13. If \(T < T_{\text{max}}\) and the optimization group does not meet the convergence conditions, then turn to step 4 to enter the next generation.

Step 13: Structural optimized post-processing. The structural parameters of best-optimized stick plates need to be rounded to meet the structural processing requirements.

Step 14: Outputting optimization results, and storing the optimization case in the case storage.

The software module of intelligent genetic optimization of excavator stick is constructed to carry out structural optimization and shown in Fig. 3, which includes parameters setting modules and function controller module. In this module, the efficiency of modeling and analysis can be improved greatly by connecting VC++ with Pro/Engineering and ANSYS.

**Figure 3.** The software module of intelligent genetic optimization of excavator stick.

**Application**

**Known Conditions of Excavator Stick**

The structural optimization of ear-plate stick for medium hydraulic excavator is taken as an example, in which the structural performance under four working conditions[7] is explored in this paper.

The known conditions include the mechanism parameters showed in Table 1 and the driving parameters of hydraulic system showed in Fig. 3. The mechanism parameters are the distance between each reaming of stick, such as reaming E, reaming F, reaming N, reaming G and reaming Q.

| Mechanism | \(L_{EX}\) | \(L_{EN}\) | \(L_{FG}\) | \(L_{YN}\) | \(L_{FQ}\) | \(L_{GN}\) | \(L_{NQ}\) |
|-----------|----------|----------|----------|----------|----------|----------|----------|
| Values    | 945.78   | 3720     | 832.15   | 2410.42  | 2848     | 2254.43  | 450      |

**Optimization Objective of Excavator Stick**

The optimization objective of stick can be expressed as to minimize the total volume of each stick plate under the premise of giving full play to the performance of structural materials. The stress
distribution is characterized by the difference between the maximum stress value of stick and each maximum stress value of stick stress characteristic section under four working conditions. Therefore, the optimization objective model is shown in Eq. 1.

\[
\begin{align*}
\min f_0(X) &= V(X) \\
\min f_n(X) &= M_{\text{max}} - M_n(X) \quad (n = 1, 2, \ldots, N)
\end{align*}
\]  

(1)

In the equation, \( V(X) \) is the expression of the total volume of each stick plate, \( M_n(X) \) is the expression of the maximum stress value of stick stress characteristic section \( n \) under four working conditions, \( \{M_1(X), M_2(X), \ldots, M_n(X)\} \) is the expression of the maximum stress value of stick under four working conditions.

**Optimization Process Knowledge based Genetic Optimization of Excavator Stick**

Before the genetic optimization of stick, the structural scheme design of stick is required, it is determined that the structural scheme of the testing case is ear-plate separated stick according to the known conditions and structural design code knowledge. The structure diagram of the ear-plate separated stick is shown in Fig.4 and the stick structural parameters are obtained.

As Fig.2 and Fig.3 show, inputting the known parameters in the software interface, clicking the “Structural Scheme” controller to import the stick structural parameters showed in Table 3, then, clicking the “One-Click Optimized” controller to complete genetic optimization of excavator stick and obtain the best-optimized stick. Finally, clicking the “Case Storage” controller to store the testing case in the CS. After structural optimized post-processing, the structural parameters value of best-optimized stick were rounded, the stress nephogram of best-optimized stick under four working conditions are shown in Fig.5.
As Fig.5 show, the best-optimized stick name is “rstickbest27”, the maximum stress occurs in third mining condition whose value is 243.64 Mpa, the allowable stress is 246 Mpa, therefore, the strength constraint of stick is satisfied. The data of the best-optimized stick is shown in Table 2.

Table 2. The data of the best-optimized stick.

| Total Volume [mm$^3$] | Optimization Time [h] | Stress of Working Conditions [MPa] | Natural Frequency [Hz] |
|---------------------|----------------------|----------------------------------|------------------------|
|                     |                      | Maximum value | Minimum value | First | Second | Third |
| 5.814×10$^7$        | 1.29                 | 243.64         | 202.14        | 37.2  | 57.68   | 106.16 |

Comparative Analysis

The data of the best-optimized stick obtained from three different genetic optimization methods are compared to verify the effectiveness of the genetic optimization algorithm based on optimization process knowledge for excavator stick. The data is show in Table 3.

Table 3. The data of best-optimized stick obtained from different optimization method.

| Optimization Method | Total Volume [mm$^3$] | Optimization Time [h] | Stress of Working Conditions [MPa] | Natural Frequency [Hz] |
|---------------------|----------------------|----------------------|----------------------------------|------------------------|
|                     |                      |                      | Max value | Min value | First | Second | Third |
| Method 1            | 8.106×10$^7$        | 54.42                | 222.06     | 177.20     | 47.10 | 54.12   | 118.4 |
| Method 2            | 7.31×10$^7$         | 6.17                 | 239.05     | 188.39     | 38.77 | 55.15   | 107.7 |
| Method 3            | 5.814×10$^7$        | 1.29                 | 243.64     | 202.14     | 37.23 | 57.68   | 106.1 |

In Table 3, Method 1 is the pure numerical optimization, Method 2 is the numerical optimization based on static knowledge[6], Method 3 is the method proposed in this paper. Compared with Method 2, the total volume of Method 3 was decreased by 20.5%, the efficiency of Method 3 was increased by 79.1%. The stress value of these methods are all less than allowable stress, the first natural frequency of these methods are all more than 30Hz. Therefore, the genetic optimization algorithm based on optimization process knowledge for stick is advisable.

Summary

The genetic optimization algorithm based on optimization process knowledge is proposed in this paper. By verifying the proposed method in the example of excavator stick, the conclusions are extracted as follows:

(1) By establishing optimization process knowledge based selecting operator, crossover operator, mutation operator, the efficiency of genetic optimization algorithm can be improved obviously.

(2) By giving full of optimization process objective knowledge and optimization process constraint knowledge, the quality of optimization objective is better.
Acknowledgement

This research was financially supported by the Education Scientific Research Project for the Young Teacher of Fujian Province, China (Grant No. JAT170613), and the Scientific Research Foundation Project of Fujian University of Technology, China (Grant No. GY-Z14075).

References

[1] G.H. Shi, Y. Chen, Y.Z. Yang, et al. Journal of Mechanical Engineering, J. 48, 8 (2012) 110-114.
[2] D. Webb, W. Alobaidi, E. Sandgren. Modern Mechanical Engineering, J. 7, 3 (2017) 73-90.
[3] A.R. Aderiani, M. Shariatpanahi, A. Parvizi. Journal of Mechanical Science and Technology, J. 31, 3 (2017) 1283-1291.
[4] S.H.L. Mirhosseyni, P. Webb. Expert Systems with Applications, J. 36, 9 (2009) 11875-11887.
[5] A. Prakash, F.T.S. Chan, S.G. Deshmukh. Expert Systems with Applications, J. 38, 4 (2011) 3161-3171.
[6] T.M. Yang. Research on Key Technologies for Knowledge-Based Structural Optimization Design for Excavator Stick Considering Multiple Loading Conditions[D]. FuZhou University, China, 2012.
[7] Tianjin Mechanical Engineering Research Institute. GB9141-88, Standardization Administration of the People’s Republic, China, 1988.