Design of Gear Reducer Based on FOA Optimization Algorithm

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Abstract. In order to optimize the design of gear reducer, gear reducer optimal design to improve reliability and security, slow convergence and local optimum for FOA algorithm is proposed based on the improved type FOA gear reducer optimization design model. To avoid falling into local optimum Drosophila optimization algorithms, improved FOA algorithm by introducing a correction factor. Superior to the gear reducer seven variables optimization design model for the study, to ensure the safety and reliability of the premise, the FOA has the advantage of improved convergence speed and avoid local optimization problems, in order to verify the proposed method and reliability.

Keywords: Flying fruit optimization algorithm · Correction factor · Gear reducer · Optimization design · Fitness function

1 Introduction

Gear reducer as an important independent drive unit, to increase its life and minimize its weight and size hold significant meaning [1]. Standard gear reducer design has a flaw caused by non-optimized parameter input. This research proposed an optimized design scheme, which could realize rapid design procedure and improve gear reducer performance without compromise the security and reliability.

Classic Fruit Fly Optimization Algorithm [2] (FOA) has advantages of fast convergence process. However by introducing a modify factor β to FOA could optimize gear reducer design scheme.

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2 Fruit Fly Optimization Algorithm (FOA)

Fruit Fly Optimization Algorithm was inspired by fruit fly ranging behavior, it is a group intelligent algorithm. Its advantages include less control parameters and fast convergence, yet it easily become “pre-mature “and fall into local optimum. FOA algorithm is shown as follow:

Step 1: Set fruit fly group size “pop-size” and “iteration”, initialize group position “X_begin” and “Y_begin”;

Step 2: Formulas (1) and (2) realize single fruit fly optimized direction and distance;

$$x_i = X\_begin + Value \times rand() \tag{1}$$

$$y_i = Y\_begin + Value \times rand() \tag{2}$$

“Value” is search distance, “x_i” and “y_i” both indicate the individual fly positions of next moment.

Step 3: Formulas (3) and (4) are to calculate distance of individual fly position to its original start point (d_i), and concentration of individual fly scent(s_i);

$$d_i = \sqrt{x_i^2 + y_i^2} \tag{3}$$

$$s_i = \frac{1}{d_i} \tag{4}$$

Step 4: Formula (5) is a determining function for scent concentration. It shows individual fly scent concentration value on the current position;

$$Smell_i = Function(s_i) \tag{5}$$

Step 5: Find best scent concentration value and position in the fly group. The “$Smell_b$” is the best scent concentration value, “x_b” and “y_b” are the best positions;

Step 6: Track single fly’s best position and scent concentration value while fly group search for best position. “$Smellbest = Smell_b$” indicates best scent concentration value; “$X\_begin = x_{\mathrm{b}}$” and “$Y\_begin = y_{\mathrm{b}}$” are fly original position;

Step 7: Iterative optimization, repeat iterative processes of step 2 to step 5 and if current scent concentration is better than previous value, move to step 6.

3 Improved Fly Optimization Algorithm (IFOA)

Based on the distance of FOA (d_i) and scent concentration value (s_i), “d_i” are randomly distributed in large area. The concentration value “s_i” becomes less after Formula (5). At this point “s_i” is used as determine function and it causes problems of partially optimization and pre-mature [3, 4].

In order to avoid such problems, a modified factor "β" is introduced to improve FOA. The improved formula (Improved Fruit Fly Optimization Algorithm,IFOA) as shown below:

$$d_i = \sqrt{x_i^2 + y_i^2} \tag{6}$$

$$s_{M\mathrm{i}} = \frac{1}{d_i} + \beta \tag{7}$$

In Formula 7, "$s_{M\mathrm{i}}$" is scent criterion function of IFOA.

$$\beta = \begin{cases} g \times d_i \\ K \times X\_axis \ or \ K \times Y\_axis \end{cases} \tag{8}$$

In Formula 8, "g" is evenly distributed and "K" is a constant value.

4 Optimized Gear Reducer Design Model

4.1 Design Variable

Research aim: designing two-level gear transmission reducer; the internal mechanics are shown below.

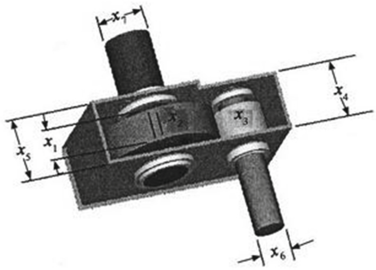

Fig. 1. Reducer internal structure

This optimized design has 7 variables [8, 9]: width x_1, module x_2, pinion teeth number x_3, bearing distance of axle 1 x_4, bearing distance of axle 2 x_5, axle 1 diameter x_6 and axle 2 diameter x_7. The values of variable take from the range below:

$$\begin{aligned} &2.6 \le x_1 \le 3.6,\ 0.7 \le x_2 \le 0.8,\ 17 \le x_3 \le 28,\ 7.3 \le x_4 \le 8.3, \\ &7.3 \le x_5 \le 8.3,\ 2.9 \le x_6 \le 3.9,\ 5.0 \le x_7 \le 5.5 \end{aligned} \tag{9}$$

Target function aims to minimize the reducer size [10, 11]:

$$\begin{aligned} \min f1(x) = 0.7854x_1x_2^2(3.3333x_3^2 + 14.933x_3 - 43.0934) \\ - 1.508x_1(x_6^2 + x_7^2) + 7.477(x_6^3 + x_7^3) \\ + 0.7854(x_4x_6^2 + x_5x_7^2) \end{aligned} \tag{10}$$

Assume:

$$A_1 = [(745x_2^{-1}x_3^{-1}x_4)^2 + 16.9 \times 10^6]^{0.5} \tag{11}$$

$$B_1 = 0.1x_6^3 \tag{12}$$

$$A_2 = [(745x_2^{-1}x_3^{-1}x_5)^2 + 157.5 \times 10^6]^{0.5} \tag{13}$$

$$B_2 = 0.1x_7^3 \tag{14}$$

In above function, A1 indicates center torsion; B1 indicates coefficients of working condition; A2 indicates coefficients of loads; B2 indicates allowed pressure of contact fatigue.

4.2 Constraints

There are 11 Constraints in this mathematical model [12–14]: size, bending stress, contact stress and axles transverse deviation etc.:

$$g_1(x) = 27x_1^{-1}x_2^{-2}x_3^{-1} - 1 \leq 0 \tag{15}$$

$$g_2(x) = 397.5x_1^{-1}x_2^{-2}x_3^{-2} - 1 \leq 0 \tag{16}$$

$$g_3(x) = 1.93x_2^{-1}x_3^{-1}x_4^3x_6^{-4} - 1 \leq 0 \tag{17}$$

$$g_4(x) = 1.93x_2^{-1}x_3^{-1}x_5^3x_7^{-4} - 1 \leq 0 \tag{18}$$

$$g_5(x) = x_2x_3 - 40 \leq 0 \tag{19}$$

$$g_6(x) = 5 - x_1x_2^{-1} \leq 0 \tag{20}$$

$$g_7(x) = x_1x_2^{-1} - 12 \leq 0 \tag{21}$$

$$g_8(x) = 1.9 - x_4 + 1.5x_6 \leq 0 \tag{22}$$

$$g_9(x) = 1.9 - x_5 + 1.5x_7 \leq 0 \tag{23}$$

$$g_{10}(x) = A_1 B_1^{-1} - 1800 \leq 0 \quad (24)$$

$$g_{11}(x) = A_2 B_2^{-1} - 1800 \leq 0 \quad (25)$$

In above function, g_1 indicates bending stress constraint; g_2 indicates contact stress constraint; $g_3 - g_9$ indicates axles transverse deviation constraint and empirical constraint; $g_{10} - g_{11}$ indicates size constraint.

4.3 Mathematical Model

As mentioned above, the goal of two-level gear transmission reducer design is to minimize its size. The new mathematical model can be illustrated as follow:

$$\min f(x) x = [x_1 x_2 x_3 x_4 x_5 x_6 x_7]^T \in R^7 \quad (26)$$

$$S.t.\, g_j(x) \leq 0\, (j = 1, 2, \cdots, 11) \quad (27)$$

4.4 Optimized Reducer Design with IFOA

The optimized reducer design process is nonlinear with multiple constraints. The new design process base on IFOA is shown as below:

Step 1: A random population with a maximum iteration is initialized based on the upper and lower limit of design variables;
Step2: Calculate single fly's best search direction and distance;
Step3: Base on the Formula (10), calculate the value of fitness function for single fly;
Step4: Base on the Formula (5), calculate fly's current position and scent concentration value;
Step5: Find the best scent concentration value and positions. The best scent concentration value is indicated as $Smell_b$, the best positions are indicated as x_b and y_b;
Step6: Keep records of fly's best position and scent concentration value. The best scent concentration value is indicated as $Smellbest = Smell_b$, fly's initial positions are indicated as $X\_begin = x_b$ and $Y\_begin = y_b$;
Step7: Use iterative optimization method repeat step 2 to step 5, and decide if the concentration value is better than previous value, suppose the concentration value is better, move to step 6.

5 Simulations

In order to prove practical value of the proposed model, the IFOA parameters are set: the iteration is set to 100 and the group size is 30. The simulation results are shown as graphs below:

Figures 2 and 3 indicate optimized reducer design converge process and fruit fly's optimized path respectively. The former one expressed as relationship between numbers of iterations and changes in target function, in simple term it is a relationship between numbers of iteration and changes in reducer volume. The latter expresses fruit fly's search process for optimized path in two-dimensional space.

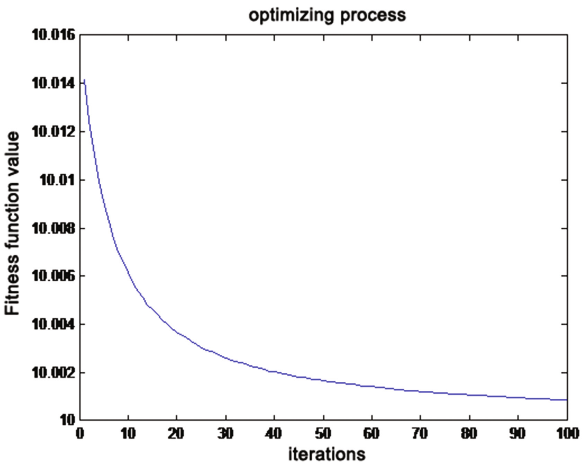

Fig. 2. Fitness function converge process

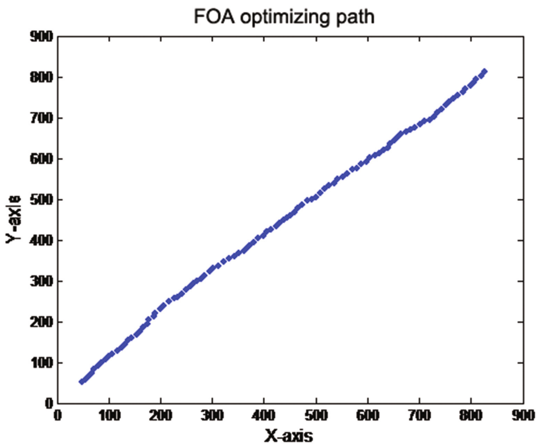

Fig. 3. FOA optimizing path

In order to prove higher reliability and usability of proposed algorithm, the basic FOA algorithm is used for comparison. The result of comparison is shown in Fig. 4. The simulation result in Fig. 4 shows that by introducing modify factor β can avoid local optimum, and improved FOA converges faster compare to traditional FOA.

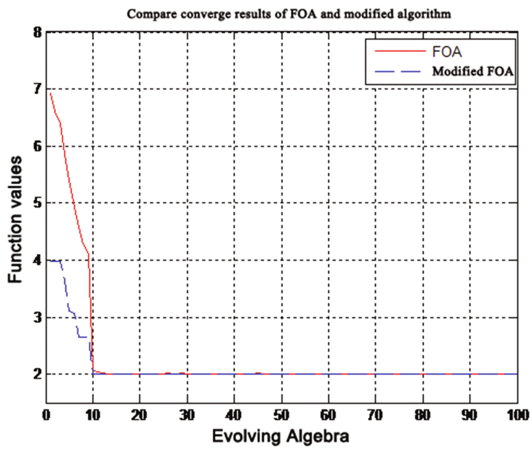

Fig. 4. Compare converge results of FOA and modified algorithm

6 Conclusions

This paper aims to improve gear life and reliability with minimum design cost. Since traditional FOA has slow converge speed and partial optimization problems, this paper proposed a modified gear reducer design algorithm model. This algorithm has 7 variables to ensure its performance and reliability.

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References

1. He, B., Lxian, C., Csheng, L.: Optimized design of gear transmission based on the shuffled frog leaping algorithm. J. Mech. Transm. **7**, 11–15 (2013)
2. Pan, W.T.: A new fruit fly optimization algorithm: taking the financial distress model as an example. Knowl.-Based Syst. **26**, 69–74 (2012)
3. Lxian, C., Zhong, C.: Hybrid discrete differential evolution with a self-adaptive penalty function for constrained engineering optimization. J. Mech. Eng. **3**, 21–25 (2011)
4. Wang, Q., Zhang, W.P., Shi, L.: Improved genetic algorithms' application in reducer optimization design. Mech. Res. Appl. **2**, 18–24 (2009)
5. Hyun, L., Fkai, K.: Planetary gear optimization based on improved genetic algorithm. Appl. Sci. Technol. **12**, 7–12 (2009)
6. Wu, T., Zhang, L.B., Huang, L.: Gear reducer optimal design based on genetic algorithm. Coal Mine Mach. **12**, 17–22 (2009)
7. Hxia, D.: Optimal design of bevel gear reducer based on genetic algorithm. Mod. Manuf. Technol. Equip. **4**, 35–41 (2010)
8. Luo, X.H., Zhang, R.H., Cao, K., Shi, Y.S.: An improved genetic algorithm and its application in optimization design of the gear transmissions. Mach. Des. Res. **2**, 17–20 (2006)

9. Jwei, W., Jming, Z., Xpeng, W.: Multi-objective optimization design of gear reducer based on simulated annealing algorithms. Trans. Chin. Soc. Agric. Mach. **10**, 5–11 (2006)
10. Li, X.Y., Wang, C.X., Guo, Z.Q., Yi, N.: An improved genetic algorithm and its application in engineering optimization. J. Inner Mongolia Univ. Sci. Technol. **3**, 9–12 (2007)
11. Jjun, Y., Hong, Z., Xguo, C.: Optimized design of gear based on hybrid genetic algorithm. Hoisting Conveying Mach. **9**, 12–16 (2008)
12. Gao, Y.G., Wang, G.B., Ding, Y.Z.: Optimized design of helical gear reducer based on genetic algorithm. Hoisting Conveying Mach. **8**, 33–37 (2003)
13. Che, L.X.: Study on differential evolution algorithms orientating analysis and design of mechanisms. J. Chin. Univ. Min. Technol. (2013)
14. Shi, X.: Optimal design of gear based on improved genetic algorithm and its three-dimensional papametric modeing technology. Qingdao University of Technology (2013)