

Optimization of power shift tractor clutch based on ahp and improved genetic algorithm

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Abstract. For the clutch optimization of multi-objective, multi-parameter and multi-constraint features, an optimization method of power shift tractor clutch based on analytic hierarchy process (AHP) and improved genetic algorithm is put forward. Based on AHP, the part objective function weighting coefficients in the multi-objective function are allocated reasonably; For the defect of traditional genetic algorithm, an improved genetic algorithm is proposed, in which the combination coefficient between the parameters and the reproduction elimination of population individual are introduced; As Dongfanghong-LA3004 tractor power shift clutch for the optimization example, based on the traditional genetic algorithm and the proposed improved genetic algorithm respectively, the clutch parameters are optimized. The contrast analysis of two kinds of optimization results show that the proposed improved genetic algorithm can get the global optimal solution, at the same time, compared with the original plan, the optimization efficiency are improved, and the optimized results verify the rationality and validity of the proposed optimization method.

Key words. Power shift tractor, clutch, AHP, improved genetic algorithm.

1. Introduction

In the process of the tractor starting, shifting and parking, the clutch plays a key role, and the optimization design of the clutch can reduce the production cost, prolong the service life of the clutch and improve the tractor's performance [1-2]. Mostly, the penalty function method, the complex method, the random search method and

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so on are used in the traditional clutch optimization design [3-6], and their optimization efficiency are low and optimization results are not accurate enough. Based on analytic hierarchy process (AHP) and the improved genetic algorithm, a clutch optimization method is put forward in this paper.

Genetic algorithm is a kind of one-dimensional random global search and global optimization modern intelligent algorithm referenced the biological natural selection and genetic mechanism, which was first put forward by the American J.Holland professor in 1975 [9]. Traditional genetic algorithm ignores the parameters combination relationship in the optimization process, and population evolution is slow, optimization efficiency is low, what is more, in the case of selecting wrong fitness function, it is likely to converge to local optimum, and cannot achieve the global optimum. For the defects of traditional genetic algorithm, an improved genetic algorithm is proposed, in which the combination coefficient between parameters and the reproduction elimination of population individual are introduced, and the global optimal solution is obtained, at the same time, the evolution efficiency is improved.

2. Clutch optimization example

2.1. Model of tractor power shift clutch design variable selection

Dongfanghong-LA3004 tractor power shift transmission sketch is shown in Fig. 1, in which A, B, C and D are four power shift clutches, and four different gears change are realized by the separate or joint combination of the four power shift clutches.

The friction plate number, the inner diameter and outer diameter of the power shift clutch B are asked to optimize and design under the condition that meeting the requirements of space layout, transmission torque, heat load and hydraulic system, the known parameters are shown in Table 1.

Table 1. The known parameters

Parameters	Symbol	Unit	Value
Engine rated speed	n_e	rmin	2100
Engine rated power	P_e	kW	192
Hydraulic system pressure	p	MPa	3.004

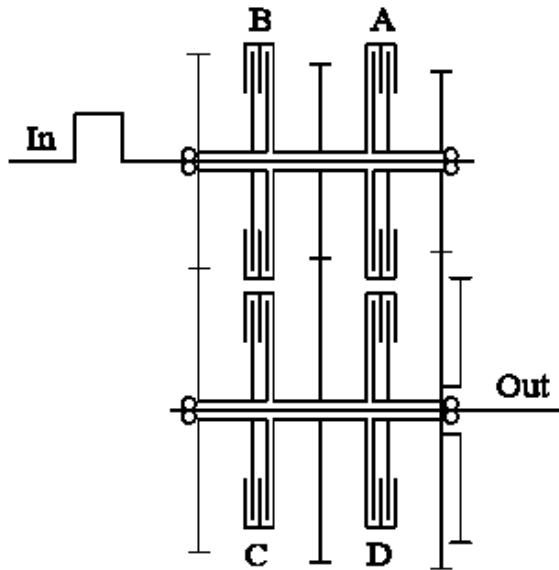


Fig. 1. Power shift transmission sketch

2.2. Design variable

The clutch transmission torque T_c can be expressed as [11]:

$$T_c = \frac{1}{3} \mu z F K \frac{D^3 - d^3}{D^2 - d^2} \quad (1)$$

where, μ is the dynamic friction factor; z is the friction plate number; F is the total pressure on the friction surface; K is pressure loss coefficient; D is the friction plate outer diameter; d is the friction plate inner diameter.

According to the parameters of influencing clutch performance in the formula (1), z , D and d are taken as the design variables. The design variables are shown as follows:

$$X = (z, D, d) = (x_1, x_2, x_3) \quad (2)$$

2.3 Objective function

The volume of the clutch is taken as the objective function f_1 :

$$f_1 = v = \frac{\pi}{4} D^2 \times [z \times (h + S)] \quad (3)$$

where, v is the lumen volume of clutch; h is the thickness of friction plate; S is the spacing of friction plate.

The average temperature of the friction plate is taken as the objective function

f_2 :

$$f_2 = \frac{Q}{2\pi cm(\frac{D^2}{4} - \frac{d^2}{4})(z - 1)} \quad (4)$$

where, Q is the generated heat of clutch combined with time; c is the specific heat of friction materials; m is the clutch parts quality absorbing frictional heat.

Q can be approximated as commonly:

$$Q = \int_0^t T_c(\omega_e - \omega_c)dt \quad (5)$$

where, ω_e is the engine angular velocity; ω_c is the angular velocity of clutch driven part; t is the required time that clutch is engaged at a time.

The volume of friction plate is taken as the objective function f_3 :

$$f_3 = \frac{\pi}{4}(D^2 - d^2) \times z \times h \quad (6)$$

The general objective function is given below:

$$\min f(X) = \min[\omega_1 f_1 + \omega_2 f_2 + \omega_3 f_3] \quad (7)$$

where, ω_1 , ω_2 and ω_3 are the weight coefficients of the part objective function f_1 , f_2 and f_3 .

2.3. Constraint condition

For the tractor shifting clutch, reserve coefficient β is recommended to select between 1.5 and 2.5 [12]:

$$\beta = \frac{T_c}{T} = \frac{\frac{1}{3}\mu s p z \frac{D^3 - d^3}{D^2 - d^2}}{T} \quad (8)$$

where, s is the friction plate's contact area.

The average peripheral v_a speed and maximum peripheral speed v_{max} of the friction plate should be less than the permit value.

$$v_a = \frac{D + d}{4} \Delta\omega \leq [v_a] \quad (9)$$

$$v_{max} = \frac{\pi}{60} n_{e\max} D \times 10^{-3} \leq 65 \sim 70 m/s \quad (10)$$

where, ω is the relative speed between the driving disc and the driven disc of clutch; $n_{e\max}$ is the maximum speed of engine.

Limited by the space structure, D is taken as [100mm, 300mm].

To avoid friction piece distortion that caused by the nonuniform radial force in friction piece [13], the ratio of the inner and outer diameter of tractor shifting clutch, namely, diameter ratio is 0.6~0.8 [14].

As the evaluation index of the clutch wear resistances, slipping friction work per unit area Q_0 should be less than the permit value .

$$Q_0 = \frac{Q}{2\pi\left(\frac{D^2}{4} - \frac{d^2}{4}\right)(z-1)} \leq [Q_0] \quad (11)$$

where $[Q_0]$ is the possible value of Q_0 .

In order to ensure the tractor starting quality, shifting quality and working efficiency, the clutch engagement time should be controlled in a certain range [16].

$$t \leq [t]_{\max} \quad (12)$$

where, $[t]_{\max}$ is the given limit of clutch engagement time.

3. AHP

The distribution of the weight coefficient is an important issue in multi-objective function optimization, the reasonable allocation can prolong the service life of the clutch and reduce processing costs, AHP is adopted to distribute the weight coefficient of the sub-objective function in this paper.

3.1. Hierarchical structure model

Hierarchical structure is divided into target layer, criterion layer and solution layer. For the clutch optimization model in this paper, the target decision layer A is the choice of objective function, namely, determining the weight of each sub-objective function; the criterion layer is respectively the sub-objective function value domain B_1 , the sensitive degree B_2 that objective function to outer diameter D and the sensitive degree B_3 that objective function to inner diameter d , the sensitive degree that objective function to inner and outer diameter are expressed in function as $\frac{\partial f_i}{\partial d}$ and $\frac{\partial f_i}{\partial D}$; the solution layer are each sub-objective function f_1, f_2 and f_3 . The hierarchical structure model is built as shown in Fig. 2.

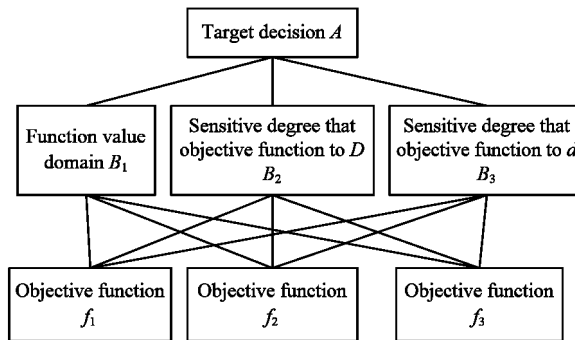


Fig. 2. Hierarchical structure model

3.2. Judgment matrix

Judgment matrix is constructed according to the experience that reference numbers 1 to 9 and their inverse as scale. The size of the general objective function is directly represented by the sub-objective function value range B_1 , which greatly influence on the choice of target decision; due to the sub-objective function values are normalized processing, the each objective function has the same effect on the objective function value domain; due to the D value is bigger, and each objective function is the function regarding D , the change of D can more cause the change of the objective function values, so the sensitive degree that objective function to D is bigger. The constructed total judgment matrix is as shown in Table 2, and the sub-judgment matrix, respectively, are shown in Table 3 ~ Table 5.

Table 2. Total judgment matrix

A	B_1	B_2	B_3
B_1	1	4	2
B_2	1/4	1	1/3
B_3	1/4	3	1

Table 3. Part judgment matrix

B_1	f_1	f_2	f_3
f_1	1	1	1
f_2	1	1	1
f_3	1	1	1

Table 4. Part judgment matrix

B_2	f_1	f_2	f_3
f_1	1	9	9
f_2	1/9	1	2
f_3	1/9	1/2	1

3.3. Hierarchy total row and single row consistency check

Because the judgment matrix is vaguely constructed based on the experience and cognition, so as to avoid that subjective factors may cause misjudgment, it is need to do the consistency check when sort the total layer and single layer. The consistency check results are represented by the consistency ratio CR, consistency

check standard is CR is less than 0.1, CR expression is:

$$CR = CI/RI \quad (13)$$

where, CI is the consistency index; RI is the average consistency index, which varies with different order n of the judgment matrix, and when $n = 3$, $RI = 0.58$; $CI = \frac{\lambda_{max} - n}{n - 1}$, λ_{max} is the maximum characteristic root of the judgment matrix.

As shown in the Table 6, all CR are less than 0.1, which satisfy the requirement of consistency check. After the normalization processing, the weight vector is presented as follows:

$$X = (\omega_1, \omega_2, \omega_3) = (0.3395, 0.3239, 0.3366) \quad (14)$$

Table 6. Consistency check results

	A	B_1	B_2	B_3
max	3.0183	3	3.0735	3.0536
RI	0.58	0.58	0.58	0.58
CI	0.0091	0	0.0367	0.0268
CR	0.0158	0	0.0634	0.0462

4. Improved genetic algorithm

4.1. Combination coefficient

When parameters are optimized based on genetic algorithm, if the corresponding fitness value is bigger while the values of two parameters are combined together, the set of values is defined as the optimal set of values, and the combination coefficient of which is larger. During the process of heredity and variation, the individuals tend to the individual or group evolution whose fitness coefficient and combination coefficient are larger. The combination coefficient is related to the fitness value, and it is defined as follows:

$$c = 2 \times \frac{p_i(k) - p_i(k)_{\min}}{p(k)_{\max} - p(k)_{\min}} - 1 \quad (15)$$

where, c is the combination coefficient; $p_i(k)$ is the fitness value of the k th generation and i th combination; $p_i(k)_{\min}$ is the minimum fitness value of the k th generation group; $p(k)_{\max}$ is the largest fitness value of the k th generation group.

As shown in formula (16), c is in the range of $[1, 1]$. Because the fitness value is the general objective function inverse normalization. When $c=-1$, it indicates that the fitness value is the worst while two parameters are taken this combination. During the process which the next generation is produced, the probability that the individual produce the combination again is almost zero; if $c=0$, it indicates that the values of two parameters are without interference, when one parameter is taken

this combination corresponding value, the other parameter is random taken another value; if $c=1$, it indicates that the influence between the two parameter values is large, and the probability that this combination appeared in the next generation is large.

Chromosome combinations are shown as Fig. 3, the genes on the chromosomes represent binary code of three parameters, the part represents the value of the parameter D , the part represents the value of the parameter d , the part represents the value of the parameter z , and the chromosome combinations are expressed as the vector form as:

$$A = [a_1 \ a_2 \ a_3 \ a_4 \ b_1 \ b_2 \ b_3 \ b_4 \ c_1 \ c_2] \tag{16}$$

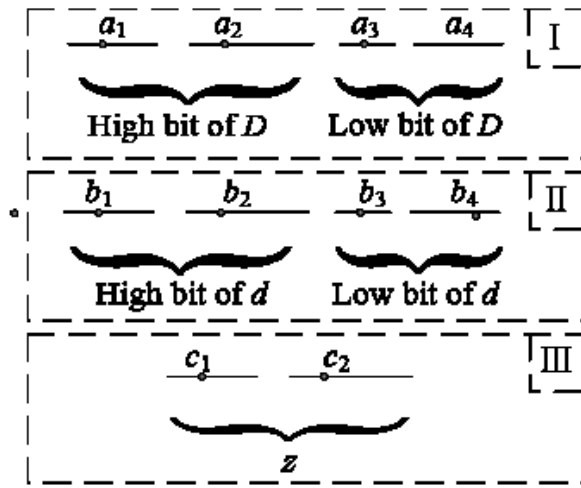


Fig. 3. Chromosome combinations pattern

During the process that the next generation individual is produced, parameter D is given priority to value, and D value in a group does not necessarily correspond to one of these combinations. So the combination of the most close to the value within the allowed range is taken as the corresponding combination. As the impact on the size of parameter selection is the high bit digital, it is suggested that the high bit binary code of the parameter d is greatly influenced by the combination coefficient, and the low bit is not affected, so b_1 and b_2 are valued as follows:

$$b_1 = \frac{1}{2} (1 + c) b_{01} \tag{17}$$

$$b_2 = \frac{1}{2} (1 + c) b_{02} \tag{18}$$

4.2. Algorithm flow

The specific flow of traditional genetic algorithm and improved genetic algorithm are respectively shown in Fig. 4 and Fig. 5. In the figures, parameter 1 is D ;

parameter 2 is d ; parameter 3 is z ; k is genetic algebra; p_c is the crossover probability; p_m is the mutation probability.

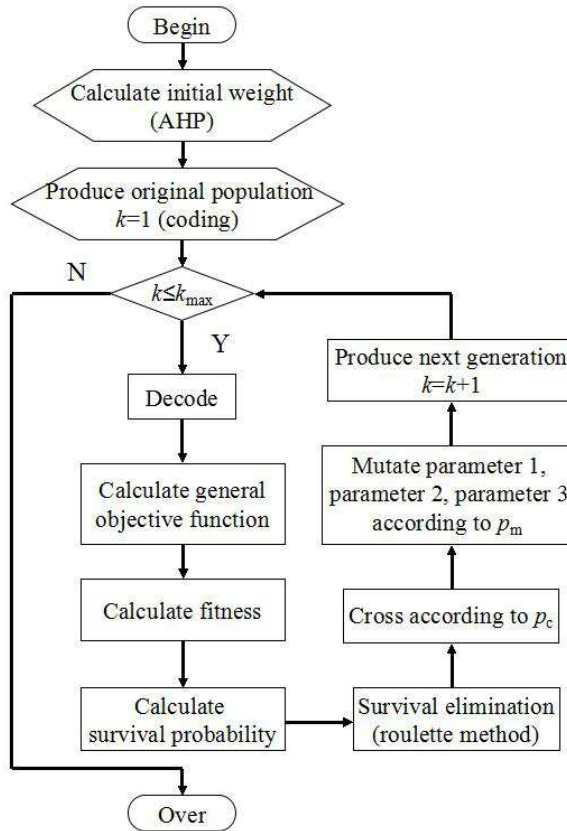


Fig. 4. Traditional genetic algorithm flow chart

Comparison of Fig. 4, it can be seen that the improved genetic algorithm is introduced the combination coefficient and reproduction elimination. Reproduction elimination is set after the survival elimination, and before the crossover, duplication and mutation, which is similar to the survival elimination, using the principle of roulette selection to eliminate individuals, the individuals after selection can produce the next generation. Two elimination processes are set in the improved genetic algorithm, which is better to simulate the natural biology evolution process, and improve the evolution efficiency.

5. Results and analysis

According to Fig. 4, k is set as 200; p_c is set as 0.1; p_m is set as 0.05. Based on MATLAB software programming, after the optimization, the relationship of friction plate outer diameter D , inner diameter d and general objective function along with

the change of genetic algebra are shown in Fig. 5 and Fig. 6.

Results and analyses are as follows:

(1) Fig. 5 and Fig.6 are respectively changes in the relationship between D , d or general objective function value of the optimal solution in each generation population and genetic algebra under the improved genetic algorithm and traditional genetic algorithm optimization. And the figures show that the results under two kinds of genetic algorithm optimization are consistent, which indicates that the improved genetic algorithm optimization above mentioned is correct.

(2) As is shown in Fig. 6, based on the improved genetic algorithm, the optimization parameters converge to the optimal solution when the genetic algebra is about 40th generation, but based on the traditional genetic algorithm, it is about 110th generation, which indicates that the improved genetic algorithm has higher evolution efficiency.

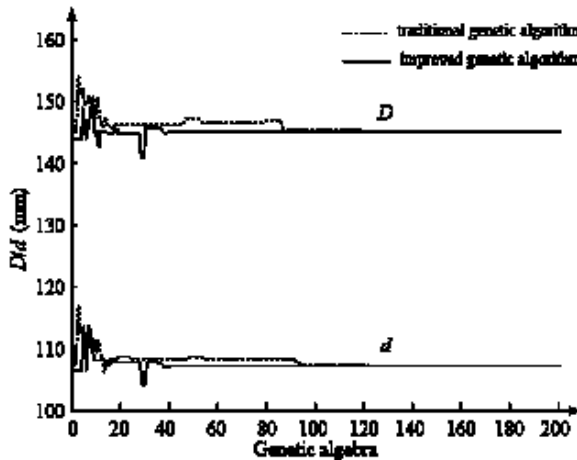


Fig. 5. Relationship between D/d and genetic algebra

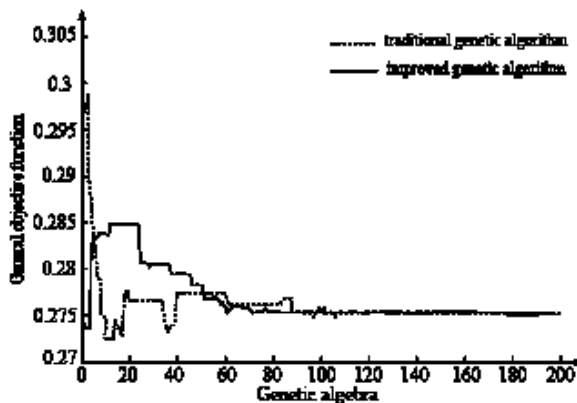


Fig. 6. Relationship between general objective function and genetic algebra

By checking, the optimized scheme can meet the request of the clutch transmission torque, heat load, space layout and the requirement of hydraulic system. And what is more, known from parameters comparison before and after optimization in the Table 7, the general objective function value of optimized scheme reduced about 9.93% than the original scheme, and under the condition that the clutch friction plate number is invariable, the outer diameter reduced about 2.70%, which is easy to install and reduce the cost.

Table 7. Parameters contrast before and after optimization

Parameters	Symbol	Unit	Before optimization	After optimization
Outer diameter	D	mm	148	144
Inner diameter	d	mm	115	107
Friction plate number	z		7	7
Diameter ratio	Γ		0.77	0.74
Reserve coefficient	β		2.046	2.129
Maximum transmission torque	T_{cb}	N·m	1784.1	1856.6
General objective function value	F		0.3051	0.2748

6. Conclusions

As the tractor power shift clutch for the research object, a clutch optimization method based on AHP and improved genetic algorithm was put forward, which has important reference value for the optimization of vehicle's clutch and vehicle design.

In the process of optimization, AHP was used to distribute the weight coefficient of the sub-objective function, which made the optimization model of objective function more reasonable; improved genetic algorithm was introduced into combination coefficient between parameters and the reproduction elimination of population individual, which made the optimization efficiency improving.

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