

Optimization of Wet Multi-disk Clutch Based on Improved Genetic Algorithm

Z.L. Zhou, Q. Li, L.Y. Xu, Q.M. Cao
College of Vehicle and Traffic Engineering
Henan University of Science and Technology
Luoyang, China

Abstract—For the wet multi-disk clutch plate parameters optimization process of multi-objective, multi-parameter and multi-constraint features, an optimization method based on improved genetic algorithm was put forward. The combination coefficient was applied to the genetic algorithm to improve the evolution efficiency; As Dongfanghong-LA3004 tractor shifting clutch for the optimization example, the optimized results verified the rationality and validity of the proposed optimization method.

Keywords—wet multi-disk clutch; improved genetic algorithm; combination coefficient

I. INTRODUCTION

In the process of vehicle starting and shifting, wet multi-disk clutch plays a key role, the optimization design of the clutch can prolong the service life of the clutch and reduce processing costs [1-3].

Genetic algorithm is a kind of one-dimensional random search intelligent algorithm[4-5]. Based on the defect that traditional genetic algorithm ignoring the parameters combination relationship in the optimization process, an improved genetic algorithm that introducing the combination coefficient is put forward, and the global optimal solution is obtained, at the same time, the evolution efficiency is improved.

II. CLUTCH OPTIMIZATION MODEL

A. Design Variable Selection

Based on the design formula of wet clutch, friction plate number z , friction plate outer diameter D and inner diameter d are taken as the design variables. So the design variables are as follows:

$$X = (z, D, d) = (x_1, x_2, x_3) \quad (1)$$

B. Objective Function

1) *Volume of the clutch*: The clutch is designed to have the smaller volume and quality as far as possible, the axial and radial size of the clutch is taken as the objective function f_1 .

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

In the formula: v is the lumen volume of the clutch; h is the thickness of friction plate; S is the spacing of friction plate, which is taken as 3mm when calculating.

2) *Specific heat of the friction plate*: Test showed that the wet clutch under the condition of maximum heating rate and the highest temperature is liable to produce the friction plate sintering[6], the average temperature is taken as the objective function f_2 .

$$f_2 = \frac{Q}{2\pi(\frac{D^2}{4} - \frac{d^2}{4})(z-1)} \quad (3)$$

In the formula: Q is the generated heat.

3) *Volume of friction plate*: Friction plate's size and quality are related to the production cost, so friction the volume of friction plate is taken as the objective function f_3 .

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

4) General objective function

$$f(X) = \omega_1 f_1 + \omega_2 f_2 + \omega_3 f_3 \quad (5)$$

In the formula: $\omega_1, \omega_2, \omega_3$ are the weight coefficients of the part objective function f_1, f_2, f_3 .

Based on Analytic Hierarchy Process (AHP), the part objective function weight coefficients were allocated reasonably as follows (the computation process was omitted):

$$X = (\omega_1, \omega_2, \omega_3) = (0.3395, 0.3239, 0.3366) \quad (6)$$

5) *Normalization processing*: If the k th generation objective function values are taken as $f_1(k), f_2(k), f_3(k)$; $f_j(k)_{\max}, f_j(k)_{\min}$ are respectively expressed as the maximum and minimum value of the objective function f_j in the 1th~ k th generation, after the normalization processing, f_1, f_2, f_3 are expressed as:

$$f_j = \frac{f_j(k) - f_j(k)_{\min}}{f_j(k)_{\max} - f_j(k)_{\min}} \quad \varphi=1,2,3 \quad (7)$$

C. Constraint Condition

1) *Reserve coefficient β* : Reserve coefficient β reflects the reliability that the clutch transmitted the engine maximum torque. For the tractor shifting clutch, β is recommended to select between 1.5~2.5[7].

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

In the formula: μ is the dynamic friction factor; s is the friction plate's contact area; p is the hydraulic system pressure.

2) *Average peripheral speed and maximum peripheral speed of friction plate*: The average peripheral speed and maximum peripheral speed of the friction plate should be less than the permission.

$$v_a = \frac{(R+r)}{2} \Delta\omega \leq [v_a] \quad (9)$$

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

In the formula: R, r are the outer and inner radius of friction plate; $\Delta\omega$ is the relative speed between the driving disc and the driven disc of clutch; n_{\max} is the maximum speed of engine. Limited by the space structure, D is taken as [100mm, 300mm].

3) *Diameter ratio of friction plate*: Diameter ratio is the ratio of the inner and outer diameter. The range of tractor shifting clutch diameter ratio is 0.6~0.8[8].

4) *Slipping friction work per unit area*: Usually, slipping friction work per unit area Q_0 is taken as the evaluation index of the clutch's wear resistance[9].

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

In the formula: $[Q_0]$ is the possible value of Q_0 , which is taken as 25~33(J/cm²).

III. IMPROVED GENETIC ALGORITHM

A. Combination Coefficient

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

$$c = 2 \times \frac{f_i(k) - f(k)_{\min}}{f(k)_{\max} - f(k)_{\min}} - 1 \quad (12)$$

In the formula: c is the combination coefficient, $f_i(k)$ is the fitness value of the k th generation and i th combination, $f(k)_{\min}$ is the minimum fitness value of the k th generation group, $f(k)_{\max}$ is the largest fitness value of the k th generation group.

As shown in formula (12), the c is in the range of [1, 1]. If $c=-1$, it indicates that the fitness value is the worst when two parameters are taken this combination, during the next generation is produced, the probability that individual again produce this combination 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 parameters value is large, and the probability that this combination appeared in the next generation is large.

Chromosome combinations are shown as figure 1, the genes on the chromosomes represent binary code of three parameters, the top four bits represent the value of the parameter D , the middle four bits represent the value of the parameter d , the last two bits represent the value of the parameter z , and the chromosome combinations are expressed as the vector form as:

$$A = [a_1 \ a_2 \ a_3 \ a_4 \ b_1 \ b_2 \ b_3 \ b_4 \ c_1 \ c_2] \quad (13)$$

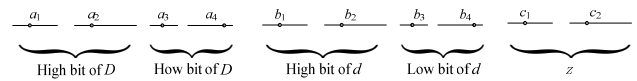


FIGURE 1. CHROMOSOME COMBINATIONS PATTERN

In 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 take the combination of the most close to the value within the allowed range for the corresponding combination, because the impact on the size of parameter selection is the high bit digital, so think 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, b_2 are valued as follows:

$$b_1 = \frac{1}{2}(1+c)b_{01} \quad (14)$$

$$b_2 = \frac{1}{2}(1+c)b_{02} \quad (15)$$

In the formula: b_{01}, b_{02} are the high bit code values of parameter d of the corresponding combination.

IV. OPTIMIZATION EXAMPLE AND RESULTS

As Dongfanghong-LA3004 tractor wet mufti-disk shifting clutch for the research object to optimize by the above optimization method. Known conditions: tractor rated speed

$n=2100\text{r/min}$, rated power $P=192\text{kW}$, the largest output torque of engine $T=1109\text{N}\cdot\text{m}$, engine rated torque $T_e=872.3\text{N}\cdot\text{m}$.

The specific flow of the improved genetic algorithm is shown in figure 2.

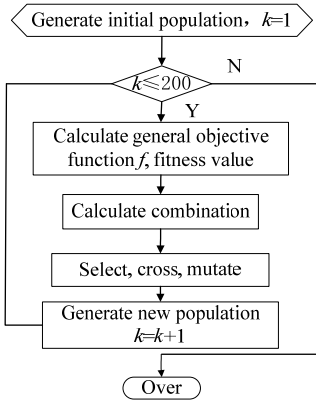


FIGURE II. ALGORITHM FLOW CHART

Genetic algorithm iterations are set to 200, 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 figure 3~figure 5.

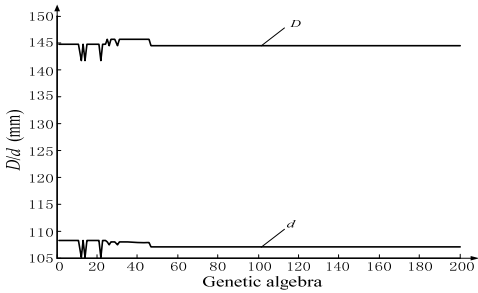


FIGURE III. RELATIONSHIP BETWEEN D/D AND GENETIC ALGEBRA

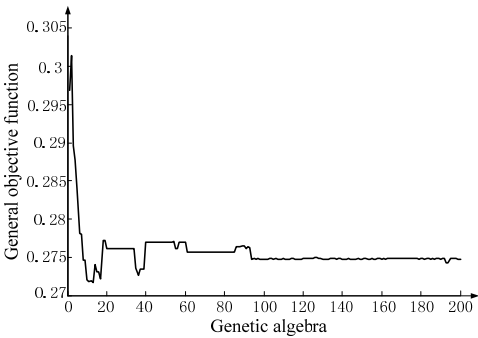


FIGURE IV. RELATIONSHIP BETWEEN GENERAL OBJECTIVE FUNCTION AND GENETIC ALGEBRA

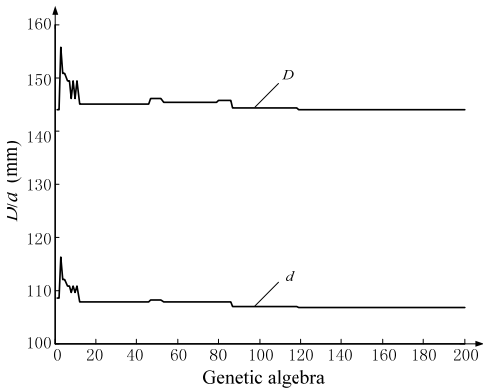


FIGURE V. RELATIONSHIP BETWEEN D/D AND GENETIC ALGEBRA WITHOUT INTRODUCING COMBINATION COEFFICIENT

Results are as follows:

- (1) Figure 3 and figure 5 are described under two kinds of algorithm optimization, and the figure shows that the results are consistent, which indicates that the improved genetic algorithm optimization above mentioned is correct.
- (2) Contrast figure 3 and figure 5, based on the improved genetic algorithm, the optimization parameters converge to the optimal solution in the genetic to about 45th generation, but based on the traditional genetic algorithm, it is about 140th generation, which indicates that the improved genetic algorithm that introducing the combination coefficient has higher evolution efficiency.
- (3) The parameters contrast before and after optimization are as shown in table 1.

TABLE I. 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
General objective function value	F		0.3051	0.2748
Reserve coefficient	β		2.046	2.129
t				

After being checked, the optimized scheme satisfies the torque transmitted by the clutch, the heat load, the space layout and the requirement of hydraulic system, what is more, the optimized scheme is superior to the original plan in the clutch size and general objective function value.

V. CONCLUSION

As Dongfanghong-LA3004 tractor shifting clutch for the optimization example, an optimization method based on improved genetic algorithm is put forward, which has important reference value of improving the performance of the clutch and transmission system. Combination coefficient is applied to the genetic algorithm, the optimization efficiency is improved, and the optimization process is more reasonable. The improved genetic algorithm proposed in this paper can be applied to multi-parameter, multi-objective and multi-constraint optimization problems, and get the global optimal solution.

ACKNOWLEDGEMENTS

This work is financially supported by the national natural science fund project (51375145), the key scientific and technological plan funding project of Henan Province (142102210424), and the key technology research programs plan fund project in department of education of Henan Province (14B460015).

REFERENCES

- [1] Goetz M, Levesley M C, Crolla D A. Dynamics and control of gearshifts on twin-clutch transmissions. *Journal of Automobile Engineering*, 219(8), pp. 951-963, 2005.
- [2] Sebastian Kahlbau, Dieter Bestle. Optimal shift control for automatic transmission. *Mechanics Based Design of Structures and Machines*, 41(3), pp. 259-273, 2013.
- [3] Marklund P, Larsson R, Wet clutch under limited slip conditions simplified testing and simulation. *Journal of Engineering tribology*, 221(5), pp. 545-551, 2007.
- [4] Boris P L, Jessica S C. A deterministic annular crossover genetic algorithm optimization for the unit commitment problem. *Expert Systems with Applications*, 38(6), pp. 6523-6529, 2011.
- [5] Y.J. Ma, W.X. Yun, Research Progress of Genetical Gorithm. *Application Research of Computers*, 29(4), pp. 1201-1210, 2012. (in Chinese)
- [6] Decuzzi P, Ciavarella M, Monno G. Frictionally excited thermoelastic instability in multi-disk clutches and brakes. *ASME Journal of Tribology*, 123, pp. 865-871, 2001.
- [7] P.X. Tang, Y.F. Liu, S.H. Wang, etc. Optimal Design of Clutch in Automatic Transmission. *Journal of Beijing University of Aeronautics and Astronautics*, 36(3), pp. 291-294, 2010. (in Chinese)
- [8] B. Ma, J.X. Zhao, H.Y. Li, etc. Effect of Clutches' structural parametes on t-hermoelastic instability. *Journal of Jilin University*, 44(4), pp. 933-938, 2014. (in Chinese)
- [9] Zhao S M, Hilmas G E, Dharani L R. Behavior of a Composite Multi-disk Clutch Subjected to Mechanical and Frictionally Excited Thermal Load. *Wear*, 264(12), pp. 1059-1068, 2008.