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CHAOS–BASED ELITE MULTI-PARENT HYBRID OPTIMIZATION ALGORITHM AND ITS APPLICATION

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The elite multi-parent hybrid optimization algorithm mainly for complex function optimization problems and the efficiency is better than other optimization algorithms. However, this algorithm consists of hybrid operation without mutation so as not to keep the diversity of population in the search process. Chaos has strong sensitivity to initial value, so after the chaos is added in the algorithm, optimization variables will present chaos state so as to better make up for the lack of population diversity and convergence speed in the elite multi-parent hybrid optimization algorithm. In this paper, combining chaos disturbance and elite multi-parent hybrid algorithm, the chaos disturbance elite multi-parent hybrid optimization algorithm with hybrid discrete variables was proposed. The procedure as DEMPCOA written in Matlab is to optimum design of automobile gearbox. Optimization example shows that the algorithm has characteristics of no special requirements for the optimization design problem, better universality, and reliable operation, higher calculation efficiency and stronger global convergence ability.

Keywords: Evolutionary Algorithm; Gearbox Optimization; Elite-preservation; Chaos; Hybrid Discrete Variables

1. Introduction

Optimization design is a very effective way to ensure that the product has excellent performance, lighten weight and volume and reduce the product cost, and it has been widely used in automobile design [1-6]. Automobile gearbox is an important part of the automobile. In addition to make automobiles with good dynamic performance, an ideal automobile gearbox should have the smallest volume, the lightest quality, the most saving material and the lowest cost under the condition of reliable work, where the lightweight has become important indicator checking advanced nature in the design to gearbox. It is the optimization design problem with hybrid discrete variable containing integer variables and discrete variables and

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continuous variables for the optimization design to the automobile gearbox, whose objective function often makes the quality minimum under the condition of guarantee the strength and the stiffness of parts. It is the most meaningful and but also more difficult in mathematical programming and operations research for discrete variable optimization [7, 8]. There have been developed many classical numerical methods for the optimization problem, and some better results have been obtained. But the traditional optimization methods such as continuous and differentiable have strong constraint for the objective function, and these methods have strong dependence on optimization problem. At the same time, the algorithm results are related to the selection of initial values and easily trapped in local minimum. In recent years, the booming evolutionary algorithm with the global optimality, parallelism and efficiency has been widely used in function optimization. With the help of the evolution of nature, the evolutionary algorithm overcoming the drawback of traditional numerical method as a global optimization method for multiple clues is based on the population and random search mechanism. It has been attracted widespread attention of evolutionary computation in the field of optimization application, and various forms of evolution algorithm emerge in endlessly. A new evolutionary algorithm called GuoTao algorithm was proposed [9], and this algorithm based on group random search in the subspace search is easy to implement. On the basis on GuoTao algorithm, literature [10] presented an elite-subspace evolutionary algorithm by adopting the elite-preservation strategy. Constructing dynamic penalty function, the elite multi-parent hybrid optimization algorithm with hybrid discrete variable was developed for the engineering optimization design to the three-axis four-speed automobile gearbox [11-13]. The elite multi-parent hybrid optimization algorithm mainly for complex function optimization problems and the efficiency is better than other optimization algorithms. However, this algorithm consists of hybrid operation without mutation so as not to keep the diversity of population in the search process. If this is a great amount of calculation, the ability to find global optimal solution could be greatly reduced, and in the later stages of the algorithm the convergence speed is slow and easy to fall into local optimum. As a kind of common nonlinear phenomena in nature, chaos seems to be confusion but has a delicate internal structure [14, 15]. It is a kind of "strange attractor" that can draw the system movement and bound in a specific range. It moves disorderly with no specific orbit and repeated over a certain range of all status. These are a few characteristics in chaotic motion such as regularity, randomness and ergodicity. The regularity and randomness at the same time makes chaos some motion forms, and the ergodicity of chaos drives the system to avoid falling into local minimum. In addition, a very small change of the initial condition will cause great change of the system behavior, namely chaos has strong sensitivity to initial value. After the chaos is added in the algorithm, optimization variables will present chaos state so as to better make up for the lack of population diversity and convergence speed in the elite multi-parent hybrid optimization algorithm. In this paper, combining chaos disturbance and elite multi-parent hybrid algorithm, the chaos disturbance elite multi-parent hybrid optimization algorithm with hybrid discrete variables was proposed. The procedure DEMPCOA was written in Matlab. This algorithm has characteristics of no special requirements for the optimization design problem, better universality, and reliable operation and stronger global convergence ability.

2. The Chaos disturbance elite multi-parent hybrid optimization algorithm to optimize hybrid discrete variables

2.1 Elite Multi-parent Evolutionary Optimization Algorithm

The optimization problem is considered as:

$$\min f(\mathbf{x}), \mathbf{x} \in D, D = \{\mathbf{x} \in S; g_k(\mathbf{x}) \le 0, k = 1,2,\cdots,q, h_j(\mathbf{x}) = 0, j = 1,2,\cdots,p\}$$

Where, $S \subset R^n$ is the search space, $l_i \le x_i \le u_i (i = 1,2,\cdots,n)$, f is the objective function, n is the number of variables, D is the set of feasible points, g_k is the constraint function and q is the number of constraints.

Supposed

$$H(\mathbf{x}) = h(\mathbf{x})(\sum_{k=1}^{q} \mu(\phi_k(\mathbf{x}))\phi_k(\mathbf{x})^{\delta(\phi_k(\mathbf{x}))} + \sum_{j=1}^{p} \mu(\varphi_j(\mathbf{x}))\varphi_j(\mathbf{x})^{\delta(\varphi_j(\mathbf{x}))}) \quad (1)$$

Where $\phi_k(\mathbf{x}) = \max\{0, g_k(\mathbf{x})\}$, $\varphi_j(\mathbf{x}) = |h_j(\mathbf{x})|$, h is the punishment intensity, and the functions as $h(\bullet)$, $\mu(\bullet)$ and $\delta(\bullet)$ are depended on the specific issues [4,16].

a is bigger positive number. The logic function is defined as [4, 9, 10]:

$$better(\mathbf{x}_1, \mathbf{x}_2) = \begin{cases} \text{True}, & if\ \ H(\mathbf{x}_1) < H(\mathbf{x}_2) \\ \text{False}, & if\ \ H(\mathbf{x}_1) > H(\mathbf{x}_2) \\ \text{True}, & if\ \ (H(\mathbf{x}_1) = H(\mathbf{x}_2)) \wedge (f(\mathbf{x}_1) \le f(\mathbf{x}_2)) \\ \text{False}, & if\ \ (H(\mathbf{x}_1) = H(\mathbf{x}_2)) \wedge (f(\mathbf{x}_1) > f(\mathbf{x}_2)) \end{cases}$$

If $better(\mathbf{x}_1, \mathbf{x}_2)$ is true, $\mathbf{x}_1$ is better than $\mathbf{x}_2$, otherwise $\mathbf{x}_2$ is better than $\mathbf{x}_1$.

The calculation steps of the algorithm are as follows:

Step 1: Randomly generating the initial group $P_0 = \{\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_N\}$ in the search space S, where N is the number of the initial group and $t = 0$.

Step 2: Sorting the group P_t from good to bad according to $better(\mathbf{x}_1, \mathbf{x}_2)$, it is still denoted to $P_0 = \{\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_N\}$, where $\mathbf{x}_1$ is the best individual and $\mathbf{x}_N$ is the worst.

Step 3: Switching to Step 5 when $better(\mathbf{x}_{worst}, \mathbf{x}_{best})$ is true, that is, the best individual is the same as the worst.

Step 4: Selecting $K(K \le M)$ best individuals of P_t as $(\mathbf{x}_1^{'}, \mathbf{x}_2^{'}, \cdots, \mathbf{x}_K^{'})$ and randomly picking $(M-K)$ individuals as $(\mathbf{x}_{K+1}^{'}, \mathbf{x}_{K+2}^{'}, \cdots, \mathbf{x}_M^{'})$ from the remaining individuals, $M(M \le N)$ individuals form the subspace $V = \left\{\mathbf{x} \mid \mathbf{x} \in S, \mathbf{x} = \sum_{i=1}^{M} a_i \mathbf{x}_i^{'}\right\}$ where $\sum_{i=1}^{M} a_i = 1$ and $-0.5 \le a_i \le 1.5$. In the subspace, L points are randomly selected to get L new individuals where the best individual is denoted to $\bar{\mathbf{x}}$. If $better(\bar{\mathbf{x}}, \mathbf{x}_{worst})$ is true, $\bar{\mathbf{x}}$ is taken the place of $\mathbf{x}_{worst}$ to form new individual P_{t+1}, otherwise $P_{t+1} = P_t$. t is replaced by $t+1$, then the calculation step is switched to Step 2.

Step 5: The best solution containing all solutions whose function values are equal to zero is outputted.

In Step 4, K elite individuals of P_t become partial basis in the subspace V so as to make full use of the valuable information of the solutions to make the algorithm faster converge to the optimal solution. It is especially suitable for single-peak function optimization problems[4]. Numerical experiments show that the elite preservation strategy can obtain significantly faster convergence. For K, it is not the bigger for the better. In spite of the better use of solution information when K is bigger, the bigger K is, the smaller the DOF of the basis in the subspace V is. That is easy to make the solutions hovering in local area of the search space and trapping in the local optimal solutions for multimodal functions. The selection to K has a relationship with the value of M. If M is bigger, K can be selected to the larger. L individuals in the subspace V are selected in order to more effectively use the information of the subspace. For the optimization problem, generally $K = M/2$ or smaller, and $L = M$ where M generally is selected $(1-3)$ times of the variable number.

2.2 Chaos disturbance elite multi-parent hybrid optimization algorithm to optimize hybrid discrete variables

Lyapunov exponent is one of effective methods depicting the chaos specific property of nonlinear system, and the number of Lyapunov exponents is the same as the dimension n of the state space of the system. If one of Lyapunov exponents is positive, the system is chaotic. Logistic mapping $z_{i+1} = 4z_i(1-z_i)$ is a classical chaotic system where the resulting sequence is chaos and Lyapunov index λ=0.6931. One-dimensional feedback chaotic Logistic mapping was studied [17] whose equation is as following:

$$z_{i+1} = 4z_i(1-z_i) + (4+e^4)z_i(\text{mod}1) \tag{2}$$

Through numerical calculation, Lyapunov index of the corresponding feedback chaotic Logistic map is obtained, that is, λ=4.0704. Since the Lyapunov index is greater than 0.6931, the chaos motions is more intensively. So chaos has good ergodicity.

The chaotic motion can be used to optimizing search. The basic process is firstly generating a group of chaotic variables whose numbers are same as ones of optimized variables, secondly in a similar way of carrier chaos adding optimization variables to present the chaotic state and at the same time enlarging the traverse range of the chaotic motions to the value range of optimization variables, and then directly using chaotic variables to search. Due to chaotic motion is regular, randomness, ergodicity and sensitivity to initial conditions, the chaotic system is introduced into the elite multi-parent hybrid optimization algorithm to be bound to increase the search capability of the algorithm.

Taking Eq. (2) as chaotic signal generator, the calculation steps of the chaos disturbance elite multi-parent hybrid optimization algorithm are as follows:

Step 1: Initializing the population and randomly generating the sequence:

$Z = (z_1, z_2, \cdots, z_n)$, $z_i \in [0,1]$, $i = 1,2,\cdots,n$

Step 2: Sorting the population according to $better(\mathbf{x}_1, \mathbf{x}_2)$.

Step 3: Generating new individuals according to Step 4 in the elite multi-parent hybrid optimization algorithm.

Step 4: Chaotic iterating to each component of Z according to Eq. (2).

Step 5: Production each offspring of the individuals in Step 3 and making successively chaos disturbance $C_i^{'} = C_i + (-\beta + 2\beta Z)$. If $better(C_i^{'}, C_i)$ is true, $C = C_i^{'}$, where the carrier scope $\beta \in [1,5]$.

Step 6: Defining C as the optimal individual in Step 5. If C is better than the worst individual of the population, C will be inserted in the population.

Step 7: If the termination condition is met, this algorithm is terminated; otherwise, the algorithm will skip to Step 3.

2.3 Engineering treatment method of design variables

(1) Discretization of discrete design variables

In chaos disturbance elite multi-parent hybrid optimization algorithm, since the new updated individual is continuous variable, the variable should be discrete after each round of update operations. The discretization method for integer design variables is similar to one for non-equidistant discrete variable, but the difference is that the value space is nonnegative integers in the given upper and lower bounds [7, 13, 18].

(2) Engineering treatment of continuous design variables

In engineering optimization design, although some design variables is continuous in the form, but its value is still under restrictions of machinery manufacturing precision and design specification. If in the optimization design the data are calculated according to floating-point number or double-precision real in the programming language and then in the decimal place is conducted in data processing according to practical requirements, the final design scheme may not be the optimal solution, and even may not satisfy the constraint conditions. Therefore, in the calculation process the result must be practice to a given decimal digits according to the requirements of practical engineering.

2.4 Procedure

The Procedur DEMPCOA based on the chaos disturbance elite multi-parent hybrid optimization algorithm to optimize hybrid discrete variables was written in MATLAB.

3.Optimization mathematical model of automobile gearbox

3.1 Objective functions and design variables

Fig.1 is the main parts diagram of four-speed common transmission. When the tooth width of each gear is equal, taking the modulus of each gear as m_{n1}, m_{n2},

m_{n3} and m_{n4}, each spiral angle as β_1, β_2, β_3 and β_4, the volume of a transmission is as following [4].

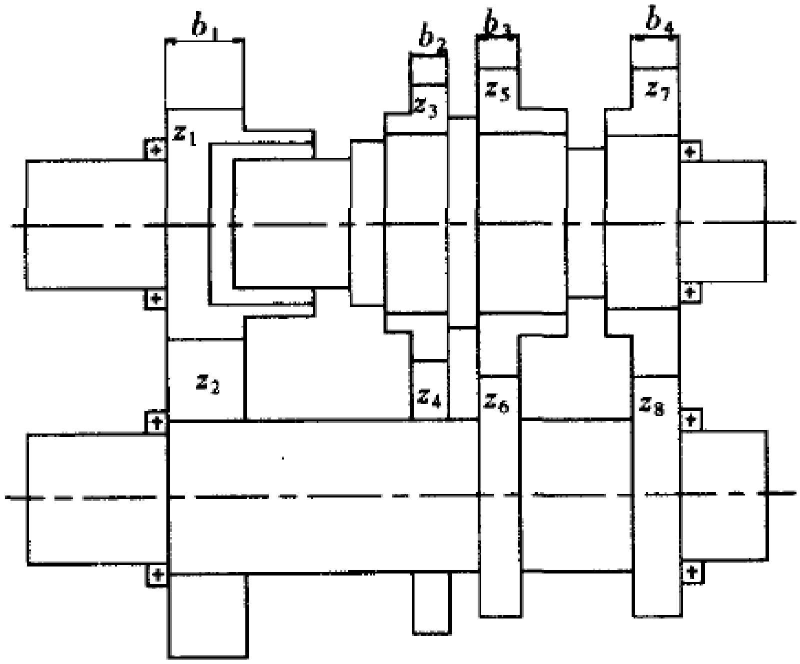

Fig.1 Main parts of four speed common transmission

$$V = \frac{\pi b}{4}[\sum_{i=1}^{4}(\frac{m_{ni}}{\cos\beta_i})^2(z_{2i-1}^2 + z_{2i}^2)] \qquad (3)$$

In addition to the direct gear, the transmission ratios of the other three gears i_1, i_2 and i_3 are:

$$i_1 = \frac{z_2}{z_1}\times\frac{z_7}{z_8}, i_2 = \frac{z_2}{z_1}\times\frac{z_5}{z_6}, i_3 = \frac{z_2}{z_1}\times\frac{z_3}{z_4}$$

The center distance of the transmission is:

$$A = \frac{m_{n1}(z_1 + z_2)}{2\cos\beta_1} = \frac{2m_{n2}(z_3 + z_4)}{2\cos\beta_2} = \frac{m_{n3}(z_5 + z_6)}{2\cos\beta_3} = \frac{2m_{n4}(z_7 + z_8)}{2\cos\beta_4}$$

It can be obtained.

$$z_3=\frac{m_{n1}\cos\beta_2}{m_{n2}\cos\beta_1}\cdot\frac{z_1 i_3(z_1+z_2)}{i_3 z_1+z_2},\ z_4=\frac{m_{n1}\cos\beta_2}{m_{n2}\cos\beta_1}\cdot\frac{z_2(z_1+z_2)}{i_3 z_1+z_2}$$
$$z_5=\frac{m_{n1}\cos\beta_3}{m_{n3}\cos\beta_1}\cdot\frac{z_1 i_2(z_1+z_2)}{i_2 z_1+z_2},\ z_6=\frac{m_{n1}\cos\beta_3}{m_{n3}\cos\beta_1}\cdot\frac{z_2(z_1+z_2)}{i_2 z_1+z_2} \tag{4}$$
$$z_7=\frac{m_{n1}\cos\beta_4}{m_{n4}\cos\beta_1}\cdot\frac{z_1 i_1(z_1+z_2)}{i_1 z_1+z_2},\ z_8=\frac{m_{n1}\cos\beta_4}{m_{n4}\cos\beta_1}\cdot\frac{z_2(z_1+z_2)}{i_1 z_1+z_2}$$

Substituting into Eq.(2) obtains the optimization objective function as

$$F(\mathbf{x})=V \tag{5}$$

The following 20 parameters are selected to the design variables in this paper.

$$\mathbf{x}=[i_1,i_2,i_3,z_1,z_2,m_{n1},m_{n2},m_{n3},m_{n4},\beta_1,\beta_2,\beta_3,\beta_4,b,z_3,z_4,z_5,z_6,z_7,z_8]^{\mathbf{T}}$$

3.2. Constraint conditions

In this paper, constraint conditions selects axial force of intermediate shaft, center distance, the maximum transmission ratio, operational performance, minimum gear teeth, modulus, spiral angle, tooth width, axial overlapping coefficients.

Because of spiral angle, there exists certain axial force when the helical gear transmits torque. In the process of design, the axial forces in the intermediate shafts should be strived to make into balance. In the meantime, there are constraints when the intermediate shafts transmit in one and second speeds [2, 6, 13].

The transmission constraints of two wheels in intermediate shafts z_2 and z_4 are:

$$g_1=m_{n2}z_4\sin\beta_1-m_{n1}z_2\sin\beta_2-100\le 0,$$
$$g_2=m_{n1}z_2\sin\beta_2-m_{n2}z_4\sin\beta_1-100\le 0;$$

The transmission constraints of two wheels in intermediate shafts z_2 and z_6 are:

$$g_3=m_{n1}z_2\sin\beta_3-m_{n3}z_6\sin\beta_1-100\le 0;$$
$$g_4=m_{n3}z_6\sin\beta_1-m_{n1}z_2\sin\beta_3-100\le 0;$$

The transmission constraints of two wheels in intermediate shafts z_2 and z_8 are:

$$g_5=m_{n1}z_2\sin\beta_4-m_{n4}z_8\sin\beta_1-100\le 0;$$
$$g_6=m_{n4}z_8\sin\beta_1-m_{n1}z_2\sin\beta_4-100\le 0;$$

The center distance A of the transmission has a great influence on the volume and quality. Its selection principle is to reduce the center distance A as far as possible under the condition of maximum torque of the engine, the maximum transmission ratio of the transmission and enough strength of gear. In general,

$A=(8.6\sim 9.6)\sqrt[3]{T_{1\max}}$, where $T_{1\max}$ is the output torque of II axis in I gear. $T_{1\max}=T_{e\max}i_1\eta_g$, where $T_{e\max}$ is the maximum torque of engine, η_g is transmission efficiency of transmission and generally is taken as 0.96. The following constraints can be obtained:

$$g_7=8.6\sqrt[3]{T_{e\max}i_1\eta_g}-\frac{m_{n1}(z_1+z_2)}{2\cos\beta_1}\le 0$$

$$g_8=-9.6\sqrt[3]{T_{e\max}i_1\eta_g}+\frac{m_{n1}(z_1+z_2)}{2\cos\beta_1}\le 0$$

$$g_9=8.6\sqrt[3]{T_{e\max}i_1\eta_g}-\frac{m_{n2}(z_3+z_4)}{2\cos\beta_2}\le 0$$

$$g_{10}=-9.6\sqrt[3]{T_{e\max}i_1\eta_g}+\frac{m_{n2}(z_3+z_4)}{2\cos\beta_2}\le 0$$

$$g_{11}=8.6\sqrt[3]{T_{e\max}i_1\eta_g}-\frac{m_{n3}(z_5+z_6)}{2\cos\beta_3}\le 0$$

$$g_{12}=-9.6\sqrt[3]{T_{e\max}i_1\eta_g}+\frac{m_{n3}(z_5+z_6)}{2\cos\beta_3}\le 0$$

$$g_{13}=8.6\sqrt[3]{T_{e\max}i_1\eta_g}-\frac{m_{n4}(z_7+z_8)}{2\cos\beta_4}\le 0$$

$$g_{14}=-9.6\sqrt[3]{T_{e\max}i_1\eta_g}+\frac{m_{n4}(z_7+z_8)}{2\cos\beta_4}\le 0$$

Determining the maximum transmission ratio, they should be considered: maximum gradability, adhesive force and lowest stable speed. In general, the biggest ratio $i_{\max}$ of automotive transmission system is the product of transmission ratio i_1 of I gear and transmission ratio i_0 of the main reducer gear. When i_0 is known, the maximum transmission ratio only is determined by i_1. So the following equation is obtained [2, 6, 13]:

$$\frac{G_a(f\cos\alpha_{\max}+\sin\alpha_{\max})r_r}{T_{e\max}i_0\eta_T}\le i_1\le\frac{F_s\varphi\cdot r_r}{T_{e\max}i_0\eta_T}$$

Where, G_a is the total weight of automobile, $\alpha_{\max}$ is maximum gradability. $\alpha_{\max}$ is generally about 30%, so $\alpha_{\max}$ is selected 16.7^0. φ the adhesion coefficient is generally selected $0.5 \sim 0.6$. η_T the mechanical efficiency of the transmission system is selected 0.835, r_r is the wheel rolling radius, F_s is the normal reaction force on the driving wheel. So there are constraints:

$$g_{15} = \frac{G_a(f\cos\alpha_{\max} + \sin\alpha_{\max})r_r}{T_{e\max} i_0 \eta_T} - i_1 \le 0$$

$$g_{16} = -i_1 - \frac{F_s \varphi \cdot r_r}{T_{e\max} i_0 \eta_T} \le 0$$

The ratio of transmission ratio in each gear will affect the use performance of transmission. It is difficult to switch gear when the ratio is too big. Generally the ratio should not be greater than 1.8 [2,6,13].

$$1.5 \le \frac{i_3}{i_4} \le \frac{i_2}{i_3} \le \frac{i_1}{i_2} \le 1.8$$

The constraints are obtained [2]:

$$g_{17} = i_1 - 1.8 i_2 \le 0, g_{18} = i_2^2 - i_1 i_3 \le 0 ,$$

$$g_{19} = 1.5 i_3 - i_2 \le 0; g_{20} = 1.5 i_2 - i_1 \le 0$$

To make gear does not undercutting, the minimum number of gear teeth must be must restricted. According to the structure characteristics and strength requirements of gear [4], $12 \le z_8 \le 18$, so the following constraints can be obtained:

$$g_{21} = 12 - z_8 \le 0; g_{22} = z_8 - 17 \le 0$$

For truck transmission, the moduli of helical gear $2.25 \le m_{ni} \le 3.0$, the spiral angle $18^0 \le \beta_i \le 26^0$ where $i = 1,2,3,4$, there is constraint:

$$g_i \le 0; i = 23, \cdots 38$$

The tooth width of helical gear $6 m_{ni} \le b \le 8.5 m_{ni}$ where $i = 1, \cdots 4$, there is constraint:

$$g_i \le 0; i = 39, \cdots 46$$

In helical cylindrical gear, the spiral angle of reference circle should guarantee the axial overlapping coefficient, namely [13]:

$$\varepsilon_\beta = \frac{b \sin\beta}{\pi m_n} \ge 1$$

The corresponding constraints are obtained:

$$g_{47} = \pi m_{n1} - b \sin\beta_1 \le 0$$

$$g_{48} = \pi m_{n2} - b \sin\beta_2 \le 0$$

$g_{49} = \pi m_{n3} - b\sin\beta_3 \le 0$

$g_{50} = \pi m_{n4} - b\sin\beta_4 \le 0$

Then the inequality constraints are obtained as: $C = [g_1, g_2, \cdots, g_{50}]$. Eq. (3) is processed to equality constraint: $Ceq = [h_1, h_2, \cdots, h_6]$

4. Calculation example

They are known the total weight of a truck 1690 kg, the maximum torque of the engine 104Nm, the reaction force on the driving wheel 1060 kg, the wheel radius 0.3m, transmission ratio i_0 of the main reducer 4.85. Taken the gear modules as discrete variables, the number of tooth $z_1 - z_8$ as integer variable, tooth width b as continuous variable and accurate to 4 decimal places, transmission ratios i_1, i_2, i_3 as continuous variables and accurate to four decimal places, the range of variables are determined. Taking operation parameters in the program $h = 10000, N = 100, M = 20; K = 3, L = 20$, the optimization results are shown in Table 1. The parameters before optimization in [2] do not meet the constraints as g_8, g_{10}, g_{12}, g_{14}, g_{48}, g_{49} and g_{50}. It is known in Table 1 that when considering the constraints as $g_{47\sim50}$, the optimization results in [13] is much better than the results in [2]. The volume decreases by 20.63% than one before optimization and the given constraints are all satisfied with considering the axial overlapping coefficient. The number of tooth is directly used as the integer variables, and it does not need to round again after optimization. The solution in this paper is close to ones in [13]. The average optimization time is 70.55 seconds for 10 times in [13], but the time is 59.484 seconds in this paper to reduce computing time and improve computational efficiency. The chaos disturbance elite multi-parent hybrid algorithm has characteristics of no special requirements for the optimization design problem, better practicability, reliable operation and stronger global convergence ability.

Table. 1.

Optimum results

Design variables	Solutions before optimization [2]	Solutions after optimization [2]	Solutions in [13]	Solutions in this paper
i_1	4.125	4.0	3.7682	3.76817
i_2	2.489	2.45	2.4804	2.27877
i_3	1.59	1.63	1.6536	1.51918
z_1	19	16	17	17
z_2	33	32	33	33
z_3	26	22	23	22
z_4	29	26	27	28
z_5	32	26	28	27
z_6	25	22	22	23
z_7	37	32	33	33
z_8	16	16	17	17
m_{n1}	2.5	2.5	2.25	2.25
m_{n2}	2.5	2.5	2.25	2.25
m_{n3}	2.5	2.5	2.25	2.25
m_{n4}	2.5	2.5	2.25	2.25
$\beta_1\ (^0)$	26	26	26	26
$\beta_2\ (^0)$	21	26	26	26
$\beta_3\ (^0)$	18	26	26	26
$\beta_4\ (^0)$	24	18	26	26
b	18	18	16.13	16.12
$F_{\min}$	645509	534602	420316	419203
Notes:	The axial overlapping coefficient constraints are not considered, and the parameters before optimization do not meet some constraints.		All constraints are considered	

5. Conclusion

(1) On the basis on the elite multi-parent hybrid optimization algorithm, introducing the chaos disturbance and constructing dynamic penalty function, the

chaos disturbance elite multi-parent hybrid optimization algorithm with hybrid discrete variables was proposed.

(2) The procedure DEMPCOA was written in Matlab. Selecting the minimizing volume of automobile gearbox as the objective function, these parameters as constraint conditions such as axial force of intermediate shaft, center distance, the maximum transmission ratio, operational performance, minimum gear teeth, modulus, spiral angle, tooth width and axial overlapping coefficients, the discrete optimization model of gearbox was established. The example shows the proposed optimization algorithm was also put in practice and the results of the theoretical study checked down.

(3) The procedure reasonably deals with the value problem of hybrid discrete variables in optimization design. The proposed algorithm has characteristics of no special requirements for the optimization design problem, better universality, reliable operation, stronger global convergence ability, convenient and effective for optimization and robust design problem with hybrid discrete variables. It is great significance to improve the design efficiency, reduce the transmission weight and reduce the cost.

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