

Epicyclic Gear Train Parametric Design Based on the Multi-objective Fuzzy Optimization Method

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Abstract:The research can achieve multi-objective fuzzy and multi constraint optimum design of epicyclic gear train which has large transmission ratio, high power, high efficiency and simple structure, compact epicyclic gear train with multi-objective fuzzy optimum method. Based on analyzing of structure types and characteristics of epicyclic gear train, the mathematical model of fuzzy optimal design for the target with small volume and high efficiency is proposed, which can realize the non - fuzzy processing of fuzzy factors. Based on the optimization results, the parametric design process of this kind of compound gear train is realized with Pro/E, and the normal design process of this type gear is defined.

Keywords:multi-objective fuzzy optimum design;Epicyclic gear train;Pro/E parametric design

1. Introduction

Epicyclic gear train as a kind of compound gear train has large transmission ratio, compact structure and large transmission power, high efficiency advantages, but its design process is complex and non-standard, the feasible design scheme can be according to the single target with the no parametric method. The optimal solution is difficult to build. Recently, with the application of fuzzy technology in all fields is increasing, optimization design of gear train is a new trends. But in the fuzzy optimization design of planetary gear train, one objective fuzzy optimization design is carried out mostly with the minimum volume object, the other factors are not considered. Based on the detailed analysis and research of the basic design process of epicyclic gear train, the multi-objective and multi constraint optimization design method is realized with the advanced fuzzy technology. based on the design result, the corresponding parametric part and assembling model are created with Pro/E, and the new gear train can be created by repaired the parametric values through the secondary development. So the development cycle can be greatly shortened.

2. The classification and scope of epicyclic gear train

According to the basic mechanism structure, the epicyclic gear trains can be divided into four types such as 2K-H[A], 2K-H[B], 2K-H[D] and 2K-H[E], the 2K-H[A] epicyclic gear train is the most commonly studied in this paper, The structure diagram shown in figure 1. Based on different power flow type epicyclic gear train can be divided into shunt and Reflux type. Due to various gear have different characteristics, the ratio range and efficient of the different basic structure and the closed transmission chain are different, each type of gear train has its own applicable scope, see Table 1.

Table 1 The transmission ratio distribution and scope of epicyclic gear train

Basic organization		Distribution principle and scope of the closed transmission chain transmission ratio i_{ab}		application scope of the epicyclic gear train transmission ratio i_{aH}	
type	Range of transmission ratio i_{ab}^H	Two pairs of external meshing	An external meshing and a pair of internal meshing	Shunt type	Reflux type
2K-H [A]	$-12 \leq i_{ab}^H \leq -1.8$	$-8 \leq i_{12} \leq -\frac{1}{8}$ $-8 \leq i_{34} \leq -\frac{1}{8}$ $\frac{1}{64} \leq i_{ab} \leq 64$	$-8 \leq i_{12} \leq -\frac{1}{8}$ $3 \leq i_{34} \leq 10$ $-80 \leq i_{ab} \leq -\frac{3}{8}$	$0.0169 \leq i_{aH} \leq 10.945$ for high efficiency growth transmission as the tie bar H is follower.	$0.0169 \leq i_{aH} \leq 10.945$ $2.864 \leq i_{aH} \leq 1573$ for slightly lower efficiency decelerated motion with wide range of transmission ratio as the tie bar H is follower.
2K-H [B]	$-49 \leq i_{ab}^H \leq -\frac{3}{8}$			$0.0159 \leq i_{aH} \leq 28.319$ for high efficiency growth transmission as the tie bar H is follower, but structure is complex	$-24450 \leq i_{aH} \leq -0.386$ $2.864 \leq i_{aH} \leq 24450$ for slightly lower efficiency decelerated motion with wide range of transmission ratio as the tie bar H is follower, but structure is complex
2K-H [D]	$0.167 \leq i_{ab}^H \leq 1.83$ $1 \leq i_{ab}^H \leq 1.83$			$-0.811 \leq i_{aH} \leq -0.00271$ $-0.00273 \leq i_{aH} \leq 0.831$ for slightly lower efficiency transfer motion with wide range of transmission ratio	$-96.334 \leq i_{aH} \leq -0.00016$ $0.000157 \leq i_{aH} \leq 103$ for slightly lower efficiency transfer motion with wide range of transmission ratio and self-locking can be appeared
2K-H [E]	$0.875 \leq i_{ab}^H \leq 1$ $1 \leq i_{ab}^H \leq 1.125$			$-0.811 \leq i_{aH} \leq -0.00273$ $-0.00275 \leq i_{aH} \leq 0.375$ for slightly lower efficiency transmission of short break work with wide range of transmission ratio	$-8.721 \leq i_{aH} \leq -0.00001$ $0.000157 \leq i_{aH} \leq 1.68$ for slightly lower efficiency transmission of short break work with wide range of transmission ratio and self-locking can be appeared



Figure 1 The 2K-H[A] epicyclic gear train

1. Central gear b 2 Central gear a 3 Output or input shaft I 4.the tie bar H5. intermediate propeller shaftIII6. Planet gear 7. Fixed axis gear 38. Fixed axis gear 2 9. intermediate propeller shaftIV10. Fixed axis gear 111. Output or input shaft II 12 Fixed axis gear 4

3. Research and application of multi objective fuzzy optimization system

3.1 mathematical model of multi-objective fuzzy optimal design

According to fuzzy optimization theory, the small volume, high efficiency is targeted by the establishment of epicyclic gear train. Multi objective fuzzy optimal design mathematical model is established to satisfy the constraint conditions, such as the constraint conditions and the strength constraints for the epicyclic gear train establishment.

3.2 The optimal solution model of the volume and efficiency function constraint

Each type of epicyclic gear train has its own optimal solution model of volume, efficiency function constraint. Now the process of optimal solution model establishment with the volume and efficiency function constraint is built through 2K-H[A] Reflux type epicyclic gear train as an example to illustrate.

(1) design variables

Design variable function

$$X = (x_1, x_2, \dots, x_{12})^T = (z_a, z_g, z_b, m_a, \phi_{da}, z_1, z_2, m_{12}, z_3, z_4, m_{34}, \phi_{d1})^T \quad (1)$$

In the equation, $z_a, z_g, z_b, z_1, z_2, z_3, z_4$ is the gear teeth number; m_a, m_{12}, m_{34} is gear modulus;

ϕ_{da}, ϕ_{d1} is the tooth width coefficient.

(2) objective function

1) General objective function expression

$$\min F(x) = (v(x), -\eta(x))^T \quad (2)$$

In the equation, $v(x)$ is Volume function; $\eta(x)$ is Efficiency function.

2) Volume function expression

$$V = \frac{\pi}{4} m_a^3 \phi_{da} z_a z_b^2 + \frac{\pi}{4} m_{34}^3 \phi_{d1} z_3 z_4^2 + \frac{\pi}{4} m_{12}^3 \phi_{d1} z_1 (z_1^2 + z_2^2) \quad (3)$$

3) Efficiency function expression

$$\eta = -\left[K_{aH} (\eta_a)^{\beta \gamma_a} + K_{bH} (\eta_b)^{\beta \gamma_b} \right]^\beta \quad (4)$$

$$\gamma_a = \operatorname{sgn} \frac{i_{ab}}{i_{ab} - i_{ab}^H}$$

$$\gamma_b = \operatorname{sgn} \frac{i_{ab}^H}{i_{ab}^H - i_{ab}}$$

In the equation, $K_{aH} = \frac{i_{ab}(1 - i_{ab}^H)}{\left[i_{ab}^H (\eta^H)^\alpha - 1 \right] (i_{ab} - i_{ab}^H)}$

$$K_{bH} = \frac{i_{ab} (i_{ab}^H - 1) (\eta^H)^\alpha}{\left[i_{ab}^H (\eta^H)^\alpha - 1 \right] (i_{ab} - i_{ab}^H)}$$

When $i_{ab}^H < 0, 0 < i_{ab}^H < \eta^H$ and $i_{ab}^H > 1/\eta^H$

$$\alpha = \operatorname{sgn} \left[\beta_b i_{ab}^H (1 - i_{ab}) (i_{ab} - i_{ab}^H) (i_{ab}^H - 1) \right]$$

When $\eta^H < i_{ab}^H < 1/\eta^H$

$$\alpha = \operatorname{sgn} \left[\gamma_b (i_{ab} - i_{ab}^H) (i_{ab}^H - 1) \right]$$

In the equation β is the master slave coefficient of the tie bar H, When the tied bar H is input component $\beta = +1$; When the tied bar H is output component $\beta = -1$; η_b, η_a is the transfer process efficiency between the sun gear a, the sun gear b and the output (for the tie bar H is input) or input parts (for the tie bar H is output). η^H is the conversion efficiency of the basis mechanism for differential gear train.

(3) Determination of optimal solution

The optimal solution equation

$$\mu_b(X^*) = \max \mu_b(X) = \max [\mu_v(X) \wedge \mu_n(X)] \quad (5)$$

The solution model is as follows:

Solution out, λ^*, X

The goal: $\max \lambda^* = \mu_b(X^*)$

Constraint as $C_j(x) \in G_j, j=0, 1, 2, \dots$ (Above normal function)

$C_j(x) \in G_j, j=0, 1, 2, \dots$ (Above normal function)

$U_v(x) \geq \lambda^*$ (Volume fuzzy objective function)

$U_n(x) \geq \lambda^*$ (Efficiency fuzzy objective constraint)

$0 \leq \lambda^* \leq 1$ (Membership degree constraint)

(4) Non fuzzy processing of fuzzy constraint variables

Based on the distribution of the membership function and the comprehensive evaluation standards, Fuzzy constraint variables are transformed into non fuzzy constrained variables by fuzzy principle, and the conversion equation of specific principle in this paper does not go into detail.

3.3 The optimal design example of fuzzy multi-objective epicyclic gear train

The transmission ratio $i_{ab}^0 = 40$ is known, input the speed of 960 r/min and the power of 30 kW, the tie bar is as Follower, $\eta = 0.6$ is the lowest efficiency. According to the design requirements of involute spur gear, such as precision grade 7, 45 steel materials, the epicyclic gear train is designed. The 2K-H[A] gear train can be design to obtain the structural parameters by the multi-objective fuzzy optimization for small volume, high efficiency. The results design results of the gear type and related documents are the same. The carrying capacity of indicators is reflected by the smallest diameter of D1, D2, D3, D4 of axis I, II, III, IV. Equation is:

$$d = 17.2 \left(\frac{M}{\tau_p} \right)^{\frac{1}{3}} \quad (6)$$

In the equation, M is the torque transmitted on the shaft. τ_p is a torsional shear stress on the shaft.

The calculation of design results are shown in table 2, Table 2 units of m^3 are V_{min} .

Table 2 Data results for design calculations

Design method	Design variables and related parameters																		
	z_a	z_g	z_b	z_1	z_2	z_3	z_4	ϕ_{da}	ϕ_{d1}	m_a	m_{12}	m_{34}	d_1	d_2	d_3	d_4	i_{aH}	η	V_{min}
Multi objective fuzzy optimization	1	5	12	2	4	1	7	0.7	0.7	8	10	12	10	3	5	6	39.	0.	0.2
	8	4	6	1	4	7	1	55	55				1	4	8	5	99	67	04

4. The parametric system of epicyclic gear train

4.1 Parameters of the overall process of epicyclic gear train

In this paper the system is mainly to complete two main tasks of fuzzy optimization design and parameter assemble to achieve the parameters of epicyclic gear trains.

4.2 Parameterized program design

After the creation of the parts model is complete, the menu "tools / programs" option is selected, and from the "menu manager" panel, and then select "edit design" to open the program edit window, then the design parameters are defined and prompted to add to the INPUT... INPUT END, the relations add to RELATIONS... RELATIONS. Program is process recording for the operation and this record is to save in the form of the program. In the range provided by the Program, the design of the parts is changed by modifying the parameters of the Program.

4.3 Parameter assembly step by Pro/E

On the Pro/ENGINEER platform, the secondary development is conducted by the Pro/Program module, the main process of 3D parametric modeling for assembly fitting is as follows:)

- 1) To determine each independent variable parameter of the total assembly, The INPUT Pro/Program statement is used to receive the various independent variables from the user.
- 2) According to the function, principle and structure of the assembly, the assembly relations are analyzed between the sub-assemblies, the parameter coordination relations are obtained between the assembly and the sub-assemblies. The desired variable parameter values of the variable sub assembly are obtained by a variety of computing relational statements in the Pro/Program according to the above parameter relations. Then use the Pro/Program EXECUTE statement, these parameters values to be passed to the sub assembly.
- 3) The parameter coordination relations are confirmed between the parts, according to these relationships, the variable parameters are converted to the variable parameter values and the assembly position dimension value of each part. By using the EXECUTE statement, the variable parameter values needed for each part can be transferred to the corresponding parts.
- 4) Variable parameters can be passed through the parent assembly in the part. According to the assembly relations of the parts, function and structure, the received variable parameter is transformed into the variable's size value. The new parts are generated by new parameters and to realize parametric modeling in the model of regenerating.

4.4 Achieve the parameters of epicyclic gear train

- 1) Complete assembly of the gear train of components in the Pro/ENGINEER environment, then appropriate program code and control components of assembly parameters are added to the program list generated by Pro/PROGRAM module to modify the size of the parts and replace parts, etc. Open the sample component model, use the regeneration command, call the program run, display operation menu; input: the model will be update with the input parameters of the system, as shown in Figure 2.
- 2) Read the file: the parameter values are read in the file. Parameter data that need to be changed is written with notepad or writing board provided by Windows, and File extension must be DAT or TXT file. According to the prompt box of the reading file, enter the file name that read data, the new model is recycled, as shown in Figure 3.

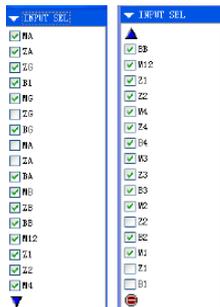


Figure 2 Display gear parameter modification

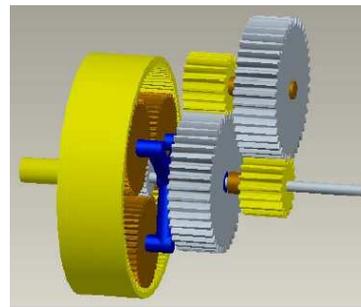


Figure 3 The new modification parameters of epicyclic gear train

5. Conclusions

The parametric design method of gear train can make overall target level of optimization design to achieve a higher level, to obtain a more ideal optimization effect. The parametric design and assembly of parametric CAD

system for epicyclic gear train can greatly reduce the designers' labor intensity and time, and provide a more convenient and quick way for engineering application.

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7.References

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