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Research on Modern Design Methods for Synchronizer

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ABSTRACT: Modern design methods of synchronizer based on optimal design, parametric modeling and virtual prototype simulation are proposed in this paper, because the development cycle of synchronizer is long by using traditional design methods. Acontact wearmodel of synchronizer lock ringsis established, which is based on principles of tribology and Majundar-Bhushan fractal contact model. The life of the synchronizer is improved by optimization design with shift frequency as the objective function,and this paper obtainssynchronizer structural parameters. Then the 3D assembly model of synchronizer is established by importing synchronizer structural parameters to the design systembased on UG secondary development and simulated in ADAMS. According to the simulation results, the optimized synchronizer has longer life than before, which is consistent with the theoretical optimization design.

Keyword:moderndesign methods, UG secondary development, synchronizer life, ADAMS simulation

I. INTRODUCTION

Synchronizer is one of important parts of the automobile manual transmission and automatic mechanical transmission, which make the angle velocity of input equal to the output's,using conical surface friction torque before shifting to avoid producing impact of different speed shift. The quality of synchronizer design has an important influence on the comfort of the shift and the transmission life. Traditional synchronizer design methodsare adopted to design experience with repeated prototype testing, a number of amendments approach to design, which also need several tests to verify the performance of the whole transmission design. So it has great limitations and blindness in the design and development, with not only a long design and development cycle, but also enormous human and financial resources, and also very difficult to obtain the ideal solution.

Based on a five or six-speed synchronizer, a mathematical model of synchronizer lock ring contact wear is established, which is based on principles of tribology and Majundar-Bhushan fractal theory. Then the life of synchronizer optimization design model is established and using improved particle swarm algorithm to work out the structural parameters of the optimal life of synchronizer. Finally, the ADAMS dynamics model of synchronizer is established through the Parasolid format by connecting UG and ADAMS, and the motion process of synchronizer is simulated to verify the accuracy of the 3D model of the synchronizer, which provides the reference for synchronizer design and development, flow chart shows as fig.1.

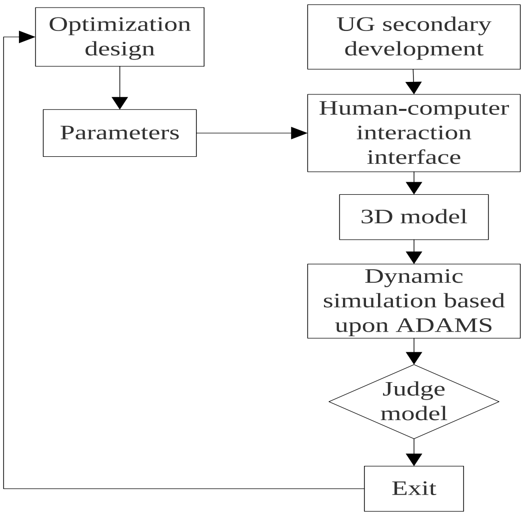

Fig.1 Flow chart of modern design method

II. SYNCHRONIZER OPTIMIZATION DESIGN

2.1 Design variable

When designing the synchronizer, it is required to meet the synchronization performance and the performance of the lock. According to the performance requirements of the synchronizer, the following five parameters are selected as the design variables.

$$\{X\}=(\alpha,\beta,R,r,B)^{-1} \quad (1)$$

Among above formulas (1), α stands for cone semi angle of lock ring; β stands for synchronizer lock angle; R stands for synchronizer cone friction radius on average; r stands for lock ring locking surface average radius; B stands for work cone width.

2.2 Objective function

The life of the synchronizer is always a difficult point to design and develop. Although the scholars have done a lot of work for the optimization design of the synchronizer, most of them are based on the synchronization time [1] of the synchronizer and the shift characteristics of the synchronizer [2]. In this paper, the parameter optimization design is carried out with the objective function of the life of the synchronizer. In which, a mathematical model of the wear ring is established firstly and then the objective function of the synchronizer is determined.

2.2.1 Assumptions of lock ring wear model

The following assumptions are set up in this article about the lock ring wear mathematical model.

(1) It is assumed that the wear process of the synchronizer is in a stable stage.

(2) In the wear process, the fractal dimension, D is assumed to remain unchanged.

(3) In the process of synchronization, lock ring axial thrust, F is assumed to remain unchanged.

2.2.2 Establish lock ring wear model

Chen Hong studies in the literature [3]that synchronizer ring is mainly adhesive wear mode. The follow formula of the adhesive wear was obtained in 1966, which is proposed by Rowe and revised according to Archard's adhesive wear theory [4].

$$V=K\cdot L\cdot\beta\cdot\frac{F_a}{\sigma_s}\cdot(1+9\mu)^{1/2} \quad (2)$$

Among above formula, expression β[5] shows as formula (3):

$$\beta=1-\exp\left[-14.4\times10^5\left(\frac{T_m^{\frac{1}{2}}}{vM^{\frac{1}{2}}}\right)\exp\left(-\frac{E_c}{R'T_s}\right)\right] \quad (3)$$

$$F_a=\frac{F}{\sin\alpha} \quad (4)$$

Among above formulas, K stands for wearcoefficient; L stands for the relative sliding distance ; F_a stands for normal load of lock ring ; σ_s stands for yield limit of soft material ; β stands for coefficient related to surface film ; T_m stands for lubricating oil temperature; v stands for relative sliding speed; M stands for lubricating oil molecular weight ; E_c stands for lubricating oil adsorption heat ; R' stands for gas constant ; T_s stands for contact point temperature ; μ stands for friction coefficient ; F stands for axial thrust of lock ring.

The external load of ideal elastic plastic material is expressed by the formula (5)[6]:

$$F_a=A_r\cdot\sigma_s \quad (5)$$

Among formula, A_r stands for real contact area.

In the actual wear process, the contact surface is mostly elastic deformation and plastic deformation of the mixed state. Therefore, formula (6) is established:

$$KA_r = K_e A_{re} + K_p A_{rp} \quad (6)$$

Among above formula: A_{re} stands for elastic contact area; A_{rp} stands for plastic contact area; K_p stands for plastic contact wear coefficient; K_e stands for elastic contact wear coefficient。

The comparison expression of adhesive wear is obtained from formula (2)、(5)、(6):

$$V = \left(\left(K_e - K_p\right) A_{re} + K_p A_r\right) L \cdot \beta \cdot \left(1+9\mu\right)^{\frac{1}{2}} \quad (7)$$

A large number of studies show that the machined surface profile has statistical self-affine fractal characteristics [7]; Different machining surface roughness profiles observed in different magnification are very similar in the structure. This feature can be characterized by fractal geometry.

In 1991, Majumdar and Bhushan proposed the M-B fractal contact model [6], whose theoretical equation shows as follow:

$$\frac{A_{re}}{A_r} = 1 - \left[\frac{DG^2}{2-D}\frac{1}{A_r}\left(\frac{\pi E^2}{225\sigma_s^2}\right)^{\frac{1}{(D-1)}}\right]^{\frac{(2-D)}{2}} \psi \frac{\left(D-2\right)^2}{4} \quad (8)$$

Among above formula: D stands for fractal dimension; G stand for fractal parameters of surface profile; E stands for composite elastic modulus; ψ stands for correction factor.

Wear depth ratio from formula (4)、(7)、(8) :

$$h^* = \frac{F}{\sigma_s \cdot \sin\alpha \cdot A_a} \cdot V_s \cdot \gamma \cdot \left(1+9\mu^2\right)^{\frac{1}{2}} \left\{K_e + \left(K_p - K_e\right)\left[\frac{DG^2}{2-D}\frac{1}{A_r}\left(\frac{\pi E^2}{225\sigma_s^2}\right)^{\frac{1}{(D-1)}}\right]^{\frac{(2-D)}{2}} \psi \frac{\left(D-2\right)^2}{4}\right\} \quad (9)$$

Among formula: A_α stands for nominal contact area.

2.2.3 Determination of objective function

The relationship between the backup allowance and synchronizer lock ring wear is shown in Figure 2.

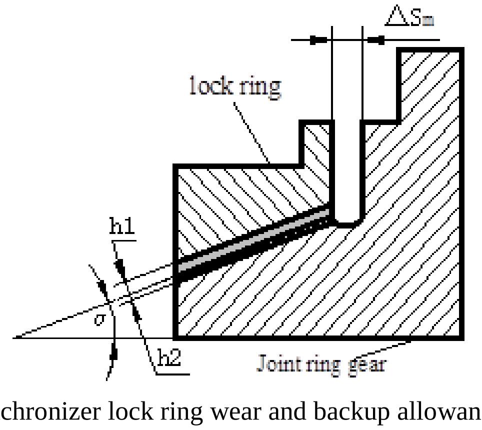

Fig.2 Synchronizer lock ring wear and backup allowance diagram

By figure (2), the relationship between the number of gear shift of synchronizer shown as formula (10):

$$N = \frac{\Delta S_m \sin\alpha}{\left(h_1^* + h_2^*\right) \cdot t_E} \quad (10)$$

Among above formula: ΔS_m stands for backup allowance; h_1^* stands forthe lock ring wear depth rate; h_2^* stands forthe joint ring gear wear depth rate; t_E stands forsynchronizer synchronization time.

Synchronization time from reference [8] shown as formula (11):

$$t_E = \frac{\omega_0 J_c J_v (r-1)}{T_c (J_c + J_v) + M_c J_v - M_v J_c} \quad (11)$$

In which: $Tc = \frac{\mu F R_m}{\sin\alpha}$ (12)

Among above formulas: ω_0 stands for Output angular velocity; J_c stands forrotational inertia of input end; J_v stands for rotational inertia of output end; *r* stands for five files in sixth gear transmission ratio; T_c stands forfrictional resisting moment; M_c stands forthe drag torque of input end; M_v stands fordrag torque of output end; R_m stands forlock ring friction radius on average。

The literature [9] shows that when the lock ring material is a special brass, wear amount of the coupling member is 0.138 times than the lock ring.

So：$h_2^* = 0.138 \cdot h_1^*$ (13)

Synchronizer life relation is obtained by taking formula (13) into formula (10), shown as formula (14):

$$N = \frac{\Delta S_m \sin\alpha}{1.138 \cdot h_1^* \cdot t_E} \quad (14)$$

2.3 Constraint condition

The selection of constraint conditions determines the degree of similarity between the optimization results and the actual situation of the project. The following constraints are selected according to the design requirements of the synchronization [10].

The condition preventing the conical self-locking:

$$\tan\alpha > \mu \quad (15)$$

The conditions meeting synchronizer locking:

$$\tan\beta \geq \frac{R \cdot \sin\alpha - \mu\mu_1 r}{\mu_1 R \sin\alpha + \mu r} \quad (16)$$

Among formula, μ_1 stands for the plum angle of friction coefficient of the lock ring and joint sets.

Friction cone pressure conditions:

$$p = \frac{T_c}{2\pi\mu B R^2} \leq [p] \quad (17)$$

Average friction cone radius to work cone width ratio:

$$2.5 \leq \frac{R}{B} \leq 4 \quad (18)$$

Meet high-grade synchronizer synchronization time:

$$0.15 \leq t_E \leq 0.3 \quad (19)$$

Meet Synchronizer axial thrust:

$$100 \leq F \leq 350 \quad (20)$$

2.4 Solution of optimized mathematical model

According to the established optimization mathematical model, we can see that the optimization is a nonlinear single objective and multi-constraint problem. The solution of this kind of problem can be solved by genetic algorithm, ant colony, simulated annealing and particle swarm optimization [11-14]. In this paper, the improved particle swarm optimization algorithm—the adaptive particle swarm optimization algorithm is choused and the optimization process is shown in Figure 3.

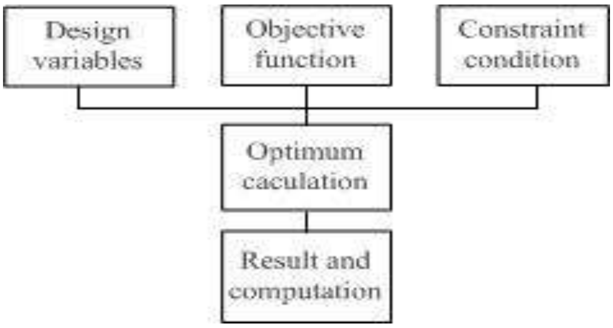

Fig.3 The optimization process

Assuming that the shift force in the synchronization process is 300N and remains unchanged, some of the main parameter values are shown in table 1.

Table1. Parameters of synchronizer optimization model

Parameter	Value
Elastic contact wear coefficient K_e	3×10^{-7}
Plastic contact wear coefficientK_p	3×10^{-5}
Yield limit of soft materialσ_s/Pa	1.2×10^{8}
Nominal contact areaA_a/m^2	1.981×10^{-3}
Fractal dimensionD	1.4
Fractal parameters of surfaceprofileG	2×10^{9}
Composite elastic modulusE/Pa	2.06×10^{11}
Correction factorΨ	2.085

In the solving process, this paper set the population size is 40; the evolution times are 150, getting the relation curve between the fitness of synchronizer shifting frequency and the number of iterations, shown in figure 4.

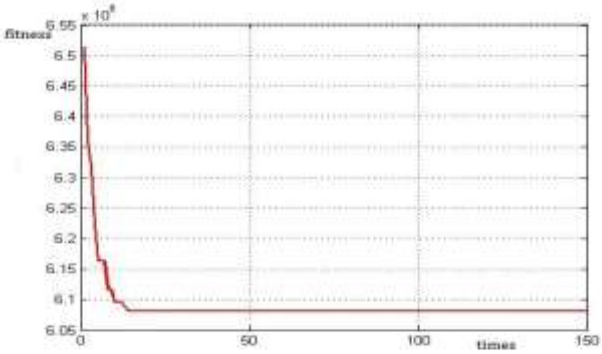

Fig.4 Relation curve between fitness and iterations

Table2. Design variables and objective function compared before and after

design variables and objective function	before	after
α/°	6.5	6.2
β/°	57	63
R/m	0.036	0.034
r/m	0.042	0.0452
B/m	0.0085	0.0091
N/次	437410	608160

From the results of Table 2, we can know that the number of the optimized shift is improved by 39%.

III. PARAMETRIC DESIGN OF SYNCHRONIZER

At present, the mainstream CAD software of mechanical industry has strong solid modeling and parametric design function, but it is necessary to improve the efficiency of the two developments.

3.1 Introduction of UG secondary development

UG secondary development provides UIStyler dialog editor, Menu Script menu script language for creating the synchronizer in UG custom menu and dialog box, NX open application programming interface (API) supports C, C#, VB. Net and other high-level programming language, reducing the difficulty of programming and improving the programming efficiency.

3.2 Human-computer interaction interface

In the human-computer interaction design need to configure the system environment variables, right click on the "computer" - properties - advanced system settings - advanced - > new user variables, and set the variable name " UGII_USER_DIR ", the value of the variable is the parametric modeling of the synchronizer files directory. This paper built three new sub folders in the file directory “application”、“startup”、“grip”.

3.2.1 The design of main menu

New *.men files in the sub directory folder “startup”, using notepad to write the text as follows:

```
Version 120
Edit Ug_Gateway_Main_Menubar
After Ug_Application
Cascade_Button Menu_Name_1
Label Parametric Design System Of Synchronizer.
End_Of_After
Menu Menu_Name_1
Button Menu_Name_21
Label
Actions Sleeve.Dlg
Button Menu_Name_22
Label
Actions Splined Hub.Dlg
Button Menu_Name_23
Label
Actions Synchronous Ring.Dlg
Button Menu_Name_24
Label
Actions Gear.Dlg
Button Menu_Name_25
Label
Actions Assembly.dlg
    END_OF_MENU
```

3.2.2 The design of dialogue box

In UIStylerinterface editor, the assembly design of dialog boxes are respectively established of joint sets, splined hub, synchronous ring, joint ring gear and synchronizer by setting the labels and data input box control.

The dialog will be saved as a C language format, UG system will generate 3 template files: *.h, *.dlg, *_template.c. And *.dlg stored in the sub directory folder "application".

3.3 Parametric modeling

In the process of parametric modeling, API calls the GRIP program and the transfer between the dialog box data and the GRIP program is the key to the design of the parameters of the synchronizer. It is need to use the ufargs function to call the dialog box data when writing synchronizer parts modeling program using GRIP. During visual studio2010 loading dialog templates. Adding UF_call_grip in the callback function to invoke the GRIP program, *dll file can be generated through the compiler, then save *dll files in the subdirectory "startup" folder.

In the main menu, click on the corresponding parts design to call the dialog box to complete the design and assembly of the corresponding parts, Figure 5 and figure 6, respectively, for the joint sets of design and the design of the synchronization.

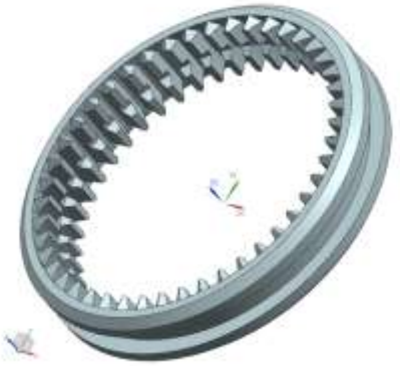

Fig.5 Parameterized 3D modelof joint**Fig.6** Synchronizer assembly model

IV.

V. SYNCHRONIZER VIRTUAL PROTOTYPE SIMULATIONS

4.1 Modeling in ADAMS

The UG parameterized 3D assembly model is imported into the ADAMS/View module for pretreatment, using Parasoid format. In addition to define the part name, material properties, and contact force, forces of constraint, but also need to set the moment of inertia of input end and the output end, initial velocity and the moment of resistance, and shifting force applied in the joint sleeve. The main parameters of the synchronizer set as shown in Table 3. In order to avoid the influence of contact force penetration in motion simulation, the simulation time is 0.5s, and the simulation step is 5000 steps in the ADAMS model.

Table3. Parameters of synchronizer

Parameter	Value
Rotational inertia of input shaft$J_c/(\mathrm{kg \cdot mm^2})$	2.3×10^7
Rotational inertia of output shaft$J_c/(\mathrm{kg \cdot mm^2})$	2.5×10^7
Cone friction factorμ	0.1
Friction cone half Angle$/°$	6.5
shifting forceF/N	300
Cone big end circle radiusR/mm	36.21
Cone small end round radiusr/mm	36.13
Average friction cone radiusR_m/mm	36.17

4.2 Synchronizer synchronization process simulation

According to the simulation results of the ADAMS model, the joint displacement curve, angular velocity curve of the input end and the output end can be obtained through the post processing. As shown in figure 9:

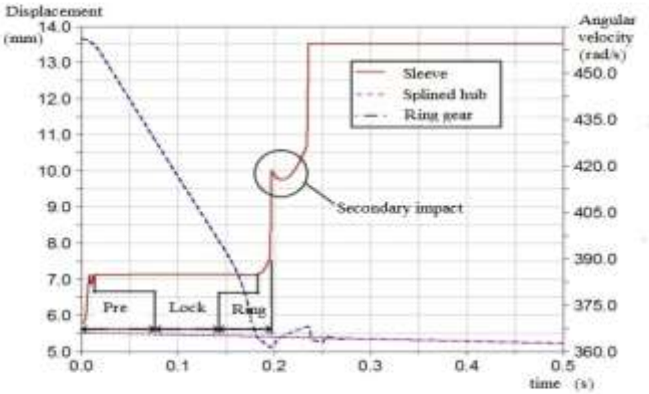

Fig.7 Synchronizer simulation results

Through the simulation curve of Figure7, we can know that the synchronization performance and the locking performance are verified by the model of the synchronous machine parameters assembly model established by UG two times, which verifies the accuracy of the 3D model.

4.3Synchronizer friction work

Synchronizer life can be expressed by the normal shift times, can also use the unit friction cone friction work said [15]. The allowable slip [16] of the synchronizer is 1.62J/mm^2, and the friction work is as shown in the formula (21) [10]:

$$W_s = \int_0^{t_E} \lambda T_c \left(\omega_v - \omega_c\right) dt = \frac{1}{2} T_c \left(\omega_v - \omega_c\right) t_E \quad (21)$$

Among formula: λ stands for sign function, shift up to 1, down to 1.

The graphs of friction cone torque and friction work obtained by ADAMS simulation shown asFig.10.

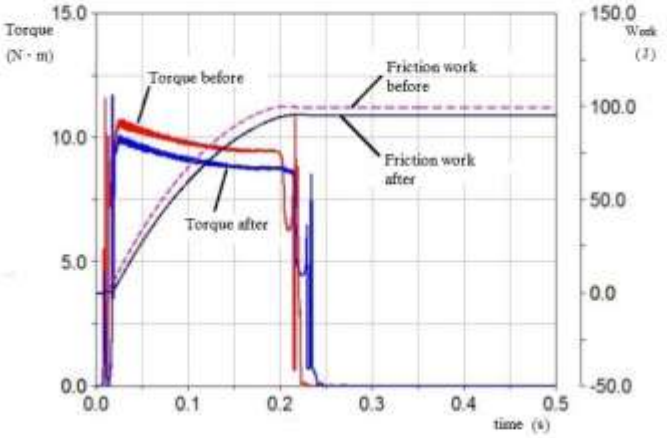

Fig.8 Torque and friction work before and after optimization

In Figure 8, the torque comparison before and after optimization shows that in the pre- synchronization phase and dial ring phase, torque fluctuations, and in locking phase, torque has a decreasing trend, but basically stabilized. The torque comparison before and after optimization is shown in Table 4

Table 4 shows that the error of torque theory and simulation is very small, which can be directly used to replace the theoretical value calculated by simulation value.

Table4. Torque value before and after

Value and Error	Before	After
theoretical value/N·m	9.54	9.44
emulation value/N·m	9.97	9.3
error/%	4.5	1.48

Figure8.shows friction work before and after the optimization respective are 99J and 95J. So the unit area friction work before and after the optimization respective are 0.052 J/mm^2 and 0.049 J/mm^{2,} both less than the

allowable sliding wear work value, which meet the design requirements. Due to the value of unit area friction work before optimization is bigger than after, we can know the optimization have a larger life after optimization, which is identical with synchronizer life expressed by the shift frequency in the optimum design.

VI. CONCLUSIONS

(1) The model of synchronizer lock ring contact wearis established, which is based on principles of tribology and Majundar-Bhushan fractal contact model. And get synchronizer performance parameters by choosing the synchronizer life as optimization goal, which make the life of the synchronizer increased by 39%, and provide a reference for design of synchronizer.

(2) Using UG secondary development to build 3D model of synchronizer parts fast and assemble, it can quickly shorten the development cycle

(3) Through the ADAMS simulation, we can know that the synchronizer friction work of per unit area after optimization is smaller than before, and the life of the optimized synchronization device is relatively large, and the results are consistent with the conclusion (1).

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