Advanced Materials Research *Online: 2012-02-27*
ISSN: 1662-8985, Vols. 479-481, pp 876-879
doi:10.4028/www.scientific.net/AMR.479-481.876

Design for NGW Type Planetary Gear Transmission

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Keywords: NGW Type, Planetary Gear Transmission, Optimization Design, Parametric Drawing

Abstract. This article analyzes the NGW type planetary gear transmission mechanism and structure, establishes boundary constraint conditions and mathematics optimization model in view of the smallest volume's project objective. It can realize the NGW type planetary gear transmission optimization design through compiling corresponding computer program, obtain the optimization design parameters. In optimization design's foundation, it applies the CAD technology to establish drawing program, realizes the parametric drawing.

Introduction

Planetary gear transmission is used widely in machinery, electronic, energy and other industries for its big transmission ratio, compact structure, high efficiency. But it has many transmission types, the design process is complex, it is difficult to obtain the perfect plan when we choose related parameters.

In order to raise the design efficiency and guarantee the design quality, it is extremely essential to carry on optimization design and parametric drawing for the planetary gear transmission. It can enable planetary gear transmission to achieve the optimum condition through choosing the most superior parameters to reduce the weight and the cost, enhance the supporting capacity. In the parametric drawing process, it can produce automatically the new blueprint by the computer through revising few parameters. This article takes the NGW type planetary gear transmission as the optimized object, takes the smallest volume as the optimization design goal, establishes boundary conditions and mathematics optimization model, compiles optimization procedure to obtain the optimized parameters. We realize optimization design using Visual C++ 6.0, and take Visual Lisp as re-development kit to establish plotting program to realize parametric drawing in AutoCAD platform.

NGW type planetary gear transmission structure composition and transmission characteristic

As shown in Fig.1 is the NGW type planetary gear transmission diagram, the key components include moving sun gear a, fixed inter gear b, planetary gear g, planet carrier H, and so on. The NGW type planetary gear transmission has simple structure, it is easy to manufacture, its external dimension is small, quality is small, transmission efficiency is higher. Usually, its velocity ratio scope is $i_{aH}^{b} = 28 - 13$, the transmission power P value is not limited, transmission efficiency $\eta_{aH}^{b} = 0.97 - 0.99$. At present this transmission type has obtained widespread application[1,2].

Optimization design

Objective function choice. In order to reduce the gear train volume, reduce the cost, we take the volume sum of the sun gear and all planetary gears as objective function in the known load, working conditions and the gear material's situation. To simplify computation, we replace approximately gear's volume with the gear pitch line column volume, then the objective function may be represented as given below.

$$V(X) = \frac{\pi}{4} m^3 \phi_d z_a [z_a^2 + n_p z_g^2] \tag{1}$$

Where, m is gears' module; ϕ_d is tooth width coefficient; z_a is sun gear's number of teeth; n_p is the number of planetary gear, here takes $n_p = 3$; z_g is planetary gear's number of teeth.

Design variables' determination. When we carry on the optimization design for planetary gear transmission, the design variables that we often select include: module m, number of teeth z_a, z_g, z_b, tooth width coefficient ϕ_d, therefore design variables are given below.

$$\boldsymbol{X} = [x_1, x_2, x_3, x_4, x_5] = [z_a, z_g, z_b, m, \phi_d]^T \tag{2}$$

Constraints establishment. The several aspects constraints are given below.

- Matches tooth condition restraint [1,2].
  - Velocity ratio i_p condition:

$$i_p = i_{aH}^b = 1 - i_{ab}^H = 1 + \frac{z_b}{z_a} \tag{3}$$

  - Concentric condition: When the modules of various counter gears are the same, teeth calculation formula of various gear is given below according to the concentric condition:

$$z_a + 2z_c = z_b \tag{4}$$

  - Adjacency condition: In planetary gear transmission design, we often symmetrically arrange several planetary gears to carry on the power divergence, sharp bearing capacity. In order to cause various planetary gears not to produce collides mutually, must guarantee to have certain gap between their addendums in their company core, namely satisfies the following condition:

$$d_{ag} < 2a'_{ag} \sin\frac{\pi}{n_p} \tag{5}$$

Where, d_{ag} is planetary gear's addendum circle diameter; a'_{ag} is counter gear vice-center distance.

  - Install condition:

$$\frac{z_a + z_b}{n_p} = C \quad \text{(integer)} \tag{6}$$

- Velocity ratio relative error condition.

$$\Delta i = \frac{|i_P - i|}{i_P} \le 0.04 \tag{7}$$

Where, Δi is velocity ratio relative error; i_P is assigned ratio; i is actual ratio.

- Standard module condition.

In the general power drive, the module should not be smaller than 2mm [3]. Therefore the standard module condition is given below.

$$2 \le m \le 50 \tag{8}$$

- The Smallest efficiency condition.

Efficiency calculation formula and efficiency's minimum value are given below [1,2].

$$\eta_{aH}^b = 1 - \frac{z_b}{z_a + z_b}\psi^H \tag{9}$$

$$\eta_{min} \ge 0.5 \tag{10}$$

- The gear width coefficient condition [1].

$$0.80 \le \phi_d \le 1.40 \tag{11}$$

- The gear teeth contact intensity's condition and bending intensity's condition [1].

Based the steeliness standard straight spur gear teeth contact intensity's and bending intensity's request, the conditions which must satisfy are given below.

$$d_1 \geq K_{\mathrm{d}} \sqrt[3]{\frac{T_1 K_{\mathrm{A}} K_{\mathrm{H}\Sigma} K_{\mathrm{Hp}}}{\phi_{\mathrm{d}} \sigma_{\mathrm{Hlim}}^2} \times \frac{u+1}{u}} \tag{12}$$

$$m \geq K_{\mathrm{m}} \sqrt[3]{\frac{T_1 K_{\mathrm{A}} K_{\mathrm{F}\Sigma} K_{\mathrm{Fp}} Y_{\mathrm{Fa1}}}{\phi_{\mathrm{d}} z_1^2 \sigma_{\mathrm{Flim}}}} \tag{13}$$

Where, K_{d} and K_{m} are mathematical formula coefficients; d_1 is pinion 1 pitch line diameter; σ_{Hlim} and σ_{Flim} are experiment gear's contact fatigue limit and tooth root bending fatigue limit (MPa); T_1 is pinion's nominal torque; K_{A} is service factor; $K_{\mathrm{H}\Sigma}$ and $K_{\mathrm{F}\Sigma}$ are correlation coefficients; K_{HP} and K_{FP} are load assignment nonuniformity coefficients between the planetary gears; u --number of teeth ratio, $u = z_2/z_1$; Y_{Fa} is tooth profile coefficient; z_1 is pinion number of teeth.

Optimized procedure compilation. This mathematical model includes five design variables, there are integer variable and solid pattern variable; the continual variable and the discrete variables. There are equality constraint condition and the inequality constraint condition. We use the dimensionality reduction method to change the three-dimensional problem into one-dimensional question. Compiled program by using *C* language.

Example: According to the following data, design NGW type planetary transmission: The velocity ratio $i_{\mathrm{p}} = 10$, input rotational speed $n_1 = 960\,\mathrm{r/min}$, input power $P_1 = 20\,\mathrm{KW}$, the efficiency is not lower than 0.5, the sun gear a is primarily moving part, the involute standard straight spur gear, the precision class 6 levels, this system is used mainly in the power drive.

We can obtain the optimal solution through inputting known data in the data window and operating procedure. The optimization design data is showed in Table 1. The design result indicates that the minimum volume of optimization design reduces 13.39% compared to the conventional design, moreover the operating speed is quick, may obtain the computed result in the extremely short time.

Table 1 Design result data

variables	z_{a}	z_{g}	z_{b}	m	ϕ_d	$\eta_{\mathrm{aH}}^{\mathrm{b}}$	$i_{\mathrm{aH}}^{\mathrm{b}}$	$V_{\min}$
conventional design result	17	67	151	4	1.00	0.97753	9.8824	1.175 47e+ 007
optimization design result	22	89	200	3	0.90	0.97747	10.0909	1.018 07e+ 007

Parametric drawing

AutoCAD permit user to improve and expand its function through the open style architecture, to realize the re-development. We can take the basic parameters as the variables and compile program to define the graph by using the components' similarity in shape. The program can automatically realize the parametric drawing after inputting the basic parameters [4].

We compile components (planet carrier, gear, axis, etc.) parametric drawing program with Visual Lisp language by using the AutoCAD re-development function, arrange organically procedure modules of all parts together, call each procedure module according to certain logical order to realize assembly drawing. The following statements are part program of parametric assembly drawing according to the optimization result data, the final assembly drawing is shown in Fig.2.

```
(defun Axing(      )                    ; Start final assembly drawing.
(setq f (open "E:\\dat\\Axing.dat" "r"))  ; Read parameter value.
……
(close f)   ; Close the file.
(command "dimasz" 9) ; Dimension style settings.
……
(command "-linetype" "l" "*" "" "") ; Linear settings.
```

……

(zzht z_a z_g z_b m ϕ_d d_1 d_2 d_3) ; Execute assembly drawing function.

……

(defun dz(z_a z_g z_b m ϕ_d d_1 d_2 d_3))； Call the first axis function.

……

(defun xxj(z_a z_g m ϕ_d d_1 d_2 d_3)) ； Call planet carrier function.

……

(defun sga (z_a z_g m ϕ_d d_1 d_2 d_3));Call sun gear function.

……

(defun xt() ; Call case function.

…… ; Program end.

)

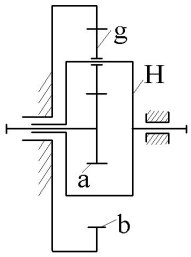

Fig.1 NGW type planetary gear transmission diagram

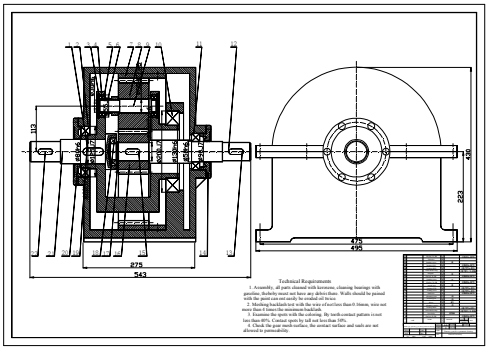

Fig.2 Parametric assembly drawing

Conclusions

We take the minimum volume as the goal to carry on the optimization design for planetary gear transmission, obtain the optimization result that is more reasonable than the conventional design result. The optimized result indicates that this method is successful. The readability of parametric drawing procedure is good, operation is simple. In the design process, it is possible to automatically produce the new design drawing by the computer through revising few parameters. This article has realized integration operation of optimization design and parametric drawing. This method can provides convenience for designers, raised the working efficiency.

Acknowledgements

This work was supported by Provincial Natural Science Foundation of Heilongjiang, China(No.E200912).

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