Computer-aided Design of Transmission Shaft and Rolling Contact Bearing Selection based on Expert System

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Abstract: In order to solve the inefficiency problem in traditional method of transmission shaft design, this paper analyzes the strength and deformation of rotation step shaft through computer program. These bearings have a large number of transmission elements, such as: gear, pulley, etc. Three dimensional modeling is applied to all of them. Moreover, a motion analysis can be made by detecting the force implemented on the transmission shaft. The finite element method is applied to calculate V shaped groove of stress concentration which is presented in a diagram, and finally, the optimal rolling contact bearing is selected based on the knowledge of expert system.

1 INTRODUCTION

To adopt the traditional method to design and analyze machine parts is a quite troublesome job. Recently, computer-aided design and analysis is introduced into this field. Therein, the transmission shaft is used to transmit force and motion, the corresponding design requires a large number of calculation and diagrams. The method of computer-aided modeling can be used to effectively design the transmission shaft and reduce plentiful of work amount. The software adopted in computer-aided design can be independently developed or resorted to the existing commercial software.

The force-transmit element on the transmission shaft must be accurately positioned. It is advised to use the shaft shoulder of step shaft to make sure that these elements are aligned to the coordinate of the shaft and assembled. Besides, the stress analysis for special points on the shaft must also be taken into consideration.

This paper studies the computer-aided analysis of transmission shaft under two dimension conditions and supposes that the force-transmit element be able to bear imaginable force. The more the elements on the shaft are, the more complicated the analysis will be. If the influence of stress concentration is taken into consideration, plus application of the traditional solution, the calculation will be very time-consuming and complicated. Furthermore, stress concentration data presented in diagrams is inconvenient for reading. The purpose of this paper is to analyze and select the optimal diameter of shaft, so as to make it strong and rigid enough to satisfy the stipulated conditions. The computer program is applied to obtain the optimal parameters for critical section and the stress concentration data is formulized and adjusted to adapt to the needs for being entered into computer. Based on the aforesaid calculation, under provided assembling condition of the shaft, the optimal rolling contact bearing can be selected. The realization of the aforesaid function cannot occur without the assistance of expert system. It can serve

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the specific application of selecting materials for the cutter and designing the cutter. Please consult the relevant literature for specific details.

2 STEP SHAFT DESIGN

This paper studies the two aspects of shaft design, i.e., deflection and rigidity, pressure and strength. Deflection and rigidity covers the two kinds of motions of bending and twisting, deflection and the inclination of force bearing point. Pressure and strength involves fatigue strength and stability. The theoretic data is shown in Table I:

Table 1:Theoretic data of bending shaft K_T .

$\frac{D}{d}$	K_T 【Note: A=（$\frac{r}{d}$）】
1.01	$0.9034\times A^{-0.18}$
1.02	$0.938\times A^{-0.19}$
1.03	$0.95\ A^{-0.2}$
1.05	$0.956\times A^{-0.21}$
1.1	$0.9496\times A^{-0.23}$
1.2	$0.926\times A^{-0.25}$
1.5	$0.916\times A^{-0.27}$
2	$0.896\times A^{-0.3}$

2.1 Influencing Factors and Linear Regression

When the shaft bears completely reverse bending force and stable torque, the critical bending stress generally lies in the stress concentration point. Stress concentration generally occurs within limited range where geometric shapes are not continuous, for example, the v-shaped groove. At the time of designing the equation, the influence from stress concentration must be taken into account. With various factors having been taken into consideration, the calculation formula for shaft diameter is as follows:

$$d=\left\{\frac{32*n}{\pi}\left[\left(\frac{K_f*M_a}{S_e}\right)^2+\frac{T_m}{S_{ut}}^2\right]\right\}^{\frac{1}{3}} \tag{1}$$

Where, M_a is bending moment, T_m is torque, n is safety coefficient, S_{ut} is the ultimate strength of material.

$S_e=K_b*K_c*K_d S_e'$, $K_f=1+q(K_T-1)$ is fatigue stress concentration factor. K_b, K_c, K_d respectively represent dimension, groove and surface factor. q is the V-shaped groove sensitive factor. The calculation formula for K_T is as follows:

$$K_T=\sum_1^6 K_{Ti}\left(\frac{r}{d}\right)^{i-1} \tag{2}$$

where,

$K_{T1}=-6.72706+11.681B-3.43687B^2$,
$K_{T2}=86.932-145.8B+41.022B^2$,
$K_{T3}=-399.4+867.15B-217.8B^2$,
$K_{T4}=416.66-2495B+462.15B^2$,
$K_{T5}=1946.7+2919.4B+4.86167B^2$,
$K_{T6}=-4161-515.5B-857.7B^2$.
$B=\frac{D}{d}$

2.2 Deflection Analysis

Deflection analysis cannot be started unless the geometric shape of the shaft is completely

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determined. It is one function for complete geometric shape of the shaft. Meanwhile, the pressure of the point we are studying is the function for the deformation and motion of this point. Therefore, in case of designing and analyzing step shaft, pressure and strength calculation must be taken into consideration. In the meanwhile of determining the deflection, the dimension of the shaft must be given. The mixed torque borne by step shaft comes from the axial force of spiral and helical gears. Therefore, deflection calculation adopts elastic limit rather than curvature radius ρ . The calculation formula for curvature radius ρ :

$$\frac{1}{\rho} = \pm \frac{\frac{d^2 y}{d x^2}}{\left[1 + \frac{dy}{dx}^2\right]^{\frac{3}{2}}} \quad (4)$$

The calculation formula for shaft camber y can be obtained by using finite element method.

$$-y_{i+3} + 4y_{i+2} - 5y_{i+1} + 2y_i = \frac{h^2}{EI}\left(M_{i-1} - 2M_i + M_{i+1}\right) \quad (5)$$

h is pitch, E is elastic limit, M is bending moment and I is moment of inertia.

3 COMPUTER PROGRAM DEVELOPMENT

This program is developed based on Q-Basic language. It is simple and easy to operate. It is applicable for personal computer. Moreover, this program is provided with such functions as digital analysis, vector calculation and graphic description. It enables the users to solve their unique problems. Besides, it is provided with interactive function and a basic database with detailed instructions on different materials attached thereto.

The calculation content includes the base reaction force from two directions of vertical and horizontal, bending moment diagram, deflection and shaft inclination. Then, based on the aforesaid calculation, the optimal rolling contact bearing is selected. To conduct shaft analysis, firstly, it is required to choose the appropriate material and design parameters, for instance: the position of rolling contact bearing and machine parts, rotating direction and the designed length of shaft. Similarly, to conduct strength calculation, it is required to choose safety coefficient, input force and rounds per minute. The calculation of force and torque of gears on the shaft is decided by the corresponding parameters entered in, for instance, pitch, etc. The bending moment is calculated in digital mode, including the two directions of horizontal and vertical. Then, it goes through smoothing processing and is presented in diagrams. The calculation of the parameter of critical point and force and torque under the condition of composite loads can be processed simultaneously. At the time of calculating bending deflection, the two directions of vertical and horizontal should be taken into account. With the aforesaid calculation result, the optimal diameter of step shaft can be obtained by using the two methods of one-dimension search and interval halving. See computer program for specific realization.

4 ROLLING CONTACT SHAFT SELECTION and DATABASE DEVELOPMENT

Due to the needs of function, the rolling contact bearing is required to have reasonable service life, high stability and rather low cost. To reach the aforesaid requirements, the dynamic bearing capacity, working conditions, equal bearing capacity and constant load and so on must be taken into account. The calculation formula for equal bearing capacity.

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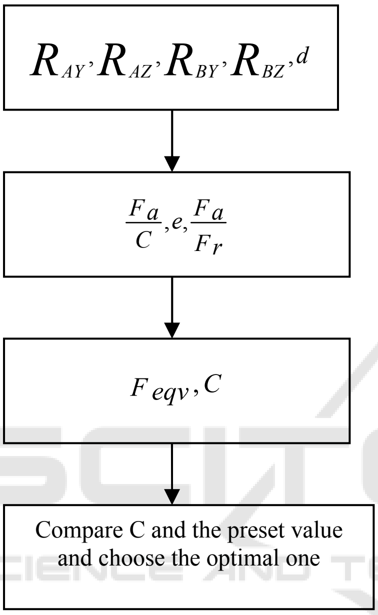
$$(F_{eqv}): F_{eqv} = X * F_r + Y F_a \qquad (6)$$

where, F_r is axial force, F_a is radial force. The calculation formula for dynamic bearing capacity:

$$C = F_{eqv}\left(\frac{L}{10^6}\right)^K \qquad (7)$$

the specific selection process is seen in the flow chart below.



Flow Chart 1

Expert system is a computer simulation program based on knowledge. It adopts knowledge-decision unit and IF_THEN rule to conduct reasoning. The expert system mainly comprises several parts like database, decision unit, and storage unit, etc. To apply this expert system, one must use LEONARDO software.

5 CONCLUSION

a. The computer program developed is considerably flexible. It allows the users to solve their own specific problems. The fatigue analysis for optimal shaft design and stress sensitive factor are formulized and entered into computer program.

b. A better protocol is found between calculation of the optimal diameter of the critical section of step shaft by using computer simulation method and analytic method. Moreover, a balance is also reached between value calculation method and analytic method in terms of bending-torsion and torque.

c. The expert system adopting the optimal rolling contact bearing is developed. It can be used for the teaching of computer-aided design.

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