Finite Element Analysis of Worm Gear Based on ANSYS Workbench

Hui Zheng [a], Yilun Han [b], Chao Sun [c], Xuelong Yuan [d]

College of Transportation, Shandong University of Science and Technology, Qingdao 266590, China.

[a]zh2257@126.com, [b]1823740313@qq.com, [c]402630408@qq.com, [d]2247693618@qq.com

Abstract

Worm gear reducer is widely used in the occasion of speed change due to its large transmission ratio. The geometric models of the worm gear and worm are established with 3D modeling software and imported into ANSYS Workbench for analysis. According to the actual condition of the worm gear reducer, the static analysis and the fatigue strength analysis of the worm gear are carried out. The statics analysis results show that the static strength of the worm gear satisfy the requirements under the working conditions, which proves the rationality of the worm gear design. The results of fatigue strength analysis show that the location where the worm gear is prone to fatigue failure is located at the connection of gear roots, and the gear teeth meet the design requirements of fatigue life under alternating load. The conclusion of the analysis can provide better theoretical support for the optimization design of worm gear in the worm drive system.

Keywords

Reducer, worm gear, ANSYS Workbench, static analysis, fatigue strength analysis.

1. Introduction

Worm drive is a mechanism of power transmission between the two axes interlaced in space. The common interlace angle between the two axes is 90 degrees. The failure forms of the worm drive include the overload fracture of the tooth root and the fatigue failure of the tooth. Since the strength of the material used for the worm shaft is usually higher than the material used for the worm gear, the probability of failure of the worm gear is much higher than that of the worm shaft. During the design process, in order to avoid premature failure of worm gear, Firstly, the bearing capacity of the gear teeth should be calculated, and then the fatigue strength of the gear teeth should be checked.

In the field of mechanical design, the development of reliability design has brought a profound impact on the whole discipline of mechanical design[1]. Finite element analysis software ANSYS Workbench is used to analyze and calculate the reliability of worm gear bearing capacity and gear fatigue resistance, which provides technical support for further optimization and improvement of worm gear.

2. Establishment of 3D Solid Model

The 3D modeling software SolidWorks is combined with the gear design software to carry out the modeling of the entity. The assembled model is imported into the ANSYS Workbench software. The simplified model is shown in Figure 1.

3. Static Strength Analysis of the Worm Gear

3.1 Determine the Parameters of the Material

Determining the basic parameters of the worm gear selection material is the premise of the finite element analysis. The material of the worm gear is made of QT - 450 material. The mechanical design manual can be obtained: the minimum tensile strength of ductile iron is 450 MPa, the modulus of elasticity is 1.5×105 MPa, the Poisson's ratio is 0.3 and the density is 7.3 g/cm3.

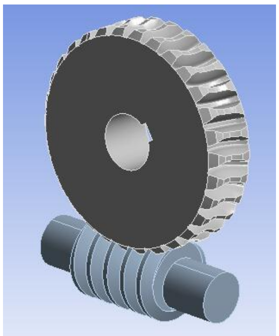

Fig. 1. simplified model diagram

3.2 The Application of Load and Constraint

In practical work, the worm gear is counteracted by the external resistance moment. It is assumed that at the moment of contact the worm is stationary and constrains all the degrees of freedom of the worm. Since the model only has translation freedom and lacks rotational freedom [2], a reference coordinate system is added to the center hole of the worm gear, and in this reference coordinate system, the external resistance torque along the axis of the worm gear is defined as 3000 N•m.

3.3 Simulation and Analysis of Static Strength

Through the finite element analysis, the static strength stress cloud diagram of the worm gear is shown in Figure 2. From Figure 2, we can see that the maximum equivalent stress of worm gear is located at the root connection. The maximum value is 100.03 MPa, which is less than 450 MPa of the material's minimum tensile strength. Therefore, the failure of static load is not occurred, and the reliability coefficient of the gear is 4.49.

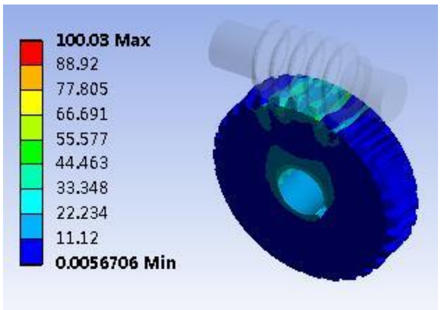

Fig. 2. Static strength stress cloud

4. Fatigue Analysis of Worm Gear

Fatigue is a common form of structural failure, which can be divided into low cycle fatigue and high cycle fatigue according to the difference of the number of stress cycles. Low cycle fatigue means that when the number of stress cycles is relatively low, due to the large stress, the material has a large local plastic deformation and thus failure. High cycle fatigue means that when the number of stress cycles is high (eg, 107), although the workpiece undergoes an alternating stress that has not yet reached the allowable stress of the static strength design, the workpiece will produce fatigue crack and extend until the last sudden failure.

The fatigue analysis theory used by ANSYS Workbench software is the most extensive linear cumulative fatigue damage theory—Miner damage theory [3]. According to the theory, the fatigue damage under each stress amplitude is independent, and the total damage is the accumulation of independent damage. In the cumulative damage process, the S-N characteristic curve of the material is mainly used for calculation.

The material of the worm gear is QT - 450. In the case of a survival rate of 99%, the values of the material constants a and b [4] are shown in Table 1.

Table 1.Values of material constants a and b

Material	Heat treatment	Form of sample	a	b
QT-450	Annealing	Cylindrical	27.5206	-8.6880

The mathematical expression of the S-N characteristic curve is:

$$\lg N = a + b\lg\sigma \tag{1}$$

In the formula, N—the number of cycles; σ—the nominal stress; a—the material constant; b—the slope parameter.

From equation (1), the stress value of the worm gear at different cycles can be obtained, as shown in Table 2.

Table 2.the stress values of the worm gear at different cycles

N	σ/MPa	N	σ/MPa
10	1128.6	20000	471
20	1042	100000	391
50	938	200000	361
100	866	1000000	300
200	800	2000000	277
2000	614	10000000	230
10000	510	20000000	213

In practical work, since the worm gear can rotate in both forward and reverse directions, the type of load is set to Ratio in the fatigue analysis module. At the same time, the coefficient of fatigue strength is 0.8 because of the difference between the mechanical parts and the material.

When the final cumulative damage coefficient is close to 1, it can be considered that the number of input stress cycles is the lifetime of the mechanism [5]. The design life of the worm gear is defined as 6 × 106 times. The simulation results show that the accumulated damage coefficient of the worm gear after 6 × 106 cycles is 0.3. The coefficient is less than 1 and the worm gear is safe and reliable. The cumulative damage coefficient of the worm gear is shown in Figure 3.

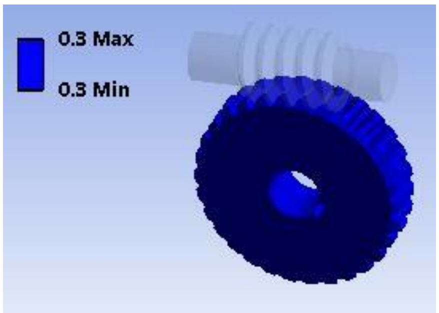

Fig. 3 Worm gear cumulative damage coefficient

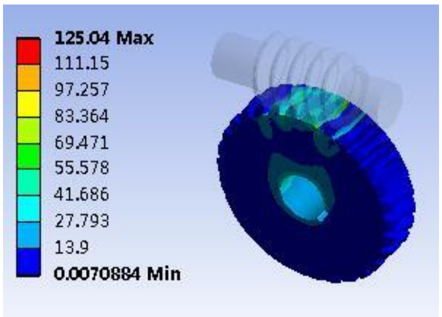

Fig. 4 Worm gear alternating stress cloud

During the design life cycle, the maximum value of the alternating stress is 125.04 MPa, and the fatigue strength of the cycle is 253 MPa, so the fatigue reliability coefficient is 2.03. The worm gear alternating stress cloud chart is shown in Figure 4.

5. Conclusion

The ANSYS Workbench software is used to simulate and analyze the mechanical properties of the worm gear in the worm drive system, and the simulation results are summarized as follows:

(1) From the analysis of static strength,the maximum equivalent stress point of the worm gear is located at the connection of the root of the tooth. Its reliability coefficient is larger, which can meet the operating requirements of gear teeth.

(2) From the fatigue analysis, the accumulated damage value of the gear teeth is less than 1 after the worm gear passes through the 6×106 cycle, which indicates that the gear teeth have better fatigue resistance.

References

[1] Liu Hunju. Mechanical Reliability Design[M]. Beijing: Science Press, 2012:01.
[2] Zhao Lijuan, Wang Enran, Xie Bo. Finite Element Contact Fatigue Analysis of Shearer Gear Shafts[J]. Mechanical Transmission,2014,2(38):97-99.
[3]Fu Susheng.Numerical Simulation and Strength Resolution of ANSYS Workbench 17.0 [M]. Beijing: People's Posts and Telecommunications Press, 2017: 251.
[4] Zhao Shaobian. Basic curve of finite life fatigue design method [J]. Mechanical design, 1999 (11): 05-07.
[5] Ma Jianwei, Jia Zhenyuan, Wei Weili. Launcher baffle fatigue analysis Based on ANSYS [J]. Equipment manufacturing technology, 2009 (11): 9-11.