Study on Contact Characteristics of Gear Pairs in the Spindle Box of Machine Tool

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ABSTRACT :*By studying the dynamic excitation mechanism of gear meshing, it is considered that the main vibration source of gear transmission system is gear meshing vibration. By establishing a three-dimensional contact finite element model of gear meshing, the time-varying comprehensive meshing stiffness of the gear under the working condition of the gear transmission system is analyzed, and the time-varying comprehensive meshing stiffness curve of the gear is obtained. Through the analysis of the curve, it can be seen that the stiffness changes dramatically due to the alternating meshing of single and double teeth, and the excitation caused by the stiffness changes is inevitable, which is the main reason for the excessive vibration and noise of the gear transmission system. At the same time, the transmission stability of spur gear is poor.*

KEYWORDS *-contact, gear pairs, FEA, machine tool*

I. INTRODUCTION

Among all kinds of lathe transmission mechanisms, gear transmission is the most widely used mechanical transmission mode. It can transfer motion and power between any axes in space, and has the advantages of high transmission efficiency, long service life, accurate transmission ratio, large power range and safety and reliability in work, so it is widely used [1]. It has an important advantage that other transmission cannot be replaced, that is, the gear transmission mechanism has the characteristics of constant power transmission. The research on improving the performance and quality of gear transmission system has always been a key technical problem in various important fields in the world [2]. With the development of science and technology nowadays, gear transmission system is developing towards high-precision and light gears to complete high-speed and heavy-duty tasks.

When the gear transmission system is working, because of the change of the number of teeth, meshing stiffness, elastic deformation caused by load, the change of backlash and manufacturing and assembling errors, the dynamic meshing excitation of the gear will occur [3]. The vibration of the gear will be generated by the internal dynamic excitation of the gear pair, and then transmitted from the transmission shaft to the bearing seat, and finally transmitted. Pass it to the gearbox body, then excite the vibration of the box body and radiate noise.Therefore, the contact characteristics of gear pairs in the spindle box of lathe are studied in the paper.

II. DYNAMIC EXCITATION ANALYSIS OF DRIVING SYSTEM

2.1 System Structure Analysis

The dynamic incentive of the whole system includes internal incentive and external incentive. External excitation is the function of external system to the system, and its determination method is the same as that of general mechanical system.Fig. 1 is the mechanism diagram of the main drive system of CNC screw milling machine. There are vibration and abnormal noise in the process of idling. From the point of view of its structure, the part of vibration and noise is a gearbox, and the structure of gearbox is mostly used in all kinds of parts of gearbox.

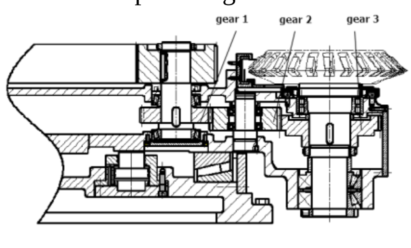


Fig.1Main drive system diagram of machine tool

For the comprehensive meshing stiffness of gears, two pairs of teeth engage in meshing, and the curve corresponding to the stiffness region is the superposition of the stiffness of two pairs of teeth at that moment. Obviously, the comprehensive stiffness curve has obvious step phenomenon.In this paper, after considering the material mechanics method, mathematical elasticity method and numerical method for calculating the deformation of gear teeth; it is finally decided to adopt numerical method to calculate the contact force and deformation of gear teeth.

2.2. Model Setting and Construction

The gear transmission system studied in this paper comes from the gear transmission system of CNC screw milling machine. The tooth width of two meshing gears is different. Due to the limitation of space structure, the middle transition gear is connected with the other two gears, and its tooth width is the largest. Based on the contact theory and finite element method of gear meshing transmission, an accurate three-dimensional contact model of gear transmission system is established. Then, using the theory of finite element, the static contact analysis of finite element is carried out, and the force and deformation of the gear teeth are obtained, which can provide accurate data for calculating the time-varying meshing stiffness of the gear transmission system.

Establishing an accurate three-dimensional model of gear is a major prerequisite for obtaining reliable results [4]. Because it is very difficult to establish the model in the finite element analysis software, this paper uses the three-dimensional modeling software to establish the assembly model of gear, and then imports it into the finite element analysis software.The established model is transferred to the finite element analysis software. Firstly, the model is meshed according to the finite element theory. Then it is discretized to get the nodes, so that the boundary conditions can be loaded on the nodes later. The meshed model is shown in Fig.2.

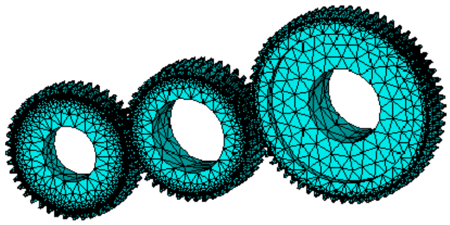


Fig.2Finite element analysis of gear pairs

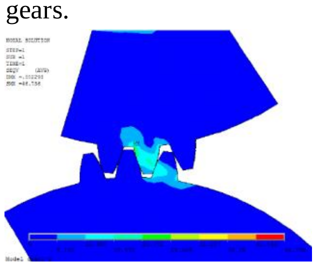
2.3 Boundary Conditions Setting

After defining element type, material properties, meshing and contact pairs, boundary conditions and loads are imposed on the model. The correct application of boundary conditions is an important step to get closer to the actual results. Therefore, the correct boundary should be applied in the correct position according to the actual working conditions of the gear transmission analyzed.Firstly, the current coordinate system of the analysis software is transferred to the cylindrical coordinate system, and then all the nodes on the inner surface of the axle holes of the main and driven wheels are rotated to the cylindrical coordinate system respectively. This is very important for the next step to apply the tangential force of the simulated rotation to the driving wheels.The displacement degrees of freedom in *x* and *z* directions are applied on the inner surface nodes of the axle hole of the active wheel. Finally, the tangential force is applied in the *y* direction of each node to simulate the torque of the active axle.

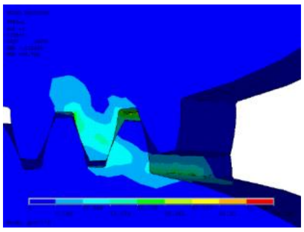
III. ANALYSIS AND DISCUSSION OF STRESSRESULTS

3.1. Contact stress analysis

The Calculation result of contact stress is shown in Fig.3. From the analysis results, it can be clearly seen that the stress at the root of the tooth is the greatest, which is in line with the actual working conditions of gear transmission. The maximum bending stress at the root of the tooth is 46.735 MPa. At the contact point of two teeth, the contact stress at the tooth surface is the greatest, and the maximum contact stress is 38.861 MPa. The finite element analysis of the static contact of gear teeth in this paper will provide a strong support for solving the time-varying meshing stiffness of gears.



(a) Overall view of stress field

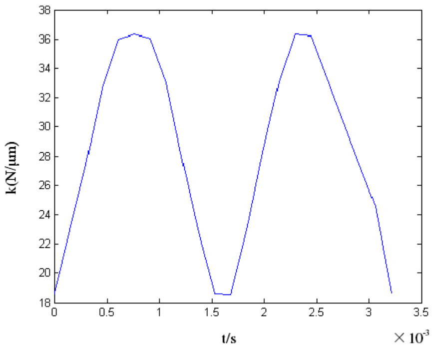


(a) Local view of stress field

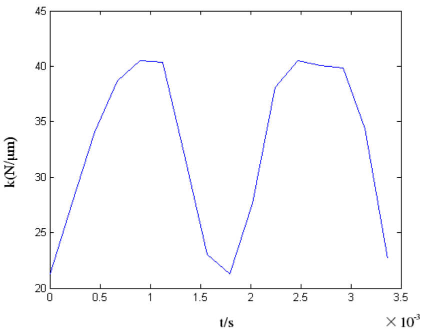
Fig.3Calculation results of contact stress

3.2. Stiffness Curve Analysis

In the finite element analysis model of gear contact, the deformation and nodal force of all nodes on the contact surface of the main and driven gear teeth are extracted respectively [5]. By comparing the nodal force and the normal deformation in the contact and non-contact areas, it is found that the nodal force and deformation in the contact area are much larger than that in the non-contact area. Therefore, when calculating the time-varying meshing stiffness, this paper neglects the influence of the nodes in the non-contact zone on the calculation results. Only the normal force and normal deformation of each node in the contact zone are extracted. Then, according to the meshing stiffness calculation formula, the stiffness is calculated separately, and then the meshing stiffness of a pair of gear teeth is calculated by linear superposition. Finally, the gear meshing stiffness is obtained as show in Fig.4.



(a) Gear 1 and gear 2



(b) Gear3 and gear 2

Fig.4Contact stiffness curve between different gears

IV. FINITE ELEMENT MODAL ANALYSIS

3.1Establishment and analysis of mode

Generally, for a system whose stiffness varies with time, only a fixed natural frequency value is obtained, and then it is determined as the natural frequency of the whole system, which is not rigorous or even unreasonable [6]. Therefore, a new analysis method is used to determine the natural frequency range of gear transmission system. With the change of time, the maximum meshing stiffness of the gears is the largest, that is, the natural frequency of the whole system is the largest.The three-dimensional model of gear transmission system is established. The model is composed of gears, transmission shafts and bearings, as shown in Fig. 5.

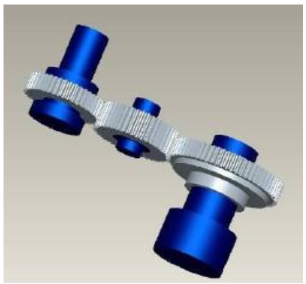


Fig.5 Modal analysis model of gear drive system

3.2Result analysis

For gear transmission system, the magnitude of low-order natural frequencies will have a greater impact on the system, so it is more practical to calculate only the first natural frequencies of gear transmission system. The inherent characteristics of the system can be obtained by modal analysis of the system.The first natural frequency of gear transmission system is between 124.81 Hz and 210.65 Hz. The rated power of the motor of the gear transmission system studied in this paper is 11 Kw and the rated speed is 1446 rpm. The meshing frequency of the three gears under the rated speed is 489 Hz.

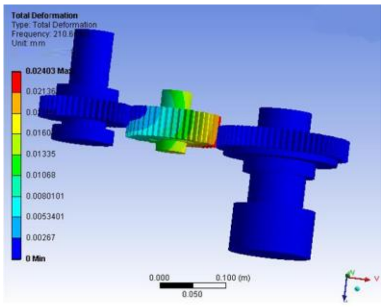


Fig.6First-order mode shapes

The first-order mode shape is shown in Fig.6. It can be seen from the mode diagram that the intermediate transition gear and its transmission shaft are the weak links of the whole system and should be improved in the structural design. In low order vibration, the main deformation occurs at this position. The maximum deformation of the first-order vibration is 0.024 mm. The maximum deformation occurs on the gear teeth near the output shaft. The vibration form is gear torsion. The maximum deformation of second-order vibration is 0.023 mm. The maximum deformation occurs on the top gear teeth of intermediate transition gear. The vibration forms are gear torsion and transmission shaft bending.

V. CONCLUSION

Based on the finite element method, the transmission system is analyzed. The internal excitation is determined as time-varying stiffness excitation and error excitation. The normal deformation and normal contact force of the gear teeth are obtained by static contact finite element method, and the time-varying meshing stiffness curve of the gear transmission system of the machine tool is obtained. In this paper, the finite element analysis software is used to analyze the contact of gears, and the model of gear transmission system is established. The modal analysis and dynamic response analysis of the model are carried out, and a more reasonable method to analyze the modal characteristics of gear transmission system is given.

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