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Study on Simulation of Dynamic Meshing Force of High speed Gear System Based on ADAMS

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Abstract. Based on 3d modeling software Pro/E, gear system solid model was built by using parametric modeling method. The virtual prototyping model of the gear system was established based on ADAMS. Then the dynamic meshing force of gear was simulated. The ruler and magnitude of mesh force was researched while the gear transmission system worked in the situation of high speed and great torque, and the numerical simulation of the gear dynamic meshing force has been realized, which provide accurate data for the strength and fatigue analysis of gear system.

Introduction

The strength and life calculation of the gear parts depends on the data of the gear meshing force. Gear meshing force obtained by conventional mechanical design is a constant force, which differs with the real situation very big. Mastering the mechanical characteristics of gear transmission accurately is of great importance to the optimization design, strength check, fault diagnosis and life prediction of gear transmission system [1].

This paper considers that gear transmission system of an aeroengine accessory works in the situation of high speed and great torque, a method of dynamic simulation of gear meshing force based on multi-body dynamics analysis software ADAMS was proposed. The numerical simulations of the gear dynamic meshing force has been realized, which provide accurate data for the strength and fatigue analysis of gear system.

Gear system molding and Data transfer

Parametric gear modeling by Pro/E. Parameterized modeling refers that a set of parameters can be used to represent the structure size and attribute of parts or series of products which have the same or similar shape. By revising parameters, engineers and technicians can get parts with different specifications to realize the parameterized design. For gears, with parameterized modeling, as long as the user input or modify some basic parameters of gear (such as the number of teeth, modulus, pressure angle and face width and so on), the software will automatically generate a 3d geometric model of a desired type gear, or rebuild the geometric model, which improve the design efficiency [3].

Parametric design centered with restraint, and is characterized by dimension driven. In the design process, each characteristic dimension needs complete it by entering precise value and add relation constraint. Related fillet radius, reference plane angle and so on have to relate to number of teeth, the modulus and so on to realize parametric design. By using Pro/E, parametric gear model is created, which is shown in Fig.1.

Data transfer between Pro/E and ADAMS. There are two ways to realize the data conversion between Pro/E and ADAMS： (1) The ADAMS/View provides interfaces for data conversion of formats such as Parasolid,STEP,IGES,SAT and DWG, etc.（2）Using the dedicated interface software Mechanism/Pro realize data conversion. This paper adopted the first method realize the data conversion, which means that in Pro/E the assembly model files would be saved as Parasolid format. In ADAMS, then click file→Import→Parasolid, the Pro/E file can be successful imported into ADAMS.

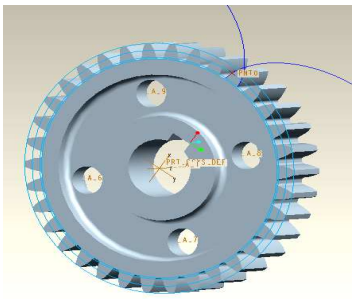

Fig. 1 Parametric gear model

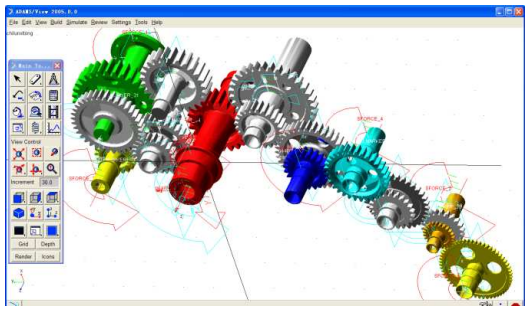

Fig.2 The virtual prototyping model of the gear system

The virtual prototyping modeling of gear system

Loading constraints. When the gear transmission system model was imported with the above method, each part stands by itself in ADAMS and has no connection with each other. It shall not constitute a real virtual prototype. After adding material parameters in ADAMS, model data of gear transmission system parts such as quality, centroid position and the rotary inertia can be obtained. On this basis, the connection of the hinge, torque and kinematic constraint were appropriately added, and then establish the gear system virtual prototype (as is shown in Fig.2).

The choice and definition of contact force. Contact force is applied between the gears, and then the dynamic meshing simulation of the gear is realized. There are two types of contact forces in ADAMS: one is based on the Impact function, another is based on Restitution function. Impact adopted the stiffness and damping coefficients to calculate the contact force, and Restitution calculated the collision force by a recovery coefficient. This paper applied Impact function to calculate contact force.

In MSC.ADAMS software, contact force is defined as:

$$\text{F\_impact}=\begin{cases}0 & q \geq q_0 \\ K(q_0-q)^e - C*\dfrac{dq}{dt}*step(q,q_0-d,1,q_0,0) & q < q_0\end{cases} \tag{1}$$

Where, *step* is step function; q_0 is the initial distance between two objects; q is actual distances in the process of collision; q_0-q is deformation in the process of collision. The formula above represents that, when $q \geq q_0$,the two objects do not contact, and the contact force is zero; when $q < q_0$, the two objects contact, the contact force relate to stiffness *K*, deformation q_0-q, collision index *e*, damping coefficient *C* and deformed distance *d* when damp effects completely.

Select parameters of the contact forces. Stiffness coefficient *K* which can be selected according to reference[4] depends on the material and structure of contact objects.

$$K=\frac{4}{3}R^{\frac{1}{2}}E^* \tag{2}$$

Where $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}$, $\frac{1}{E^*}=\frac{(1-\nu_1^2)}{E_1}+\frac{(1-\nu_2^2)}{E_2}$, R_1 R_2 The equivalent radius of two gear contact points, ν_1 ν_2 are the ratios of the two gears, respectively, E_1 E_2 are the Young's modulus of the materials of the two gears.

Select the material of the gear 20Cr2Ni4A, its Poisson's ratio is ν=0.29, the Young's modulus is E=2.07E+11Pa. Stiffness coefficient of each contact can be obtained from calculation, which is shown in table 1. Also, select the collision coefficient e=1.5; damping coefficient *C* is 50N•S-1/mm; The depth of penetration *d* is 0.1mm. Given the friction while colliding, coefficient of kinetic friction is 0.05; coefficient of static friction is 0.08.

Tab 1. Contact stiffness of all levels of gear mesh

Contact	1	2	3	4	5
Stiffness(N/mm)	7.40E+05	8.00E+05	6.70E+05	6.60E+05	7.80E+05
Contact	6	7	8	9	10
Stiffness(N/mm)	7.10E+05	6.70E+05	6.70E+05	6.60E+05	6.10E+05

Simulation and analysis of the results

Gear system of aeroengine accessories will transfer the engine power to each accessory. In the process of operation, gear system would suffer from the environmental stimulation of the engine, the accessories, the main fuel pump, fuel booster pump, spout oil pump, booster pump, lubricating pump. The stimulation makes the changes of the dynamic load very complex, which is the main reason of leading to vibration, impact, noise and fracture of gear teeth. [5]

The simulation of dynamics meshing force. Conduct the simulation based on the virtual prototyping model of the gear system. Apply the driven speed n=13316r/min (78983°/s) in the input shaft 1. Load torque of each output shafts (as is shown in table 2) can be calculated by the operating power of every output shaft in this working condition, and the load torques were then applied on the output shaft of the virtual prototype. The simulation time took 0.2 s, and the simulation step took 0.0001 s.

Table 2 Load torque of each output shafts

The shaft of power output	Aircraft accessory	Fuel booster pump	Main fuel pump	Spout oil pump	Fuel booster pump	Lubricating pump
Load torque (N.mm)	267549	67442	145008	106646	42510	25245

The analysis of the simulation results. The dynamic meshing force curve of each gear can be obtained by the simulation. This paper takes the dynamic meshing force of gear contact 1, 8 and 10 as an example for analysis. Fig.3 is meshing force curve of gear contact 1, gear contact 8 and gear contact 10 in the time domain and frequency domain.

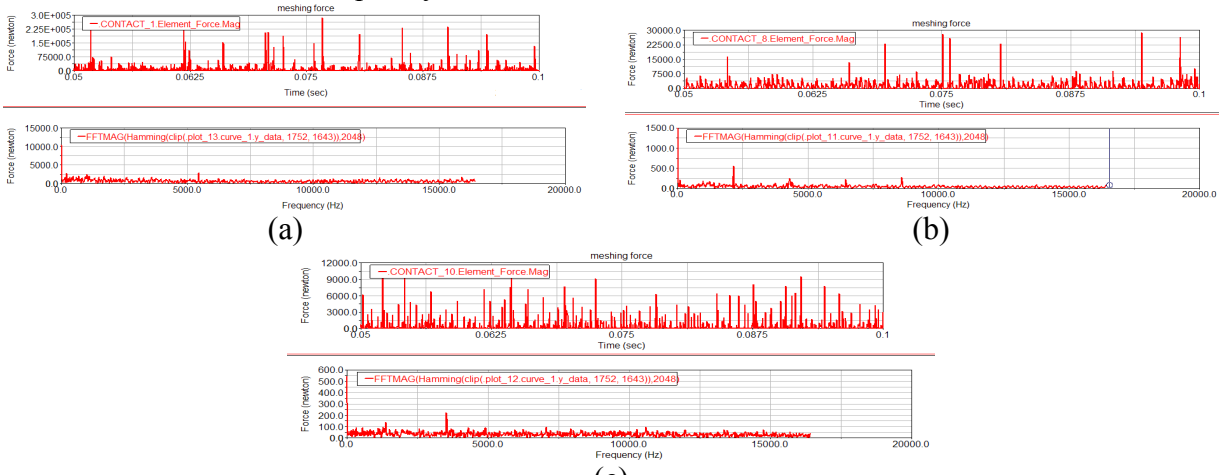

Fig.3 Mesh force of gear contact in the time domain and frequency domain.
(a)gear contact 1 (b) gear contact 8 (c) gear contact 10

Form the frequency domain curve of mesh force, when the frequency was 2151.5Hz, the amplitudes of gear contact 8 is maximum; when the frequency was 3532.6Hz, the amplitudes of gear contact 10 is maximum. According to the theory calculation formula of the gear mesh frequency $f_z=Z•n/60$ (Z is number of teeth, n is revolving speed), the mesh frequency of gear contact 8 and 10 are 2149.1Hz and 3530.8 Hz by calculation respectively. The simulation value of the gear meshing frequency is identical with the theoretical value, which verified the rationality of the simulation model.

The magnitude of mesh force is caused by the deformation which was driven by two contact gears overcoming load torque in the process of doing work. It can be seen from the Fig.3 that there is distinct dynamic load in gear mesh force, and the force oscillate above and below a certain value (static load). That indicated that there are obvious impact and vibration in the course of gear meshing. We could also find that the dynamic load appears non-symmetrical cycle. The cyclical fluctuations of the meshing force are easily caused fatigue rupture.

The numerical analysis of meshing force is provided in table 3, F_m is the average, F_{max} is the maximum of meshing force, and it can see from Fig.3 the minimum of meshing force is zero, λ is the ratio of the maximum to average. The speed of gear contact 1 is higher than gear contact 8, and the gear contact 8 is higher than gear contact 10. As is shown in table.3, gear contact 1 had the laggest λ, and gear contact 10 has the smallest λ. The higher the revolving speed of meshing gear, the greater the amplitude of meshing force. So the revolving speed of gear has great effect on the amplitude of meshing force.

Table 3 Analysis of gear meshing force

Gear Contact	1	8	10
Fmax/N	287260	28801	9721.4
Fm/N	10279	1557.8	536.4
λ	27.9	18.5	18.1

According to the analysis, it was found that the meshing force of multi-gear transmission with high speed and big torque is more complicated, fluctuation is very big, and the maximum amplitude is many times the average. As is shown by the table 3, the maximum of gear contact 1 is 27.9 times its average, which has a serious impact on the life of the gear. So far the gear is mainly designed by static load, the simulation analysis of the dynamic mesh force indicated that the design based on static load differs greatly with the load in the real work.

Conclusions

Based on 3d modeling software Pro/E, the building methods of parametric gear were researched, and an aeroengine accessory gear system dynamics simulation model was built. Based on ADAMS， the dynamic meshing force of gear was simulated， then the dynamic meshing force curve of each gear were obtained.

The comparing of meshing frequency of the simulation with the theoretical has verified the accuracy of the simulation. It can simulate the reality working process of the system. The simulation and analysis of the gear dynamic meshing force showed that big vibration and impact appeared in meshing in the situation of high speed and great torque. The simulation and analysis of this paper can predict the dynamic characters of the gear transmission system comprehensively. It will play a directive role in improving the dynamic performance and the design of gear transmission system, and it can provide accurate data for the strength and fatigue analysis of gear system.

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