CAD/CAE system for the ring planetary reducer with small tooth number difference*

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Abstract: A CAD/CAE system of the ring-type planetary reducer with small tooth number difference is presented. It is a parameterized CAD/CAE system adopting the object-oriented technique and comprising in itself the geometric feature database (including the modules of ring-plates with inner teeth, eccentric shaft modules and output shaft modules), standard component database and material database. In comparison with design by handwork , this computer aided design and analysis system has the advantages of improved quality, shortened design period and reduced cost. The reliability of the system has been verified by a illustrative example.
Keyword: planetary reducer; computer aided design; computer aided engineering

1. Introduction

Ring planetary reducers with small tooth number difference are a new kind of gear drive, of which the 2-ring and 3-ring reducers have found widest application in industry. In comparison with the various existing types of gear drives, this kind of reducers have many advantages such as simplicity and compactness in structure, light weight, large transmission ratio, high efficiency, high load capacity, low cost, etc [1-3].

For inner gearing with small tooth number difference, the key problem of geometric calculation for meshing gear pair is how to avoid interference. This problem can be solved using short teeth or a gear with positive modification coefficient, However, the side effect of doing so is the reduction of contact ratio. Therefore, the main content of geometric calculation is how to select the parameters reasonably so as to satisfy both of the two requirements mentioned above. In addition, in order to avoid unnecessary repetitious calculation and shorten the lead time of a product, modern design methods such as finite element analysis design optimization, reliability design, etc. are applied to product design process. In this case, solid modeling, engineering analysis, dynamic simulation, interference inspection for assembly, and so on can be carried out. For all those reasons, it is necessary to develop a CAD/CAE system of the ring planetary reducer with small tooth number difference.

2. The CAD/CAE system for the ring planetary reducer with small tooth number difference

2.1 The contents designed for the system

The CAD/CAE system includes a material subsystem, geometric modeling, manufacture technologies, a subsystem of machine elements, etc. Material properties, heat treatment method, surface treatment process, etc. are chosen in the material subsystem. The classical strength calculation, finite element analysis, endurance life prediction, structure shape optimization, dynamical simulation, noise and vibration prediction, efficiency analysis, prediction of transmission characteristics, processing parameter choice, and such operations can be conveniently carried out in the calculation and analysis subsystem, while we perform processing parameter determination, size calculation in process, machining route inference, machining route queuing, and so on in the manufacture technology subsystem. The machine element subsystem includes parameter calculation for the inner gearing, CAD modular for the planar gearing, CAD modular for ring-plates with inner teeth, CAD modular for eccentric shaft, bearing, gear housing, etc.

2.2 Development method

The CAD/CAE system of the ring reducer with small tooth number difference is a mechanical computer aided engineering system for special purpose. It is tied up with the MCAE system for general purpose, but there is some difference between the two systems. That is why good mechanical CAD/CAE software need be chosen as a supporting platform to carry out the second development. Two aspects have to be taken into consideration: one is new ideas and new technologies for the software development, and the other is the industrial environment of ring gear reducer manufacture. According to existing development

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experiments for the CAD/CAE system and the design ideas of software engineering, this system adopts the object-oriented technique. Based on the project database, a parameterized CAD/CAE system is developed which integrates the geometric feature database (including the modular of ring-plate with inner teeth, eccentric shaft modular and output shaft modular), standard component database, material database, etc. Furthermore, the following principles are always observed in the process of the software development.

a) Parameterization: The structure size of a product must be a variable parameter, so that the product model can be changed on line according to the work condition. In this way the developed software is somehow alive and can tackle practical problems.

b) Objectiveness: Every structure is defined as a goal, and the object-oriented technique of geometric modeling is adopted to do solid modeling and packaging. The debugging, testing, defending and upgrading of the software can be easily implemented by making use of the software resources and relative codes.

c) Characterization: Based on product model analysis, a product model can be decomposed into its simple and basic component models. The parameterized feature model database is setup in order to build the whole product model rapidly.

d) Integration: A software system must be in a integrated packing, i.e. all the function modular must be integrated together, so that it is convenient for a user to not only install and test but also run the system.

e) Standardization: A software system is often the fruit of combined efforts of many people who usually accomplish the task by assembly their individual work, wherefore they must make their work legible to and compatible with that of the others in their group. Aiming at efficient development pursuit as well as easy maintenance and testing of the system and convenient assembly of function modules, every function module must be in a compatible style. Therefore the development of a software system must have its predetermined specifications and observe relative standardizing principles.

f) The combination of interactive mode and program mode: The interactive mode enables the intercommunication between a user and the system when the system runs so that he can send commands to the system to control program operation; while the program mode ensures that the system runs completely according to the prepared program. The combination of the interactive mode and program mode makes operation more flexible and simple.

2.3 Structure of CAD / CAE system for planetary reducers

When the system starts, the option of the gear reducer structure scheme is entered first, where the major parameters of a reducer can be determined easily. Then the engineering drawings satisfying the preset parameter requirements and structure scheme of components such as external gears, ring-plates with internal teeth, eccentric shafts, output shafts, bearings, etc. can be taken out from the subsystem. After the required engineering drawing of standard components are obtained from relevant modules, the reducer design can proceed to dynamical simulation and finite element analysis of the gearbox. If necessary, the design should be revised until the satisfactory results are obtained. At last the structure design should be finished in detail with the generation of revised engineering drawings in which the choice of blueprint interface is automatically completed. The title fence content such as the title fence and the standard picture frame can be performed either automatically or by man-machine interactive mode. The block diagram of the CAD/CAE system for the gear reducer is shown in Fig. 1.

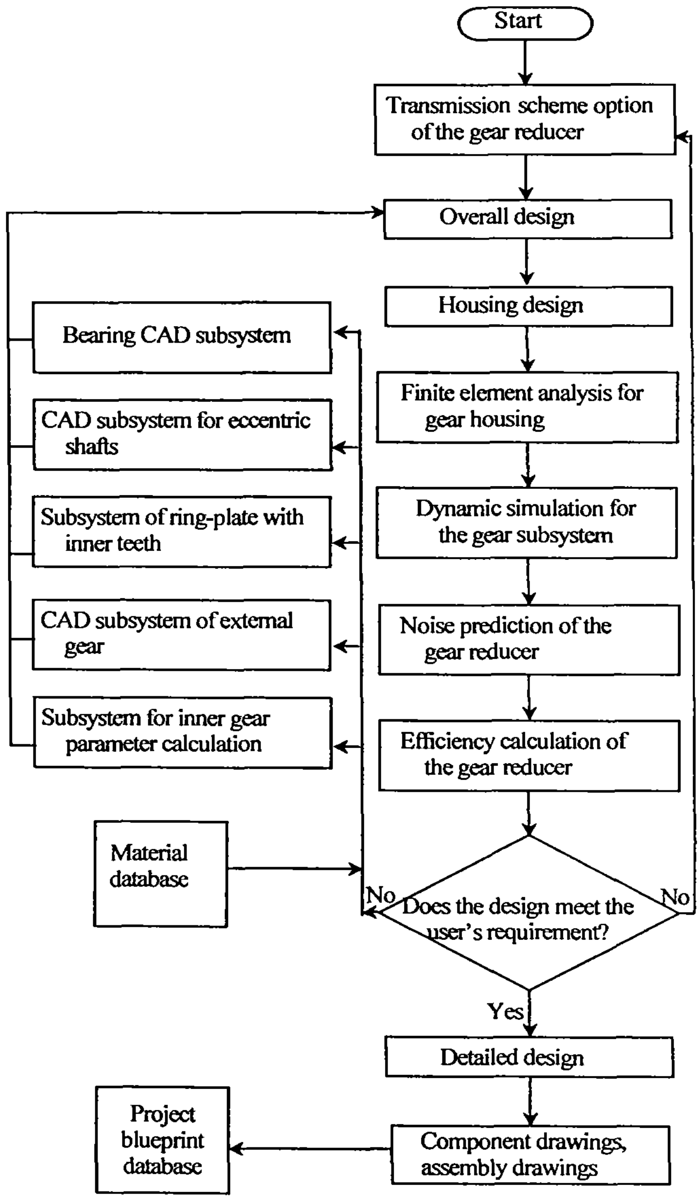

Fig. 1. The block diagram of the CAD/CAE system organization

3. Subsystems of CAD/CAE for gears

The integration optimization of both components and system can be realized by using the CAD/CAE system for the ring-type gear reducer with small tooth number difference, in which, various advanced approaches and analogy design methods are provided. In order to reduce manufacture cost and gearbox weight, shorten development period and improve the product quality, the most suitable gear parameters and components size in gearing should be determined by dynamic simulation of a transmission system and prediction of endurance life as well as finite element analysis.

Now the subsystem of gear parameter calculation for inner gearing and CAD subsystem for ring-plates with internal teeth are chosen as two examples to introduce here in brief.

The key problem is how to determine the modification coefficient in design of inner gearing with small tooth number difference. The iterative results of actual gear dimensions can be different from each other even though the iterative approach are the same. In fact, the difference is due to different manufacture process. Nowadays, the most popular manufacture process for planetary gears is gear-generating method, in which an external gear is generally produced by a hobbling machine while an internal gear is made on a gear shaper. The iterative formula under various actual processing conditions is listed in this CAD/CAE system. So we can choose the suitable one in man-machine interaction way.

The calculation block diagram for the gear parameter subsystem is shown in Fig.2.

In the iteration of modification coefficient, its iterative value can effect the actual center distance of the gearing. Considering actual situation of gear manufacture the actual center distance of gearing should be in round numbers or in two decimals. The gear parameters listed in Table 1 are an illustrative example.

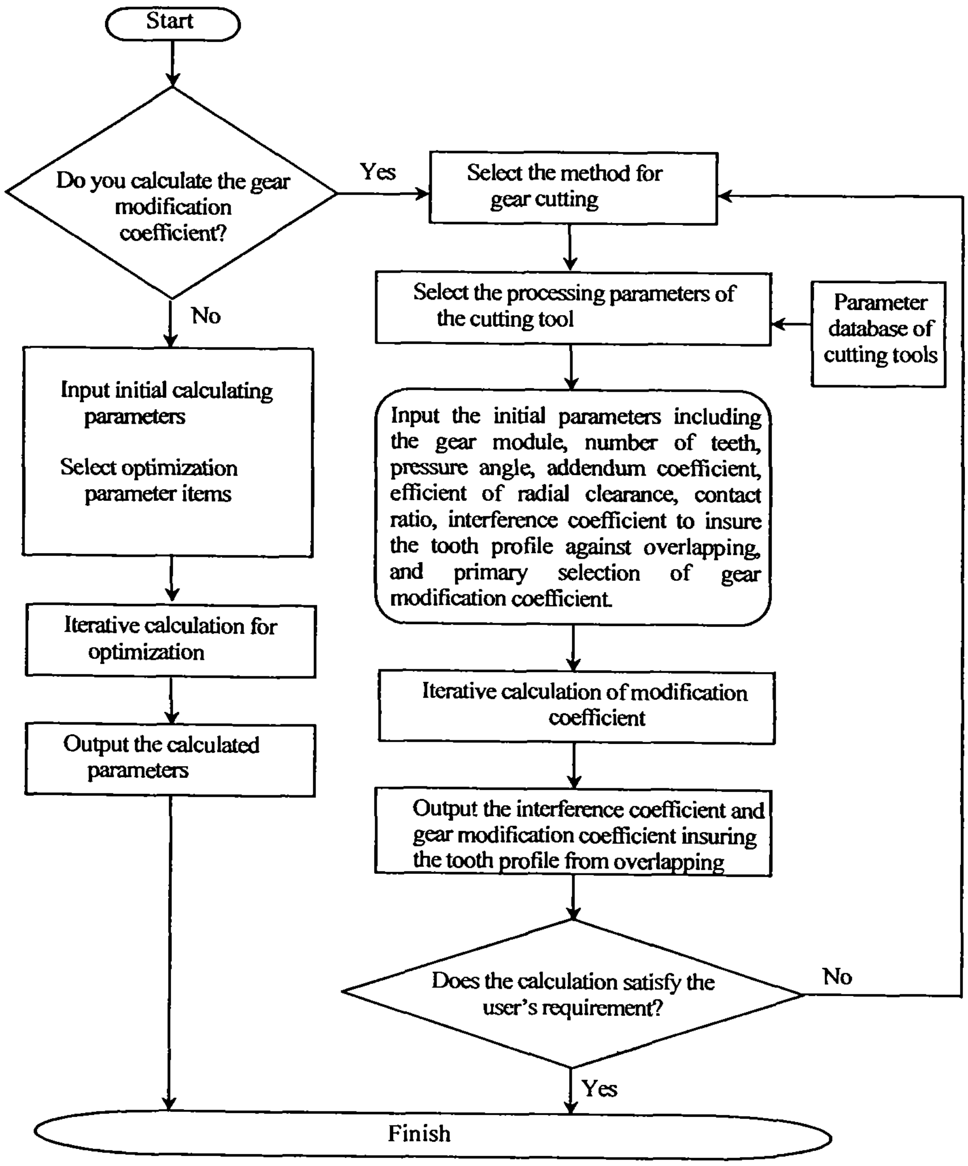

Fig.2. Calculation block diagram for gear parameter

Table 1 The gear parameters#

Initial data										Iterative results					
m	Z_1	Z_2	h_a^*	c^*	Z_0	X_0'	h_{a0}^*	ε'	G_s'	X_1	X_2	a	α'	ε	G_s
2	56	58	0.7	0.25	38	0.42	1.25	1.1	0.5	1.37†	1.685†	2.42†	39.039 °†	1.124†	0.05047†
										1.231‡	1.528‡	2.4‡	38.456 °‡	1.1025‡	0.050‡

In the table, m is the module of the gear; Z_1 the tooth number of the pinion; Z_2 the tooth number of the gear; h_a^* the addendum coefficient; c^* the clearance coefficient; Z_0 the tooth number of the shaper cutter; h_{a0}^* the addendum coefficient of the shaper cutter; X_0' the modification coefficient of the shaper cutter; ε' the initial contact ratio; G_s' the initial iterance coefficient of the tooth profile; X_1 the modification coefficient of the pinion; X_2 the modification coefficient of the gear; a the center distance of gearing; α' the engagement angle; ε the contact ratio; and G_s the iterance coefficient of the tooth profile.

† Parameters for the external gear hobbling machine and the internal gear shaper;

‡ Parameters for the external gear shaper and the internal gear shaper.

In the CAD subsystem of ring-plate with internal teeth the first step is geometric modeling of gear in which the geometric model of gear components are divided into an overall shape tissue of ring-plate, a tissue of inner gear processing, a supplementary processing tissue, and a supplementary function tissue. The whole geometric model of a gear can be obtained by Boolean calculation of these tissues. Then the preliminary check of bending strength, contact strength and limited endurance life should be carried out. The finite element mesh of gear blank and tooth profile can be auto-generated by mesh auto-generation. The further static and dynamic analysis of gears is pursued by finite element method. The displacement field and stress field of all gear components can be acquired.

The finite element meshes of a ring-plate with inner teeth and the Von-mises stress contour plot of an inner tooth profile are given in Figs.3 and 4, respectively.

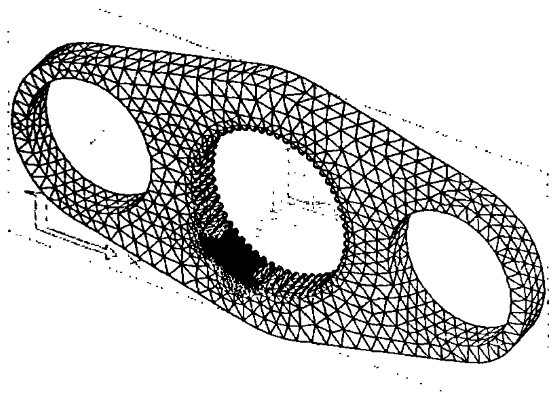

Fig.3. The block diagram for finite element meshes of a ring-plate with inner teeth

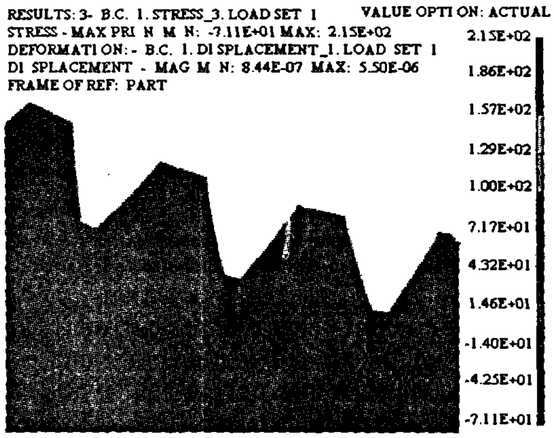

Fig.4. The block diagram for Von-mises stress contour plot of an inner tooth profile

4. Conclusion

The overall scheme optimization and structure optimization of relative components can be facilitated by CAD/CAE system of ring-type planetary reducer with small tooth number difference. The parameters of ring-plates with internal teeth and corresponding pinion can be accurately determined in this system. The development principles such as parameterization, objectiveness, characterization, integration and standardization make this system reliable in practice. This software system aims at reducing the manufacture cost, decreasing the gearbox weight, shortening the development period and improving the product quality.

References

1 ZHU Caichao, Qin Datong. Vibration control and experiment of three-ring reducer. Chinese J Mechanical Engng, 1998, 11(4): 319-325.

2 YING Haiyan,Yang Xihe. Study on K-H type three ring reducer. Mechanical Transmission, 1992, 16 (4): 37-43 (in Chinese).

3 SHU Xiaolong. Determination of load sharing factor planetary gearing with small tooth number difference. Mechanism and Machine Theory, 1995, 30(2): 313-321.