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STANDARDS AND SPECIAL FEATURES OF THEORETICAL MODELS OF PLANETARY GEARS

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Abstract: *The paper reviews existing standards for planetary gear trains calculations. The authors suggest main additional issues to the contents of these standards. Different options for the improvement of the design of planetary gear trains are analyzed. Special attention is dedicated to the discussion of original theoretical models of planetary drives. The objective of the theoretical research are the advantages of different theoretical models to be investigated and improvements of the methods for the calculation and design of planetary gear trains to be suggested. Based upon the investigation carried out new main characterictics of a new theoretical model for designing planetary gear trains are summarized. This new model is to be created with the help of CAD systems.*

Keywords: *Planetary Gear Trains, International Standards, Theoretical Models, Application of CAD systems.*

INTRODUCTION

Planetary gear drives possess great kinematic advantages: they can be uses as summing or differential mechanisms. Depending on the kinematic scheme, they can reach a gear ratio up to 3000. Compared to conventional mechanical drives, the planetary gear trains are characterized with less weight and dimensions transmitting the same or greater torques. The power is transmitted through several symmetrically positioned satellite. Therefore, the power flow is distributed in several branches. This is the reason for diminishing the load of the meshing and of the bearings and the efficiency coefficient reaches for some kinematic schemes the values of 98 %.

STANDARDS FOR PLANETARY GEAR TRAINS CALCULATIONS

The basic standards applied for calculating planetary gear trains are: DIN3990, ISO 6336 and AGMA 2001. The contents of the first two standards mentioned concerns mainly the strength calculation of cylindrical gears. Nevertheless, DIN3990 contains quite good examples calculated for planetary gearings and ISO 6336 gives more specifically extended instructions about the calculation of planetary drives.

Annex E in ISO 6336 (Analytical determination of load distribution) is entirely based on the AGMA 927-A01 standard. It is a practical and useful method to obtain a realistic value for the face load factor $K_{H\beta}$. The input needed concerns the geometry of the shafts, the information for the bearings and for the loadings. Consequently, all data needed to perform a load distribution analysis according AGMA 927 are available.

SOME IMPORTANT SUPPLEMENTS TO PLANETARY GEARS STANDARDS

The approach described in ISO6336, annex E, is quite suitable for calculating the load distribution in gear trains. The algorithm has been adapted to the specific features of the combination of the sun shaft, the planet carrier and the planet gears for planetary gear sets, (Kissling, U., 2013). The deformation and tilting of the planet carrier resulting from bending and torsion of the sun, the shaft and the pin–bearing-planet-system are combined, as shown in Fig. 1.

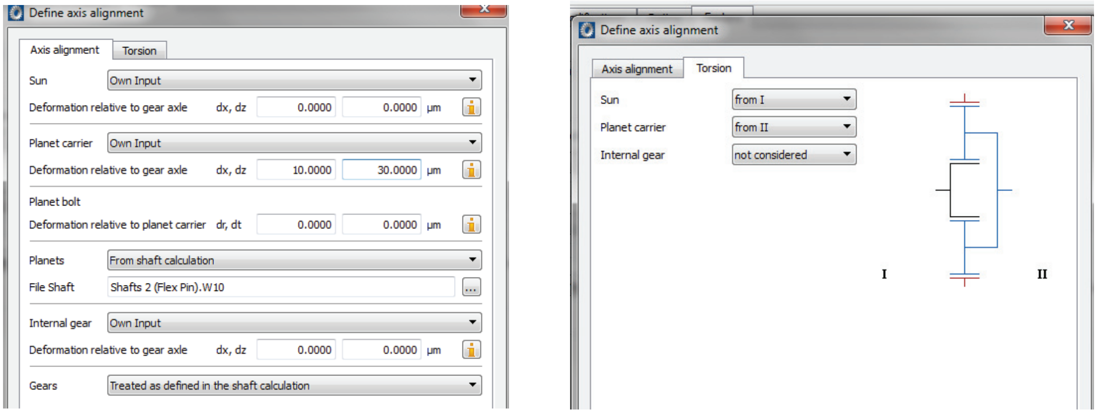

Fig. 1. Definition of deformation and tilting of elements in a planetary system, (Kissling, U., 2013)

The algorithm as described in AGMA927 is defined for one gear meshing. Usually, in a planetary gear set, the sun is meshing with several planets. The load distribution in one of the sun’s meshing interacts with the other meshing section. This also applies to both meshings on each planet and the meshings of the planets with the ring having internal teeth. Therefore, a specific calculation approach using a concurrent iteration over all meshings is developed in (Kissling, U., 2013). This algorithm is shown on Fig. 2.

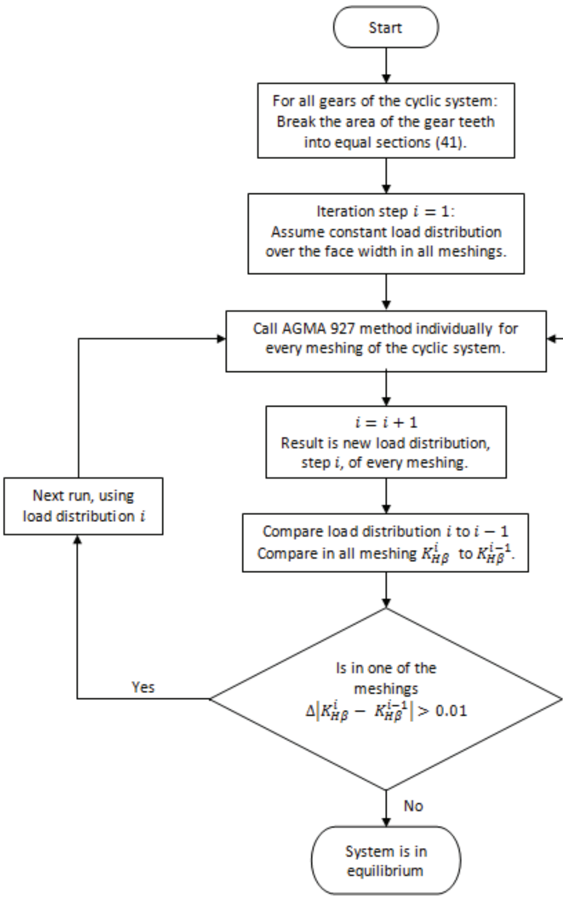

Fig. 2. Application of AGMA927 algorithm to planetary stages

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According to (Kissling, U., 2013) and Fig.2, in order to obtain a final solution for a planet stage with 3 planets: 5 times the 6 meshings of the system have to be calculated.

The idea of the adaptation of the AGMA927 algorithm to planetary gear trains is developed further in (Kissling, U., H. Dinner, 2014). They define in a detailed way the displacements in a planetary gear stage. These displacements are a combination of various effects: torsion and bending of the sun; torsion and bending of the ring gear; torsion of the planet carrier; bending of the planet pin relative to the planet carrier; tilting of the planet gear relative to the planet pin (considering clearance and stiffness of the bearings); current position of the planets (the tilt/shift of the planet carrier is mainly independent upon the rotational position of the carrier).

Another author (Mahr, B., 2011) emphasizes that in contemporary industry applications it is increasingly important to use space and resource-saving gears. One possibility to fulfill this requirement is to design the rim of internal gears of planetary trains as thin as possible in order to reduce the overall space as much as possible. The execution of this objective is connected with a significantly greater utilization of the material strength for tooth root fracture. The same author author analyzes the origin and the influence of the thin rim factors applied in AGMA 2001 and in ISO 6336 and compares them to the calculation of internal gears according to VDI 2737. The main differences between these methods are analyzed using a FEM model, Fig. 3.

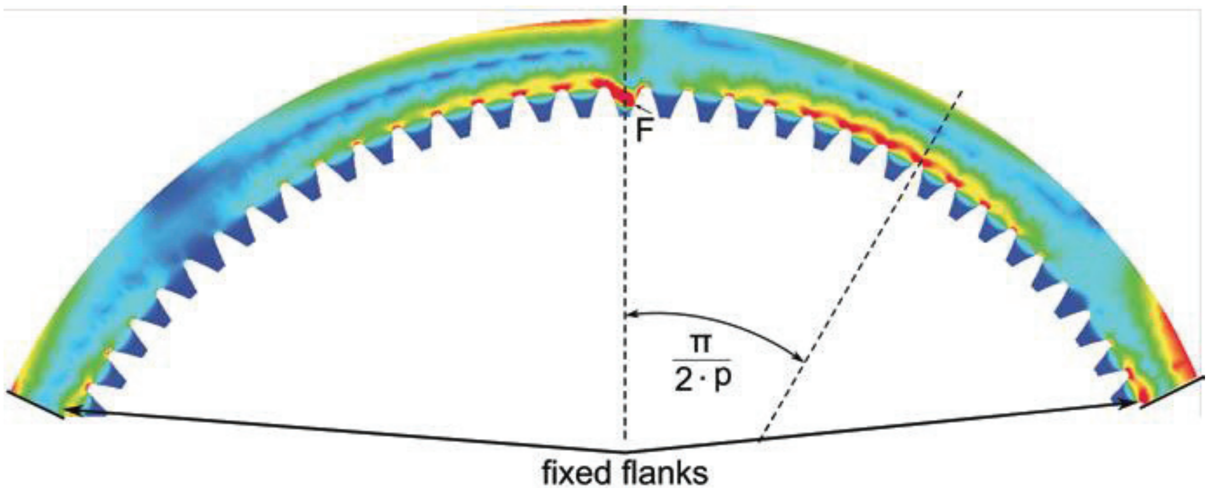

Fig. 3. FEM – model, (Mahr, B., 2011)

The theoretical analysis presented in (Mahr, B., 2011) gives a reliable assertion of different calculation methods for the contact strength of the rim of internal gears for critical applications. The authors of this paper consider that these important supplements have to be taken into consideration during the process of creating new theoretical models of planetary gear trains.

IMPROVING THE DESIGN OF PLANETARY GEAR TRAINS

A great number of literature sources analyze the options for the improvement of specific design features of planetary gear trains. The load distribution of a planetary stage in a wind turbine gearbox is analyzed in (Kissling, U., 2013). In modern planetary stages, the so-called ‘flex pin’ design for the planet shafts is well known, but not quite often used, (Hicks, R. J, 2004). The flexible pin enables the maximum possible number of planets to be used. Load sharing is achieved by ensuring that the deflection of the planet spindle under its normal load is considerably greater than the manufacturing errors, which cause upappropriate distribution.

The planet gears can better adapt according to this concept to the tilting of the planet carrier, thus improving the load distribution over the face width. A conventional design is compared to a flex pin design. The difference in the load distribution is shown on Fig. 4.

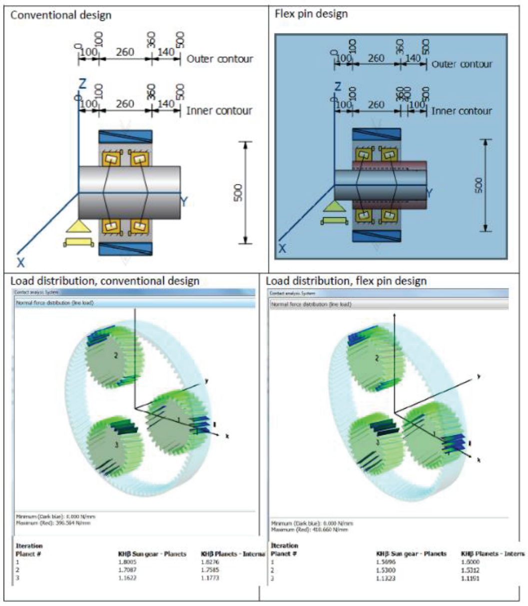

Fig. 4. Load distribution in a planetary stage with two different bearing design modifications, (Kissling, U., 2013)

A tilting of the carrier generates in every meshing a different load distribution, therefore - also a different load distribution factor $K_{H\beta}$. The conventional design factor $K_{H\beta}$ increases from 1.04 (without tilting) up to a maximum of 1.83; for the flex pin version $K_{H\beta}$ increases from 1.04 (without tilting) up to 1.60. This circumstance proves, that the 'flex pin' design concept ensures better adaptation to carrier tilting in comparison to the conventional design. Applying the design procedures described is to be considered advantage by producing new products with high quality in this area.

ORIGINAL THEORETICAL MODELS OF PLANETARY GEAR TRAINS

The authors' team implemented a significant survey of publications of researches working in the area of planetary gear trains. In order to compare different gears with respect to their lifetime, a model of a complete gearbox for a 4 MW wind turbine including all relevant parameters: a defined load spectra (speed and torque versus time on the input shaft) is established, (Dinner, H., 2013).

Based upon the software system KISSsys the complete gearbox, consisting of two planetary stages and one helical stage is analyzed and modeled. The kinematics of the epicyclic gears is preliminary known.

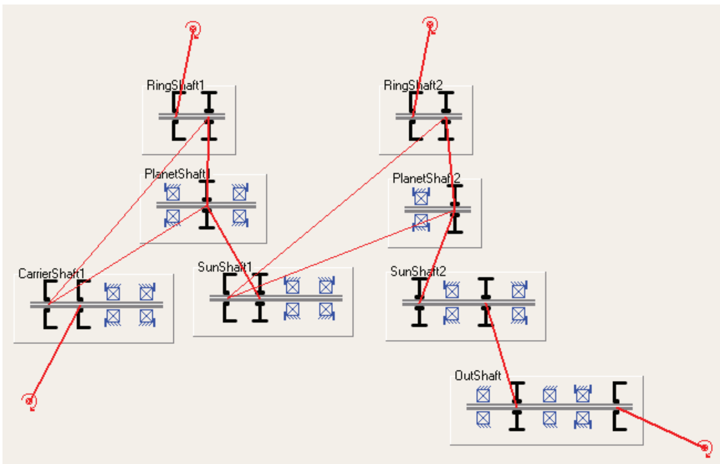

Fig. 5. Gear box with power flow – red, mechanical elements (shafts, gears, couplings) - black, (Dinner, H., 2013)

Therefore, the loads on the gears, bearings and shafts can be calculated. The approximate technical data of the gearbox are quite interesting: Power rating 4MW; Nominal torque 2500 kNm; Nominal speed 15 rpm; Reduction 1:120; Diameter 2000 mm; Length 2800 mm; Lifetime required 20 years. The two rings of the planetary stages are fixed, the first stage has five, the second three planets. The power flow of the gear box is shown on Fig. 5.

A research study of planetary gear trains with internal meshing concerning the evaluation of basic parameters of planetary gear meshing is presented in (Dobreva, A. and S. Stoyanov, 2012). Approaches and methods for a complex analysis of the internal meshing and for the determinations of the permissible and optimal values of its geometry parameters considering different groups of criteria are suggested, applied and investigated. The research is further developed into a theoretical investigation about the energy efficiency of planetary gear trains in (Dobreva, 2013) and into an optimization of planetary transmissions for vehicles based upon computer aided frequency analysis of planetary gears in (Stoyanov, S. and A. Dobreva, 2010), (Dobrev, V. et al, 2012) and (Stoyanov, S. et al, 2017).

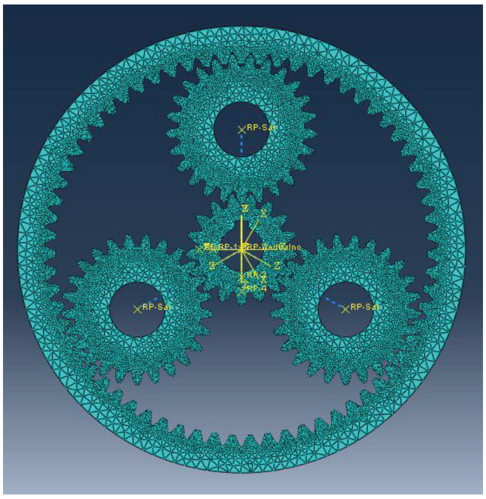

Fig. 5. Finite element model of the meshing for a planetary gear train

The two dimensional model of a planetary gear train described in these literature sources has been further developed and supplemented. With the help of this model several important characteristics of the vibrations have been determined. The design models for planetary gear trains have been created based upon CAD software products, Fig. 5.

CONCLUSIONS AND FUTURE WORK

The authors' team presents a summarized survey on several important topics in the area of planetary gear trains. Based upon this investigation, the following conclusions can be deduced:

- essential features of planetary gear trains which are to be improved have been identified.
- the theoretical analysis presented is to be applied for creating new numerical model which is to be investigated by the authors' team.
- In order to achieve this objective, a precise preliminary model of the involute teeth profile of each pair meshing within the planetary gear train is to be elaborated based upon SolidWorks.

Important signifficant advantage of this future work will be the increasing of the computational efficiency by applying the appropriate software products elaborations.

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