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Research paper

Implementation of a finite element model for stress analysis of gear drives based on multi-point constraints

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ABSTRACT

Gear researchers are always trying to find a trade-off solution between obtaining accurate results from gear stress analyses and low computational costs. Both factors, accuracy on the one hand, and a low computational cost on the other hand, usually go in opposite directions. In this paper, a finite element model for stress analysis of gear drives is proposed with the ultimate goal of obtaining accurate results regarding contact and bending stresses with lower computational cost than those finite element models where mesh refinement is not applied. The proposed finite element model allows the whole cycle of meshing to be analyzed and is based on the application of multi-point constraints for mesh refinement and the application of elements with a reduced number of integration points. Node coordinates are computationally and automatically determined by application of the gear theory. Several numerical examples are presented for a spur gear drive, although the same ideas can be applied in other types of gear drives. Accurate results of maximum contact pressure along the cycle of meshing with an important reduction of computational cost are achieved, mainly due to the reduction of the number of degrees of freedom that multi-point constrains provide, rather than by the use of reduced-integration elements.

1. Introduction

Stress analysis is an important aspect in the design and the analysis of gear drives. The solution of the stress analysis should provide the actual size of the contact pattern due to the transmitted load, the contact stresses on the contacting surfaces and underneath the contacting surfaces, the bending stresses at the fillet of the gear teeth, and the surface deformation for the calculation of loaded transmission errors.

Many approaches for gear stress analysis have been applied so far. Many of them are based on the application of the finite element method in which this paper is focused on. First applications of the finite element method in gears were directed towards the determination of root bending stresses as in [1] for a two dimension analysis and in [2] for a three dimension analysis. Later, finite element analyses covered as well the determination of contact stresses as in [3] for a two dimension analysis and in [4] for a three dimension analysis. The analysis of the stress evolution along a whole cycle of meshing and the automatic determination of the node coordinates were steps forward in the application of the finite element method to gears [5]. Some improvements of the finite element model to consider torsional deformation of the gears and the effect of shaft deflections came later [6–8].

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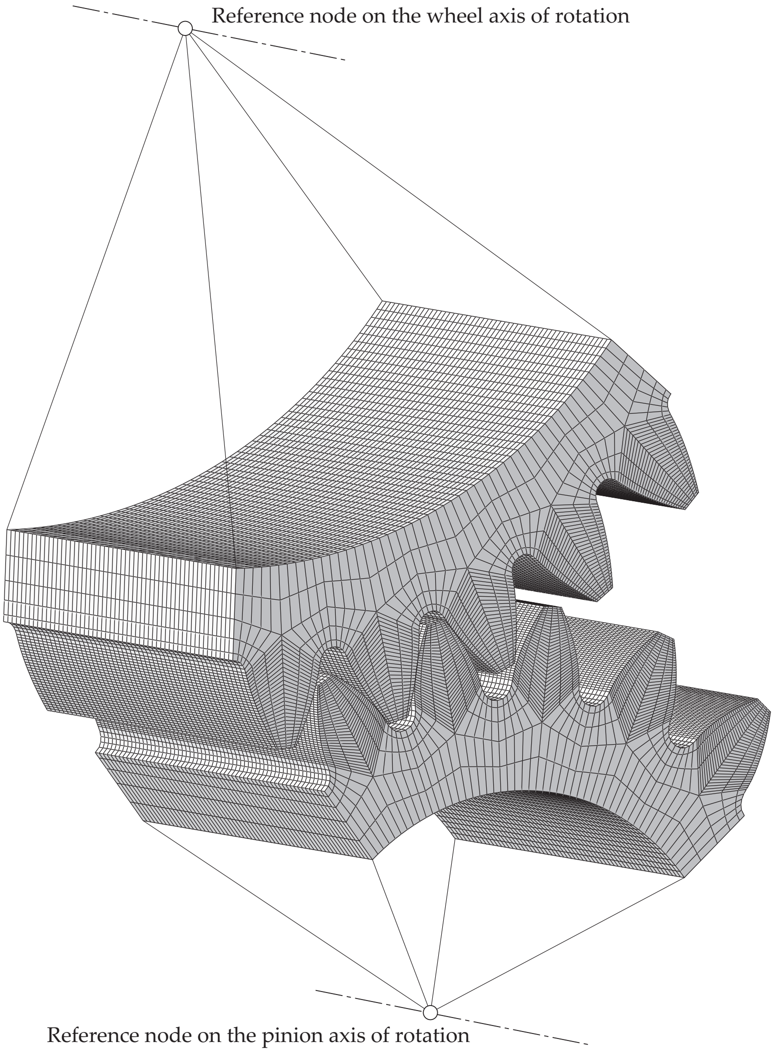

Fig. 1. Example of a finite element model that requires a high computational cost.

Some other approaches for stress analysis of gears are based on numerical methods that combine analytical solutions with finite element analysis. Those methods are in general more computational effective than those that are based exclusively on the application of the finite element method [9]. Other numerical methods with reduced computational cost are based on the application of shell theory to gears [10]. Although finite element analysis can be very accurate, in general its main drawback is the computational cost derived from the amount of finite elements that are required around the contact area and along the fillet profile. First examples of reduction of the number of finite elements in the fillet region of the gear teeth by means of transition elements can be found in [11] for a three dimension problem. Here, transition elements in the contact region for a two dimension problem were applied as well. Later, a reduction of the number of elements based on the application of surface-based tie constraints was applied in [12]. The high computational cost of many finite element models is due mainly to the symmetry of the mesh in both, driving and coast sides, as the finite element model proposed in [5] and shown in Fig. 1 for the case of a spur gear drive. Reduction of computational cost in the finite element analysis of gear drives may find application in the optimization procedures to get high efficiency and low weight gears [13–15].

In the characterization of gear materials, several magnitudes regarding strength are managed [16]. Regarding the contact area, a fatigue strength for Hertzian pressure and a tensile strength can be considered. Maximum contact pressure and effective Tresca or Von Mises stresses should be taken into account for comparison with those magnitudes previously mentioned, respectively. Regarding the bending area, a fatigue strength for tooth root stress is usually considered. For such a value, the maximum principal stress should be taken into account for comparison.

The main goals of this research are summarized as follows and are based on the application of a finite element model that allows to: