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# Differential hypoid gears: the necessity for a multi-physics approach

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## 1 Introduction

A multi-physics approach to investigate the dynamics of differential hypoid gears is presented in this work. Initially, a multibody model of a hypoid gear pair has been developed using ADAMS commercial software. The geometric data of the gears have been determined using Tooth Contact Analysis (TCA). At high transmitted loads, an Elasto-hydrodynamic (EHL) regime of lubrication is prevalent between the gear teeth, where the lubricant film behaves as incompressible body. EHL conditions generally exhibit insignificant damping and relatively high lubricant stiffness. An iterative solution between dynamics and teeth lubrication is required in order to obtain the correct teeth loads and motion of the gear wheels. Time restrictions are forcing the use of extrapolated equations for the tribological calculations coupled with the dynamic model. In addition to teeth contact loads, flank friction is another connection between dynamics and tribology, dissipating energy in the system.

In parallel, a fully numerical model of EHL elliptical point contact has been developed, taking into account non-Newtonian and thermal effects. In the case of highly loaded teeth contacts, a mixed regime of lubrication is encountered due to thin films. The EHL model predicts the film thickness and power loss in a quasi-static manner (by employing snapshots from a typical meshing cycle). These calculations give detailed distributions of pressure, temperature and film thickness between the contacting teeth. Therefore, the EHL model is suitably developed to produce information about the power loss encountered in the hypoid gears. This multi-physics approach is presented in Fig.1.

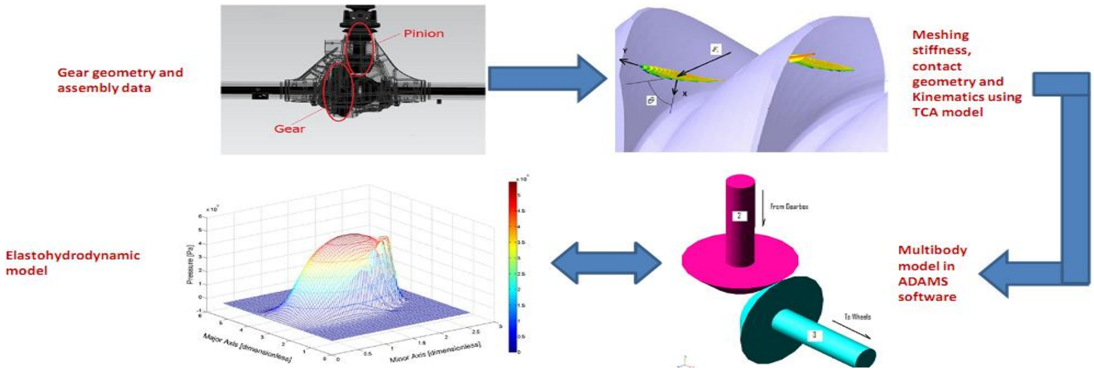


*Fig. 1*
*The modelling approach*

## 2 Dynamic model

A model of the gear pair that includes both torsional and lateral degrees of freedom can be used for dynamic modelling purposes [1-4]. Nonlinearities sourcing from variations of the teeth stiffness, contact radii, gear backlash and the supporting bearings have been included. A linearised version of the model can predict system resonances as well. Main outputs are the Dynamic Transmission Error (DTE), the transmitted force through the bearings, the generated flank friction and the lateral motions of the gear wheels. The frequency spectra of the maximum and minimum amplitudes of the lateral motion are presented in Fig.2, while Fig.3 shows the transmitted lateral force in the radial direction of the pinion. The importance of capturing accurately the lateral motion of the gear wheels, as well as the transmitted force lays in their role in structure-borne noise investigations. The main Noise, Vibration and Harshness (NVH) issue in differentials is usually axle whine, which is a structural-borne noise phenomenon.

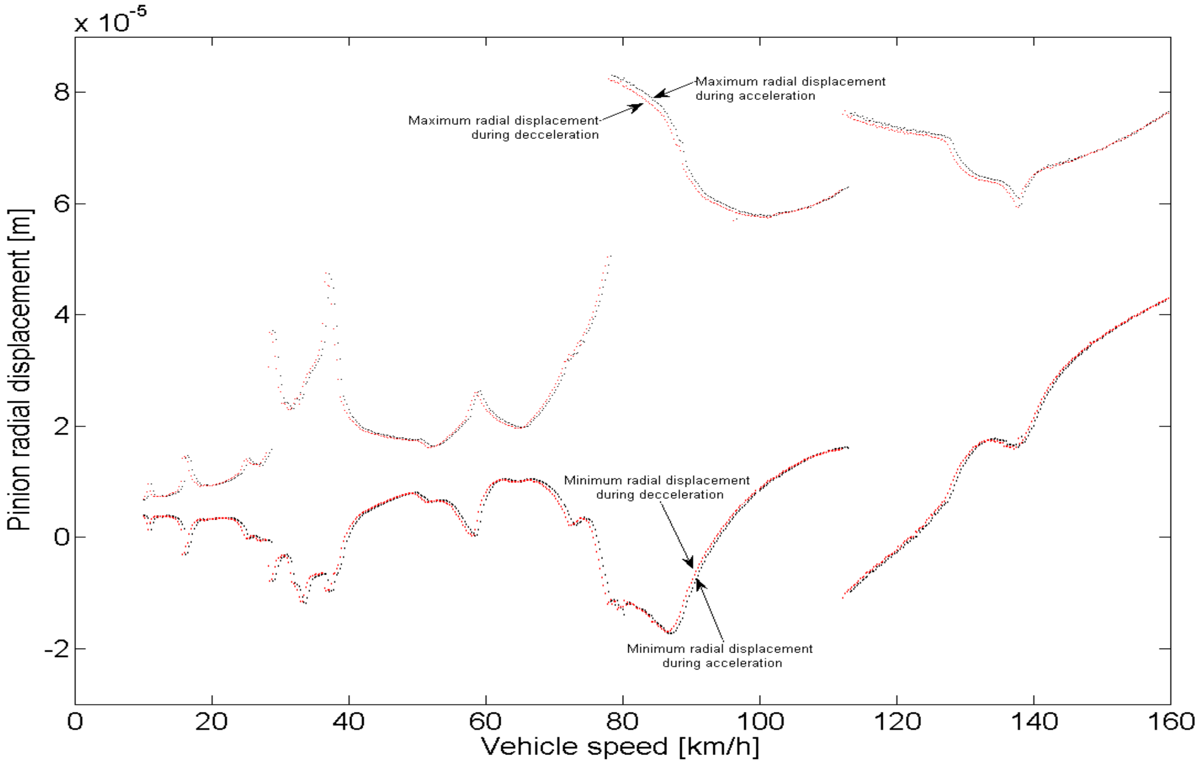


*Fig. 2*
*Frequency spectra of the lateral motion maximum and minimum amplitudes*

## 3 Tribological model

A numerical EHL model of hypoid gears is presented in [3], which can be used to derive more detailed data, such as film thickness, flank pressure and temperature distribution. Nevertheless, due to high computational time, an equation extrapolated by Chittenden et al. [6] is used for film thickness calculations, being suitable for hypoid gears [5]. An equation derived by Evans et al. [7] has been used to calculate the friction coefficient between the mating teeth (being also applicable to hypoid gear contacts). Finally, the EHL model is using the flank load and surface geometry, as well as contact kinematics from the dynamic model. Fig.4 shows the pressure distribution for a typical snapshot of the meshing cycle.

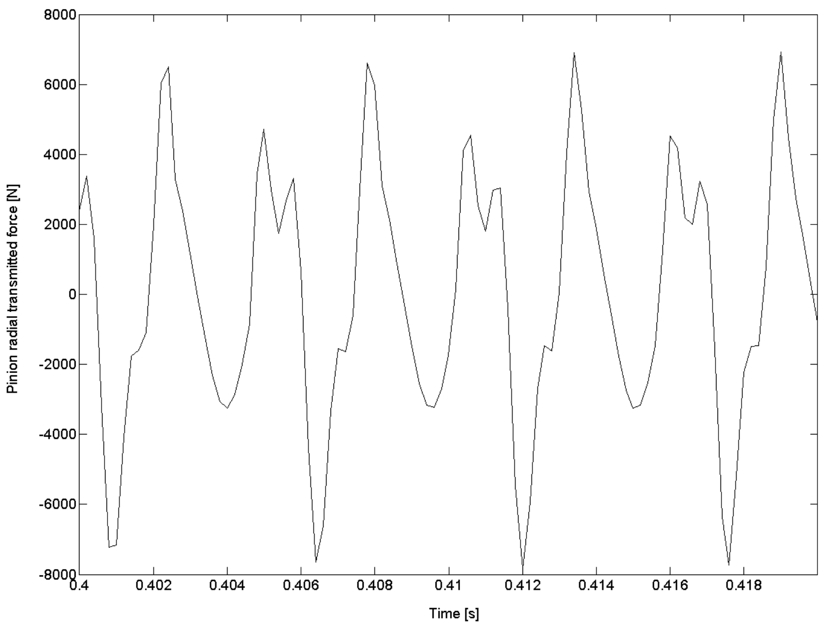


*Fig. 3*
*Transmitted lateral force time history*

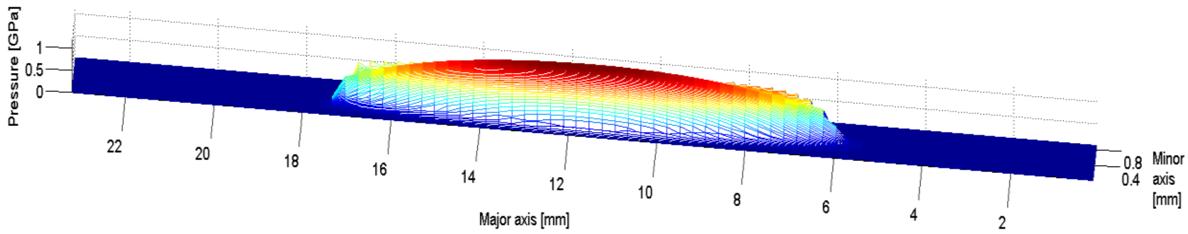


*Fig. 4*
*Pressure distribution – a snapshot of the meshing cycle*

## 4 Conclusions

As a conclusion, tribological predictions are essential to study the gear pair's parasitic losses (efficiency). On the other hand, dynamic modelling returns the transient behaviour of the gear pair (DTE and transmitted force), as a predictive tool for NVH behaviour. The two problems have to be solved simultaneously due to the strong physical relationships between them.

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