Experimental and numerical validation of dynamic transmission error using advanced gear contact model in a multibody framework

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The increase of fuel price and stricter emissions regulations impose a more efficient energy consumption in all sectors of human activities; mechanical engineering is not excluded from this trend and can be considered to be highly involved in the renovation process. Mass reduction is only one of the possible solutions that can be adopted to reduce the energy needs of a mechanical system.

Geared transmissions, as key components in many mechanical systems, can not be excluded from the mass reduction process. Reduction of gear thickness as well as holes and slots in the web of the gear are common industry practices when lightweight design has to be achieved. Topology parameters of the holes such as number, position and shape heavily affect the static and dynamic behavior of the gears and consequently of the transmission, by producing periodic fluctuations in the mesh stiffness with a periodicity linked to the web geometry, which may cause sidebands phenomena in the system dynamic response. Several authors investigated modulation and the associated sideband families in vibration spectra of geared transmissions. The presence of sidebands was related to periodic displacement functions of the rotational angle by Blankenship and Singh [1], which act as additional excitations for the gear pair system. The dynamic behavior of faulty transmissions was investigated in other works [2],[3] where cracks, pitting, mounting and manufacturing phenomena cause modulation effects and additional excitation yielding a richer order content in the dynamic response of the system .

Design tools help the transmission engineer in his main challenge to deliver a reliable and high-performance product at a lower cost and with lower time-to-market. Different and coupled factors are acting at the same time during gear meshing, increasing the phenomena complexity, such as non-linear load-dependent contact deformations, friction, clearance and time-varying mesh stiffness. The minimum requirement for a design tool is to reproduce these phenomena in a computationally-efficient way.

Since the past decades several simulation methods have been made available, each of them representing different trade-off between accuracy of predictive results and computational efforts.

Analytical tool and gearbox-specific tools can support the designer in the early design stage providing quick results thanks to the low required computational efforts. The somewhat reduced accuracy, on the other hand, especially in case of coupled or system level phenomena and the need for specific know-how represent a limit to their effective industrial application.

Non-linear finite elements simulations are placed at the top of the chart in terms of accuracy of the results but at the cost of high computational requirements: typically several order of magnitude higher than analytical representation. This issue limits their application to quasi-static simulations, usually considering a single gear pair.

Multibody simulation softwares with gear-dedicated tools, such as Siemens LMS Virtual.Lab Motion [4], represent a trade-off between accuracy and computational cost. These tools allow to the user to obtain sufficiently accurate prediction of geared systems in a feasible time and have already proven the fidelity of the results against the experimental measurements.

The main idea behind this approach is already described in several works: [5], [6], [7] and can be described by considering the global deformation of the meshing gear as the superposition of two effects as reported in fig. 1. The first effect is the global bending deformation of the loaded teeth. This effect can be considered as linear and therefore can be well represented by a coarse FE mesh. The second contribution comes from the non-linear Hertzian contact that can be effectively described by the analytical expression provided in [8].

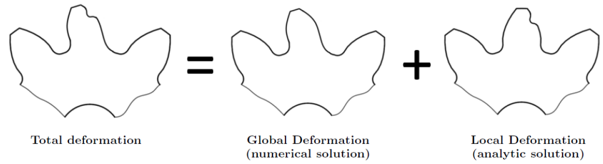

Fig. 1: Global deformation from FE analyses and local non-linear analytical contribution [5]

In this work the approach described above is extended to the analysis of lightweight gears, i.e. gears with a dedicated blank geometry allowing to obtain mass reduction. Through a detailed modeling of the geometry of the gear blank the effects of different topologies of the gear are taken into account during the multi body simulation. The lightweighting contribution is considered as an angle-dependent global compliance of the gear, and the dynamic equation coupling the global and local effects is then solved in order to obtain time-domain data. The simulation results are then validated trough an experimental campaign on an high precision gear test rig [9]. The results are compared in terms of Transmission Error, defined as the difference between the actual position of the driven gear and the position it would occupy if the gears were infinitely rigid and the teeth profiles perfectly conjugate. The Transmission Error (TE) is considered as one of the main excitation sources in a system where meshing gears are present [10] and therefore is a good indication of the systems behavior. The results will be analyzed for different working conditions in terms of operating speed and transmitted torque, allowing to the investigation of the influence of the different lightweight strategies on the static and on the dynamic behavior of the gears. Different types of cylindrical gears will be analyzed, including both spur and helical gears. The advanced formulation of the gear contact model in the multibody framework allows also to recover the time-domain stress and strain values in the gear body from the multi body simulation with an accuracy comparable to the one of dynamic finite elements method. This feature allow to analyze the loading state of the gear related to the different topologies of the gears bodies. The strain values will be compared to the ones obtained from the experiments through the application of strain gages on the gear bodies.

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