Flexible Gears for Detailed Gearbox Analysis

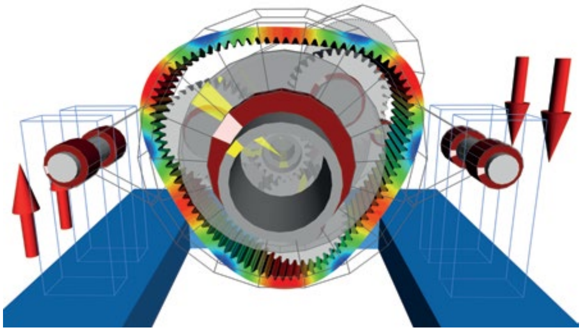

Fig 1: Flexible ring gear with exaggerated deformation

Originally developed in order to simulate timing mechanisms of high performance F1 race engines, the Gear Pair element has become a key feature in SIMPACK for drivetrain analysis. Due to the efficient analytical approach, the Gear Pair element is commonly used for complete system simulation within almost all SIMPACK industrial sectors, e.g., transportation, power generation and machinery. The Gear Pair element is used for simulations ranging from resonance analyses and load generation to rattle and whine investigations.

From the first release in 2005, the SIMPACK Gear Pair has succeeded in achieving an ever increasing importance amongst users, and therefore, has been continually enhanced over the years. This article focuses on the latest enhancement of this primary SIMPACK element, flexible gears.

FLEXIBLE GEARS INTRODUCTION

For most system simulations, gear wheels can be considered rigid with the contact locations being computed analytically. The contact stiffness is a function of gear geometry, material properties, contact position and load in accordance with DIN 3990/ISO 6336. However, for some applications, the deformation of the gear wheel needs to be considered. Additional eigenmodes of the gear body or teeth can have a significant influence on tooth contact and loading and be essential for detailed NVH analyses, e.g., gear whine. With weight optimized gear boxes, the influence of the gear wheel deformation becomes increasingly important.

Up to now, a process loop between MBS and FEM was necessary in order to calculate deformation and optimize micro geometry, which can be quite time consuming. By considering the flexibility of the gear wheel from a FEM tool directly within SIMPACK, the required task effort can be significantly reduced.

FLEXIBLE GEAR WHEEL

SIMPACK FlexModal is used for the modal reduction of the elastic gear. The final mass and stiffness matrices, including local mode shapes in terms of FRM 's or IRM 's, are substantially smaller than the original FEM model which minimizes the calculation effort without compromising accuracy. At least one master node for each tooth must be used. With the use of several nodes per tooth, deformation along the flank width can be considered, e.g., for determining required micro geometry correction in order to compensate for gear wheel twist. Generally, the eigenfrequencies of the individual teeth are very high, and therefore, can be neglected.

Fig 2: Critical gear eigenmode

FLEXIBLE GEAR WHEEL FUNCTIONALITY

- Consider gear wheel deformation for contact location
- Include additional eigenfrequencies of flexible gear wheel
- Include tooth misalignments and pitch irregularities (e.g., broken tooth)
- Calculate the load and deformation along the flank width
- Optimize the flank modifications depending upon transient loads
- Design and optimize gear stages without a SIMPACK-FEM process loop

COMPLEX SYSTEM BEHAVIOR OF NON-STANDARD GEARWHEELS

With flexible gear wheels, e.g., slotted gearwheels or ring gears fixed within gearbox housings, the influence of non-standard gearwheels on system behavior can now be evaluated. The gearwheel shown in Fig. 2 has a non-constant stiffness about the rotational angle. The symmetric arrangement of the slots leads to a harmonic change of stiffness and eigenfrequencies in the form of a sinus vibration. The main response of the solid gear is associated with the torsional eigenmodes. Bending and axial eigenmodes of the gear body are not significant.

The slotted gearwheel results in a more complex system with additional sideband excitations. The sum of orders is much more complicated compared to the solution of the solid gearwheel, Fig. 3. Additionally, bending and axial eigenmodes appear for the slotted gearwheel due to the lower system stiffness.

CONCLUSION

Flexible gearwheels can now be used directly within SIMPACK which enables additional effects to be considered and eliminates the need to switch between different CAE tools. This new method results in extremely accurate and efficient simulations in the time and frequency domain. Engineers can now easily switch between upper fidelity levels, e.g., rigid and flexible gears, in order to better understand system behavior and optimize simulation time. This new solution-oriented method is a significant step in extending the boundaries of efficient system simulation within SIMPACK.

REFERENCES

[1] Schulz, C.; Mulski, S.: Modelling and Simulating flexible Gears – A solution-oriented approach, NAFEMS World Congress 2015, San Diego 2015.

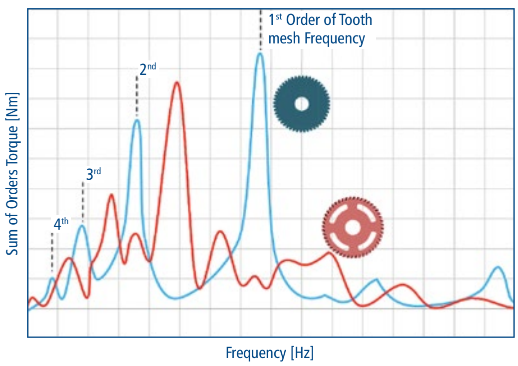

Fig 3: Sum of all orders