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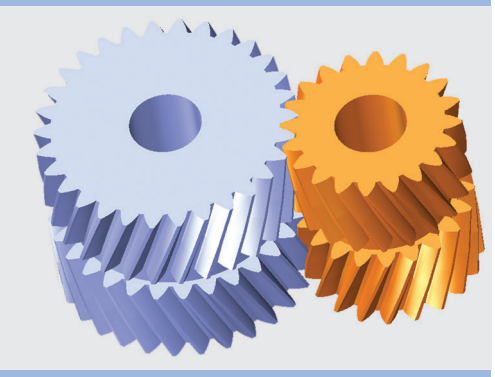
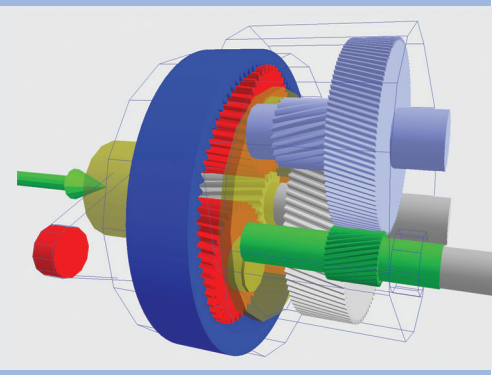
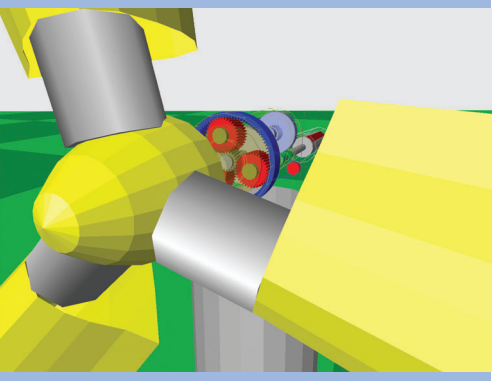
Modelling and Simulation of Drive Line Gears



Parallel Helical Gear Pair



Two Stage Planetery Gears



Wind Turbine with Two Stage Planetery Gears and Two Stages of Parallel Helical Gear Pairs

Planetary gears are often used when drive systems and drivelines are required to transfer large torques or large speed transformations. Planetary gears can also be used for splitting the power to different outputs (power split device) or for combining the outputs of different drive shafts into one (summation gear). The SIMPACK Force Element 'Gear Pair' allows gearwheel reduction stages or planetary gears to be easily generated. The Force Element also considers changes in the separation of the shafts during a simulation allowing planetary gears, which are subject to high stresses and bearing movement of the planets and sun, to be accurately simulated.

AREA OF APPLICATION

The SIMPACK Force Element Gear Pair is used primarily for modelling gear pairs with involute external or internal tooth geometry for helical or spur gears. Entire gearboxes can be built in SIMPACK with the Force Element. The most important applications in automotive and railway vehicle design are:

- Manual transmissions
- Drive of Balancer Shafts
- Gear Chains for the drive of camshafts in motor sport engines
- Transfer Gearbox
- Power Splitter
- Axle Transmission
- Differential and Planetary Gears

The standard SIMPACK functionality can be used to build up adjustable axial and radial piston pumps as well as entire engine models. The Gear Pair adds the potential to couple these components with complex power splitting and summation gearboxes. These gearboxes can have variable transmission ratios; the control and setting of which can be modelled.

The simulation of powertrains in multi-body software offers the following advantages over signal processing programs: Each individual gear stage applies a load dependent reaction moment on the gearbox housing. This reaction moment, due to the nature of MBS modelling, is automatically considered for the rest of the system.

Gearboxes that are elastically mounted or contain flexible structural components behave as a power splitting gearbox. This elasticity has a large influence on the calculation of the eigenfrequencies of power trains. If this flexibility is not considered for torsional vibration analyses then the eigenfrequencies and eigenmodes calculated are not consistent with the resonance effects seen in the real system. This can lead to unexpectedly high loads within the system.

The deflection of the shaft as well as the radial compliance of the shaft mountings due to the teeth forces reduces the torsional transmission stiffness of gear pairs.

Other important influences on the vibrational behaviour of gearboxes with helical gears include:

- The axial play in the gearwheel and in the pinion mountings increases the play between the contacting teeth. This is significant when the torque direction changes.
- The stiffness of the axial mounting also has an effect on the overall transmission stiffness for gearboxes without torque direction changes. This is because the teeth transmission stiffness is also dependent on the longitudinal stiffness of the shaft mountings.

These effects can only be avoided by using double-helical gears, whereby the axial forces cancel each other out. This is provided that the elastic shaft bending doesn't lead to unsymmetrical contact of the left and right helical gearing.

HIGHLIGHTS OF THE FORCE ELEMENT GEARWHEEL

- Parameterisation in accordance with DIN standards
- Calculation of individual tooth stiffnesses from the number of teeth and the addendum modification factor according to DIN 3990.
- Calculation of the rotation angle dependent tooth contact stiffness from the current contact ratio whilst considering the tip relief.
- Dynamic changes in the separation of the gear shafts is considered when calculating the contact conditions.

- The tooth play is dynamically dependent on the radial displacement.
- Contact on both tooth flanks due to a small separation of the shafts.
- Numerically very efficient by keeping to a minimum the Newtonian iterations for the calculation of the position of the tooth contacts.

THE CONSTRUCTION OF A GEAR SYSTEM IS PERFORMED IN TWO STEPS

A) DEFINITION OF THE GEOMETRY OF THE GEARWHEELS

The definition of the gear geometry is performed via the standard parameter entry in the 'GearWheel' 3D Geometry Primitive.

- Normal Module, Profile Shift
- Normal Angle of Attack
- Helix Angle
- Tip and Root Diameter, face width
- Number of Teeth, Backslash

The discretisation used for the graphical representation does not have any influence on the accuracy of the force calculation.

B) DEFINITION OF THE GEARWHEEL FORCE ELEMENT

The parameters of the 'GearPair' Force Element are used to describe the physical attributes in the calculation of the teeth forces.

- Tip Relief factor (It reduces the large changes in normal stiffness, which can occur for multi-tooth contact when gear teeth pairs commence and cease meshing.)
- The Gearwheel Form Factor. This is used for the calculation of the weakening of the tooth, when compared to a gearwheel of complete cross-section.
- Stiffness Ratio of the parabolic normal stiffness function
- Material Properties for each of the two meshing gears (Young's modulus, Poisson's Ratio)
- Normal Contact Damping Parameters (coming into and out of contact)
- Friction Coefficient for tangential force calculation,

By means of the three parameters 'Tip Relief Factor', 'Form Factor' and 'Stiffness Ratio' it is possible to correlate the results of the periodically changing tooth stiffness with test results or with a static FE calculation.

STEADY STATE FORCED RESPONSE OF GEARWHEELS

Gear pairs show the following two important characteristics when transmitting force:

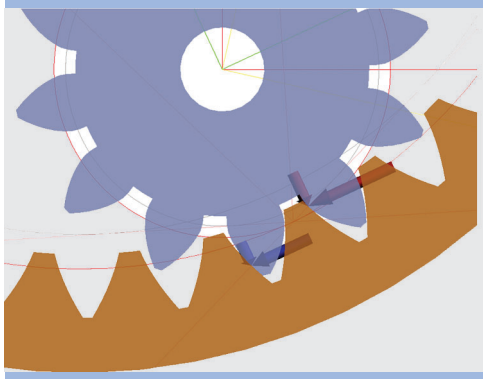
- Periodic change in the contact stiffness
- Non-linear restoring force due to play in the teeth

The periodic change in the contact stiffness generates a parametrical vibration excitation; this is described in the literature under Mathieu differential equations. The respective stabile and instabile solution sectors are dependent upon the excitation frequency and the periodic changes in the stiffness.

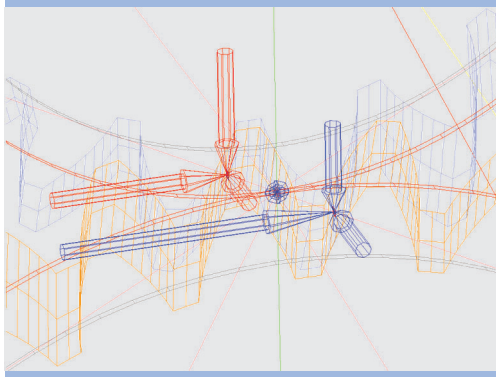
If the vibration induced amplitudes in the torque transmission are greater than the static loading then this can lead to 'lift off' from the tooth flanks. This effect can increase beyond the tooth play and cause contact on the opposing flank. The resulting non-linear restoring effects creates a left weighted form for the amplitude resonance curve describing linear systems. This leads to the typical jumps in amplitude when performing a frequency sweep. For high frequencies this causes the resonant frequencies to move away from the excitation frequency.

SUMMARY AND OUTLOOK

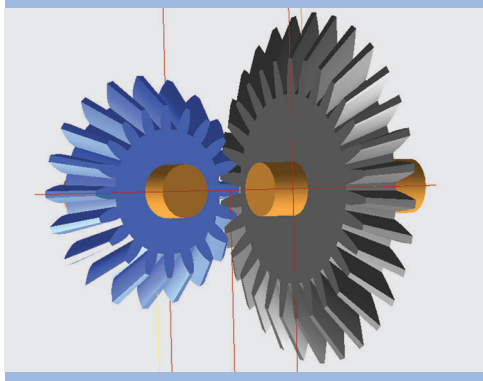
The SIMPACK Force Element Gear Pair is easily configurable and allows gearboxes containing numerous gear pairs to be modelled efficiently. The algorithms used in the force calculation are fast, reliable and numerically stabile. At present the most important uses for the 'Gear Pair' Force Element are in the automotive field – drive trains, camshaft drives and balancer shafts. The other main application is for gearboxes transmitting large amounts of power, such as in wind turbines. These diverse uses have shown that the applications to which the Force Element can be applied is likely to continue on growing.



Forces Acting on an Internal Gear Pair



Parallel Helical Gear Pair The Arrows Show the Resulting Force Components for Two Pairs of Teeth in Contact



Bevel Gear Pair