Contact Modeling of Meshing Gear Wheels using Tangentially Movable Teeth

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**Introduction – SIMPACK FE 225**

**fully rigid gear wheels modeling in SIMPACK (force element 225):**

- ✔ simple to model
- ✔ computationally efficient
- ✔ capable of including many important features of real applications
- ✔ possibility of simulation of technical systems consisting of many gears
- ✗ not accurate for some real application conditions

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Introduction – FEM

fully elastic gear wheels (FEM):

- accurate for real application conditions
- takes into account all the details
- requires prohibitively costly and time consuming computations
- simulation of technical systems consisting of many gears is almost impossible
extension of force element 225 through tangentially movable teeth:

- simple to model
- computationally efficient
- capable of including many important features of real applications
- possibility of simulation of technical systems consisting of many gears
- accurate for some more real application conditions by choosing appropriate values for elastic elements
Introducing teeth coordinates as new force states into the equations of motion.

In the rigid modeling approach: SIMPACK force element 225

The rotation of each gear wheel is described through only one rotational coordinate.

In the extended approach:
- This rotational coordinate is used only for describing the rotation of the gear body.
- The tangential displacements of the teeth will be described through additional rotational coordinates which can be supposed as states assigned internally to the force elements.
Considering elastic elements between teeth and gear body

Identical elastic elements including parallel spring-damper combinations are considered between the teeth and the gear body in order to:

- Model elasticities between the teeth and the gear body
- Restrict the movement of the teeth relative to the gear body

Equation of motion of each tooth:

\[ m_t r_d^2 \ddot{S}_i = k r_d^2 (\phi - S_i) + c r_d^2 (\omega - \dot{S}_i) + T_i, \quad i = 1, \ldots, n \]

- \( m_t \): Mass of each tooth
- \( r_d \): Dedendum circle radius
- \( c \): Damping coefficient
- \( k \): Spring stiffness
- \( \phi \): Rotation angle of the gear body
- \( \omega \): Rotational velocity of the gear body
- \( S_i \): Rotation angle of the tooth \( i \)
- \( T_i \): Contact torque

Stiffness and damping coefficients of elastic elements may be identified through a parameter identification procedure using an FEM program.
new search algorithm for finding contact situations

Contact Search Algorithm

pitch angle of gear 2
left flange angle of gear 2 in contact region
right hand side contact
left line of action
right line of action
left hand side contact
left flange angle of gear 1 in contact region
pitch angle of gear 1
1- specifying the tooth of gear 1 whose left hand side flange is located within $-p_1/2$ and $+p_1/2$

2- specifying the neighboring teeth whose left hand side flanges are inside the contact region

3- considering the teeth of gear 2 corresponding to the already considered teeth of gear 1

4- calculating the angle and position of the intersection point of these flanges with the left line of action

5- calculating the relative turn angle corresponding to each probable contact

6- repeating these steps for right hand side contacts
Modification of Contact Forces and Torques

modification of applying contact forces and resulting torques

in the force element 225:
- the resulting contact forces and torques of the contacting teeth are summed up
- returned as the total force and torque vector applied to the gear bodies

in our modeling strategy due to the effect of the elastic elements, the procedure of applying contact forces and torques must be modified

1- the contact force of each contacting tooth is projected onto the normal and tangential directions

\[
F_n = F_x \sin \theta - F_y \cos \theta
\]

\[
F_t = -F_x \cos \theta - F_y \sin \theta
\]
2- the resulting torque of the each tangential force is calculated and is considered in the equation of motion of the corresponding tooth $T = F_t r$

3- the amount of tangential force of each elastic element between the teeth and the gear body is evaluated

$$F_{te} = kr_d (\phi - S) + cr_d (\omega - \dot{S})$$

4- the total contact force of the gear body can be calculated now by summing up the normal forces of the contacting teeth and the tangential forces of the elastic elements

$$F = \sum F_n + \sum F_{te}$$
comparison of spur gears using a fully rigid and newly developed approach

magnitude of contact forces applied to gear 2

Example 1

rigid modeling approach (SIMPACK force element 225)

new approach

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Example 1
one side flange contact between two spur gears

simulation time for one contact:
- FEM 10h
- rigid body approach 0.2s
- new approach 2.0s

Example 2

- angular velocity of gear 1
- angular velocity of gear 2

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the SIMPACK force element 225 for contact simulation of gear wheels has been extended through a tangentially movable teeth approach in order to

- improve the results to be close to the accurate results of FEM
- preserve the low computational effort

the required steps to do so are

1- introducing teeth coordinates as new force states into the equations of motion
2- considering elastic elements between the teeth and the gear body
3- changed search algorithm for finding contact situations
4- modification of applying contact forces and resulting torques

main question in this newly developed approach

identification of the stiffness and damping coefficients of considered elastic elements between the gear body and the teeth (practically based on an FEM reference solution)