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Jørgensen, Martin Felix

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Multibody Model for Planetary Gearbox of 500 kW Wind Turbine

Martin F. Jørgensen

DTU Mechanical Engineering
Overview / topics

1. Introduction
2. Aeroelastic model (FLEX 5)
3. Experiments vs. simulations
4. Multibody model - description
5. Results
6. Conclusions
1. Introduction

**Objective:** To create a multibody program for modelling drivetrain loads, forces etc on main components such as bearings and all stages in the gearbox.

**Method:** Matlab code with input for generator and rotor loads from FLEX5, using a complete structural model of the wind turbine.
1. Introduction

“Multibody drivetrain model of a 500 kW wind turbine for predicting gear tooth stresses in a planetary gearbox” – methods:

(a) Illustration of rotor, nacelle, main shaft, gearbox (planetary + 2 parallel stages), brake, 500 kW generator, 3 yaw motors etc.

(b) Outline of method used.
2. Aeroelastic model (FLEX 5)

a) **Input:**
   a) “Real” atmospheric turbulent wind speed.
   - Wind field (based on TI+mean wind sp)
   - Blade aerodynamic data: Lift+
     Drag coefficients, radial stations
   - Elastic properties, mass, structural
damping, (bending) stiffness, distances,
generator data (mass, moment of inertia, slip, loss/efficiency)

\[ C_l = \frac{L}{\frac{1}{2} \rho V_{\infty}^2 c} \]
\[ C_d = \frac{D}{\frac{1}{2} \rho V_{\infty}^2 c} \]

b) **Output:**
   Main shaft/generator torque, rotor/blade forces, displacements etc.
2. Aeroelastic model (+ validation: winddata.com)
4. Multibody model – bodies and constraints
4. Multibody model – bodies and constraints

For a constrained mechanical system with \( m \) independent constraints
\[ \Phi = 0 \] (9.51)
the velocity and acceleration equations are
\[ \Phi_q \dot{q} = 0 \] (9.52)
and
\[ \Phi_q \ddot{q} - \gamma = 0 \] (9.53)
The equations of motion for this constrained system are as given in Eq. 9.6:
\[ M \ddot{q} - \Phi_q^T \lambda = g \] (9.54)
Equation 9.53 can be appended to Eq. 9.54 and the result can be written as
\[
\begin{bmatrix}
M & \Phi_q^T \\
\Phi_q & 0
\end{bmatrix}
\begin{bmatrix}
\ddot{q} \\
-\lambda
\end{bmatrix}
= \begin{bmatrix}
g \\
\gamma
\end{bmatrix}
\] (9.55)

Convert 2\textsuperscript{nd} order Initial Value Problem \( \rightarrow \) Two 1\textsuperscript{st} order ODEs:
ODE45 in Matlab to integrate and get velocities and positions
4. Multibody model – bodies and constraints

\[ \Phi : (A_{70} \cdot \nu_r)^T \left( \{x_1 \ y_1\} + r_{p1} (\omega_1 \hat{v}_r) \right) - (A_{70} \cdot \nu_r)^T \left( \{x_2 \ y_2\} - r_{p2} (\omega_2 \hat{v}_r) \right) = 0 \]

20 deg. pressure angle

2D gear constraint equation
4. Multibody model – equations of motion

\[ \begin{bmatrix} M & \Phi_q^T \\ \Phi_q & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ -\lambda \end{bmatrix} = \begin{bmatrix} g \\ \gamma \end{bmatrix} \]

Reaction forces (in bearings/gear tooth forces etc):

\[ M\ddot{q} = \sum F \quad \text{or:} \quad M\ddot{q} = \sum F_{ext} + \sum F_{react} \Rightarrow M\ddot{q} - \Phi_q^T \lambda = F_{ext} \]

Used for calculating bearing and gear tooth reaction forces and moments
5. Results (gear tooth normal forces)

- Sun/planet ≈ 236 kN
- Planet/ring ≈ -236 kN
- Par.gear 1 ≈ -83 kN
- Par.gear 2 ≈ 30 kN
5. Results

Example: Mean sun/planet gear tooth stresses:

- 6 m/s
- 10 m/s
- 14 m/s
- 16 m/s
- 8 m/s
- 12 m/s
- 18 m/s
- 20 m/s
5. Results

Rigid gearbox animation

Flexible gearbox animation
(work in progress)
6. Conclusions

- Realistic dimensions and input parameters have been used for modelling a real 500 kw wind turbine and gearbox.
- Input to multibody code from Flex 5 has successfully been validated using real data (wind speed + strain gauge torque + electrical power).
- A realistic drive-train multibody model has been made.
- The multibody program makes it possible to extract e.g. bearing and gear tooth forces and moments (information which cannot be found with Flex 5 without modifications).
- Results from the program can easily be extracted for further analysis using FEM or other tool (e.g. FEM-model of gear tooth stresses made in Comsol Multiphysics).
Thank you for your time