DESIGN OF A HIGH SPEED TRAIN USING A MULTIPHYSICAL APPROACH

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WHAT DO WE ANALYSE?

AERODYNAMICS

STRUCTURAL ANALYSIS

DYNAMICS

NOISE & VIBRATIONS

TRIBOLOGY
STRUCTURAL ANALYSIS

- Different FEM analysis
  - Static linear / non-linear
    - Proof case assessment
    - Fatigue: Goodman / Miner / Dang Van
    - Sub-modeling
      - Bolted joints and Interference fits
  - Thermal – Stress (wheels)
  - Non-linear dynamic (crash)
  - Linear dynamic (modal)
  - Mechanisms and multibody dynamics
STRUCTURAL ANALYSIS

- Main simulation tools
  - HyperMesh pre-processor
  - Abaqus solver and post-processor
Modal FEA

Structural eigenmode
STRUCTURAL ANALYSIS

- Modal FEA
  - Frequency response
    - Based on modal combination techniques
    - Requires modal damping to be defined
      - Frequency dependent
      - Unknown until experimental modal test is performed
STRUCTURAL ANALYSIS

- Crashworthiness FEA
  - Structure collapse analysis provides
    - Reaction load / displacement curve
    - Energy / displacement curve
    - Survival space preservation assessment
    - Deformation analysis
STRUCTURAL ANALYSIS

- Crashworthiness FEA
  - Requires material model definition → Difficulties
    - Real Stress – Strain curve (material tolerance)
    - Stiffness loss at welded regions (aluminium alloys)
    - Spotwelds → fail criteria
  - Very hardware demanding
  - Needs experimental correlation for validation
STRUCTURAL ANALYSIS

- Thermal - Stress FEA
  - Sequentially coupled thermal – stress analysis
  - Requires knowledge of physical and mechanical properties related to temperature
    - Specific heat
    - Thermal conductivity
    - Thermal expansion
    - Stress - strain curve
    - Creep behaviour
  - Film coefficients depend on geometry and wheel speed
    - Data can be obtained by means of CFD
STRUCTURAL ANALYSIS

- Thermal - Stress FEA
  - Braked wheel analysis
  - Brake – Traction sequence simulation
NOISE & VIBRATIONS

- Main problem: NOISE PREDICTION
  - Current situation
    - High dependence on prototypes and tests on finished vehicles
  - Target
    - Prediction information feedback on early stage
- Two types of problems
  - Structure-borne noise
  - Air-borne noise
Structure-borne noise
- Low modal density
- Low frequencies
- Way to solve → FEM

Disadvantages of FEM
- Huge number of elements depending on the bandwidth
- Huge models (a complete train)
  - Sections can be defined
- Interaction with the rest of the elements not considered
  - Other equipment, seats, etc.
- Damping unknown
NOISE & VIBRATIONS

- Air-borne noise
  - High modal density
  - High frequencies and bandwidth
  - Way to solve → SEA

- Disadvantages of SEA
  - Definition of different materials and couplings
  - Uncertainty
  - Accuracy
What about the mid-frequencies?
- Medium modal density
- Neither FEM nor SEA suitable for this problem
- Way to solve → ?
  - No method has proven to be suitable for all frequencies
- Hybrid methods → They combine FEM and SEA
DYNAMICS

○ Studies performed
  ● Modal analysis
  ● Dynamic stability
  ● Curve equilibrium
  ● Time simulations
  ● Active suspension design
  ● Wheel profile design
  ● Comfort
  ● Gauge analysis

○ Tool
  ● In-house Multi-body simulation (MBS) software
DYNAMICS

- Multi-body model (MBS model)
  - Bodies (rigid or flexible)
    - Geometry
    - Mass and CoG
    - Inertia
  - Connection elements
    - Stiffness and damping elements
    - Kinematical restrictions
    - Active control elements
  - Vehicle-track interaction
    - Wheel-rail contact

REAL SYSTEM EQUIVALENCE

MULTIBODY SIMULATION MODEL
Bodies
- High-speed trains → Flexible carbody
- Objective
  - Represent the influence of carbody structural modes on vehicle dynamics behaviour
- How
  - FEM modal analysis → Input for MBS model
- The more structural modes on the MBS model
  - The more precision
  - The higher computational cost
- Solution
  - Influence of modes >20Hz → Residual flexibility
DYNAMICS

- Influence on stability

![Dynamics graph]

- Influence on running comfort

![Comfort index graph]

Direct influence of carbody flexibility on vehicle dynamics
DYNAMICS

- Suspension elements
  - Function
    - Connect different bodies
    - Ensure good comfort and ride quality
    - Provide good stability
  - Types
    - Linear
    - Non-linear

- Selection of suspension parameters
  - Compromise between the different ride conditions
Vehicle-track interaction
- Track features → Excitation to the vehicle
  - Straight or curved track
  - Real track irregularities
    - Time domain
    - Frequency domain
  - Simulation of specific irregularities
- Accurate modelling of wheel-rail contact needed
  - Cornerstone of vehicle running dynamics
    - Source of excitations
  - Tribology problems (wear prediction)
    - Impact on life cycle costs

DYNAMICS
Wheel profile design
Wheel reprofiling
Vehicle-track interaction

Current work lines

- Wear prediction
- Multipoint contact
- Tridimensional contact (flange contact at different plane)
- Coupling with traction and brake
- Left and right rail with different friction coefficient
- Variable friction coefficient as a function of contact position (flange lubrication)
AERODYNAMICS

- Resistance to motion
  - Aerodynamic term has a great influence in high speed
  - A proper CFD simulation is very challenging
    - Great level of geometry detail is required
    - Many parameters have an influence
      - Nose design
      - Pantograph configuration
      - Inter-coach geometry
      - Bogie features
      - Etc.
• Crosswind issues
  • A safety requirement
  • A well-established European methodology
    • Geometry characterization
    • Defined wind scenarios
    • Coupling with real-time MBS simulations
  • Challenges
    • Proper simulation of reality
    • Parametric optimization
      • Nose shape
      • Roof features
      • Etc.
AERODYNAMICS

- Open air phenomena
  - Safety issue for passengers on platforms and workers close to the track
    - Pressure effects are not a problem for simulation
    - Viscous effects and wake are difficult to simulate
  - Structural requirement for passing trains and infrastructure equipment
    - Input for FEM calculations
      - Static value
      - Load collectives
AERODYNAMICS

- Tunnel phenomena
  - Pressure variations
    - Many combinations possible
      - Type of tunnel, type of trains, etc.
    - Tackled with CFD and 1-d simulations
    - Input for FEM calculations
  - Micro-pressure wave generated at the exit portal
    - Many factors play a role
    - Transient CFD seems suitable
AERODYNAMICS

- Ballast flying
  - Initiation
    - Dynamics
    - Ice drop
    - Aerodynamics (very important at high speeds)
  - Continuation
    - Mainly aerodynamic
  - Challenges
    - Proper simulation of the flow in the underbelly region
    - Flow-stones interaction
    - Motion of stones and collision with other stones/elements
AERODYNAMICS

- Aeroacoustics
  - Aerodynamic contributes to
    - Structure-borne noise
      - Flow-structure interaction
    - Air-borne noise
      - Flow behaves as a noise source
  - Very challenging to simulate

- Refrigeration
  - Cooling of equipment
  - Climatic comfort of passengers
AERODYNAMICS

- Aerodynamic design
  - Many effects
  - Many variables
  - Interaction

- Interaction with
  - Structural design
  - Dynamics
  - Noise & vibrations
  - Tribology (2nd order)

- Optimization of design
  - Energy efficiency

Need for advanced design approach
GENERAL OVERVIEW

- AERODYNAMICS
- STRUCTURAL ANALYSIS
- DYNAMICS
- NOISE & VIBRATIONS
- TRIBOLOGY
THANKS FOR YOUR KIND ATTENTION!!!