Virtual Development of Drivetrains

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Contents

- Introduction
- Development Approach
- Tools and Applications
- Software Development
- Virtual Production Development
Introduction
Product and Production

Hand Craft
Combination of Man and Machine

- Tailor made
- Quality depending on Skill of Craftsman
- High Cost and Price
- Long Lead Time
- Low Volume

Mass Production FORD
Equipment Specialization and Division of Work

- Low Customer Orientation
- Good Quality
- Dramatic Cost Reduction
- Reduction of Delivery Time
- High Volumes

Lean Manufacturing
The TOYOTA Production System

- Optimization of all Resources, Low Cost
- Focusing on Elimination of Waste to achieve complete Customer Satisfaction
- High Flexibility
- Low Volumes per Type
- High Total Volumes

(Quelle: BMW Group, WPS Training)
Product Development

Virtual Product vs. Virtual Production

(Quelle: Lindemann, nach: Gausemeier, 2006)
Simultaneous / Concurrent Engineering

Front Loading

Concept
Design
Test
Production Planning
Procurement
Production
Pre-Prod’n
Production

Reduction

Concept
Design
Test
Production Planning
Procurement
Pre-Production

Simultaneous Engineering

Conventional Engineering
Virtual Development

Geometry
Function
Hardware
Software
System
Development Approach
Development Process

**Definition and Validation**

- **Vehicle (OEM)**
  - Requirements from Vehicle
  - Simulation Tools, Tolerance Calculation
  - Emulators, Hil.
  - Regression Testing, Bench Test, Mule Vehicle Test
  - Acceptance
  - In Vehicle Testing (OEM)

- **Vehicle**
  - Requirements Analysis
  - Testing of Functionality
  - In Vehicle Testing

- **Transfer Case**
  - Concept, Component Specification, Software Specification
  - Detailed Functionality Testing
  - Transfer Case Tests

- **Component Development**
  - Functional Software
  - Operating System
  - Electronics
  - Mechanics
  - Component Tests

**Virtual Product Development**

Source: Magna Powertrain
The V-Cycle will be run through several times
Tools and Application
System Function: Simulation-Environment VeDyna

- **Vehicle:** Validated vehicle-models
- **Component:**
  - 4x4 Algorithm
  - Consumption-module
  - Temperature-module
- **Driver Model:** VeDyna Advanced Driver 2

Source: Magna Powertrain
Component Function

Multi Body Simulation of parking lock system with AMESIM

**Input**
- Vehicle and drive unit data (masses, dimensions, ratios, stiffnesses damping…)
- Load case (impulse shift)
- Material

**Output**
- Torque as function of time in relevant positions of transmission
- Peak force on pawl

*Model*

*Source: Magna Powertrain*
Component Function

Multi Domain Simulation of Hydraulic Actuation System

Rotor gear profiles geometry generation with MATLAB/SIMULINK

Source: Magna Powertrain
Component Function
Multi Domain Simulation of Hydraulic Actuation System

Evaluation with Reference Pump AMESIM 1-D Hydraulic simulation

Option: Pump stiffness and gap variation, FEA with CATIA

Source: Magna Powertrain
Analytical Strength Assessment
KISSsoft and BEARINX: Dimensioning of shafts and bearings

**Input**
- Shaft geometry
- Loads, load spectra
- Material
- Bearing type, dimension
- housing stiffness (option)

**Model**
- Beam model for shafts
- Notch geometry choice according to FKM method
- Load spectra adapted according to FKM (rainflow)
- Material data modification (heat treatment)
- Bearing model: analytical (integrated in tool)

**Output**
- Safety figures (fatigue, static)
- Stresses, Hertzian pressure

Source: Magna Powertrain
System Structural Dynamics

Model Generation for FEA analysis: example eRAD

E-Motor
Planetary Gears
Bearings
Boundary Conditions
Housings
Actuator System
Differential / Planetary Carrier
Disconnect System

Assembled System Model

Source: Magna Powertrain
System Structural Dynamics

Determination of Modal System Behavior

- First results extracted by the FEM Solver
- Natural Eigen-Frequencies and their corresponding modeshapes
- Structural weakness areas by use of the modal strain energy distribution
- Description and documentation of the extracted natural frequencies and their mode shapes in the so-called modal map.
- Comparison of the determined natural frequencies to acting excitation frequencies and first assessment

Source: Magna Powertrain
System Structural Dynamics

Determination of System Response

- Determination of system response behavior due to acting excitation loads
- Vibration motion behavior at excitation frequencies up to 2500 Hz
- Acceleration run over frequency at structural points to identify resonance areas
- Surface velocity prediction to identify structural areas with potential to radiate sound

Source: Magna Powertrain
System Structural Dynamics

Example of Optimization Loop

- Calculation of Response behavior for chain excitation load case
- View vibration animation at resonance frequency and identify relevant mode shape or shapes out of the modal map
- Together with the designer discuss and define countermeasures
- Update the FEM model with the countermeasure and recalculate compare the results to the initial design

Source: Magna Powertrain
Ball-Ramp System

Simulation using Multi-Body Capabilities of Abaqus

Source: Magna Powertrain
Ball-Ramp System

Details: Rigid Body Parts with Contact Surfaces

Ball movement

In analysis, the ball is a perfect sphere. The “mesh” is displayed only for visualizing motion.

Source: Magna Powertrain
Ball-Ramp System

Details: Contact Area and Contact Path Differences

Contact pressure evolution animation (shown for two cycles)

Source: Magna Powertrain
Ball-Ramp System

Contact Path Hysteresis with Aberration in End Position

Ball 1 motion (displayed for 5 cycles)

Source: Magna Powertrain
Rolling Gear Simulation - AUDI Sport Differential

Nonlinear Tooth Root Stress Analysis (Abaqus)

Source: Magna Powertrain
Rolling Gear Simulation - AUDI Sport Differential

Nonlinear Tooth Root Stress Analysis (Abaqus)

Only tooth root (tensile) stress displayed.
Contact stress omitted.

Source: Magna Powertrain
Dynamic Deflections: Parking Pawl Engagement

Nonlinear FE Analysis (Abaqus)

Source: Magna Powertrain
FEA Solver: NASTRAN

Model

Source: Magna Powertrain
FEA Solver: NASTRAN

Nonlinear Loading

- Taper roller bearing cones
- Shafts, wheel body elements
- Roller elements (nonlinear)
- Input torque
- Pair of contact forces
- Output torque

Source: Magna Powertrain
FEA Solver: NASTRAN

Nonlinear Loading

Source: Magna Powertrain
FEA Solver: NASTRAN
FEA Fatigue Analysis: FEMSITE

Stress plot

Safety plot

Source: Magna Powertrain
FEA Fatigue Analysis: FEMSITE

Stress plot

Safety plot

Source: Magna Powertrain
FEA Fatigue Analysis: FEMSITE

Shear load distribution on screws

Flange separation under load

Source: Magna Powertrain
Hypoid Gears: GLEASON (T 900) and ANSYS

FEA-based strength analysis program by GLEASON

Source: Magna Powertrain
Heat dissipation - Thermal model of coupling: ANSYS
### Software Application during Development

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Source: Magna Powertrain
Software Development
Software Development Process

System Specification

OEM´s Solution

Software-in-the-Loop

Hardware-in-the-Loop

Control Design

Software-in-the-Loop Test

Target Code Generation

SW-Code-Implementation

Source: Magna Powertrain
Feasibility Study – „Proof of Concept“

- All components that have influence on functionality
- Estimation of functionality e.g.
  - Maximum torque capacity
  - Control behaviour of torque build-up
  - System availability
  - ...

- Simulation model of
  - Power supply
  - ECU PWM driver
  - Worm gear motor
  - Ball helicline
  - Clutch

- Simulation based on
  - Simulink simulation modules using libraries
  - Approved on former programs

Source: Magna Powertrain

Actuatoric System of ATC
Transfer Case Functionality - Achieving Requirement Spec.

- Detailed simulation
  - shows all components’ influences
- e.g. DC Motor
  - Temperature dependencies
  - Torque ripple of motor
  - Eddy current losses
  - Brush voltage drop
  - Friction of worm gear unit
  - ...
- Delivers accurate information about
  - Energy consumption
  - Torque set behavior and speed
  - disturbances due to
    - Temperature
    - Power supply
    - Aging of wiring harness
    - ...

Typical Results

Source: Magna Powertrain
Functional Approval Model

- Approved simulation models tested using prototype parts
- Control software included
- New control strategies developed simultaneously
- Allows to generate software specification

Source: Magna Powertrain
Functional Approval Model - Quality

Simulation of
- Torque capacity
- System dynamics
- Current consumption
- Detailed interface data
- …

Comparison Simulation vs. Measurement

Motor Characteristics @ Temp.
Development Tools

- Matlab
  - Simulink
  - Stateflow
    - Functional software modeling
    - Hardware modeling
    - Simulation of ECU and plant
    - Test bench

- Micro Autobox

- Targetlink
  - C-Code generation and optimization
  - Fixed-point simulation and validation
  - Supports interface to CANape (ASAP2)

- CANape
  - CANapeGraph
  - CANalyzer

- Measurement Tools
  - Temperature
  - Voltage, Current, ...
Software Development Process

**specification**

**functional software**
Model-in-the-Loop (MIL)
Host PC, highest precision

**fixed point effects**
Software-in-the-Loop (SIL)
Host PC

**on-target verification**
hardware-in-the-Loop (HIL)
execution time/code profiling
On Target

Source: Magna Powertrain
Example for automated testing
Virtual Production
Virtual Production Development

Source: Magna Powertrain
Virtual Production Development

Source: Magna Powertrain
The End