Optimization in Consideration of Fatigue Results Shown by the Example of an Aircraft Landing Gear System
MAGNA’s Presence Worldwide *

*As at March 2008

Employees – 83,000

238 Production  60 Engineering, R&D
100 Years experience to drive Innovation
Engineering Center STEYR – Range of Services

- System Integration
- Drivetrain & Axle Engineering
- Commercial Truck Engineering
- Engine Engineering
- Simulation & Testing Services
- Software & Support
- Production In Low Volumes

*FEMFAT*

- Axle Drives
- Engine Components Development
- Electronics
- Injection Systems
- Engine Integration
- Marine Engines
- Product Definition
- Optimization
- Validation
- Functional Development
- Acoustics
- Product Cost Optimization
- Production Integration
- System Integration
- Testing Services
- Software & Support
- Production In Low Volumes

*FEMFAT*
**FEMFAT – Local Stress Concept Crack Initiation**

- Stress Tensors
- Material Properties
- Stress Gradient
- Mean Stress Influence
- MultiAXial Load
- Technological Influences
- Size Influence
- Temperature Influence
- PLASTic Deformations
- SPOT Joints
- Anisotropical Behaviour of Arc WELDs
- etc.

Application of specimen data to components

- \( S/N_1 \) modified by FEMFAT
- S/N material from specimen tests
- Finally: Component S/N curve including all influences
FEMFAT - Influence Factors

- Notch Influence (Stress Gradient)
- Mean Stress
- Thermo Mechanical Temperature
- Isothermal Temperature
- Surface Treatment Surface Roughness
- Plastic Fiber Orientation
- Statistic
- Tempering (for Tempering Steel only)
- Cast Micro Structure
- Effective Plastic Strain
- Technological Size
- Boundary Layer
Enhanced Optimization by using Fatigue Results

FEM

Fatigue Based Optimization

Classic Stress / Strain based Optimization

FLP Based Optimization

Steel

Gray Cast Iron

optimal topology using only 30% of the design space's volume
Optimization regarding fatigue

Start FE-Model

Optistruct

Life Solver

Material

Damage, Safety Factor

Adapted FE-Model

Hyperstudy

Hyperstudy

Stop condition fulfilled?

Yes

New Design

No

Process controlled by the optimization tool
Multi axial fatigue analysis based on modal approach

- FE-Model
- Optistruct
- Static Behavior (Mean Stress)
- Optistruct (linear)
- Dynamic Loads
- Mode Stresses (real)
- Mode Participation Factors (complex)
- Inverse Fourier Transformation
- FEMFAT-MAX
- Endurance Safety Factors
Optimization regarding fatigue Landing Gear

- FEA Model
- Design Variables (Shape Optimization)
- Stress Based Optimization
- Fatigue Based Optimization
- Conclusion
FEA Model

- Side and Drag Strut Attach Lugs
- Torsion Link Attach Lug
- Upper and Lower Torsion Links (Topology Optimization)
- Outer Cylinder
- Upper Torsion Link
- Lower Torsion Link
Design Variables

Baseline

Design / Shape Variable
Enhanced Optimization Loop By Using HyperStudy (Stress Based)

Shape optimization
Minimize maximum stress value in critical area
Enhanced Optimization By Using HyperStudy (Stress Based)

Objective definition: Minimize stress values (max. stress value from the critical node group)

Adaptive Response Surface method (HyperOpt)
Enhanced Optimization By Using HyperStudy (Stress Based)

Result design variables:

Adaptive Response Surface method (HyperOpt)
Stress Based Optimization (LC Braking)

Baseline

Node 102153
v. Mises Stress: 762 MPA

Node 102153
Safety Factor: 0.44
Stress Based Optimization (LC Braking)

Node 102153
v. Mises Stress: 653 MPa

Run 17

Node 102153
Safety Factor: 0.48
Enhanced Optimization By Using HyperStudy (Fatigue Based)

Shape optimization
Minimize maximum stress value in critical area
Objective definition: Maximize safety factor  
(min. safety factor value from the critical node group)

Adaptive Response Surface method (HyperOpt)
Enhanced Optimization By Using HyperStudy (Fatigue Based)

Result design variables:

Adaptive Response Surface method (HyperOpt)
Fatigue Based Optimization (LC Braking)

Baseline

Safety Factor: 0.44

v. Mises Stress: 762 MPa
Fatigue Based Optimization (LC Braking)

Run 16
Safety Factor: 0.5
v. Mises Stress: 640 MPa
Summary

Baseline

Safety factor : 0.44
v. Mises stress : 762 MPa
Mass : 133.00 kg

Stress based

Safety Factor : 0.48
v. Mises stress : 653 MPa
Mass : 133.67 kg

Fatigue based

Safety factor : 0.5
v. Mises stress : 640 MPa
Mass : 133.45 kg
Outlook

Including dynamic effects:

Enhanced Optimization Loop

Basic FEM-model

Optistruct

Life-Solver

Controller

Convergence criteria reached

New design

Basic FEM-model

Optistruct

Life-Solver

Controller

Adapted FEM-model

Convergence criteria reached

New design

Motionsolve

Adapted FEM-model

Controller

Life-Solver

Convergence criteria reached

New design
Manual Approach

Attachment part

Damping ≤ 2%

Eigenfrequency Analysis

Frequency Response

Damping ≥ 6%

Impact Analysis

Transient Response

(Quasi) Static Stress distribution
(Load at CG, component depending)

Representative Collective

Stress-distribution

Fatigue (FEMFAT)

Fatigue (FEMFAT)

Representative Collective

Total life time
Manual Approach: Spare wheel carrier (ξ=1%)

acceleration at frame: 0.18mm (harmonic, vertical)
response: 3.2g (bracket outside)

Stress component for each Eigen-frequency:

1st Mode is dominant

Up to 2% modal damping stress combination of different modes at the Eigenfrequencies is not necessary
Summary / Conclusion

Topology optimization leads to global design

Shape optimization leads to local design improvement

Integration of FEMFAT leads to improved optimization results:

- adequate interpretation of static and dynamic loads
- consideration of load histories
- consideration of material properties
- many other influence factors can be considered
Summary / Conclusion

+ enables consideration of complex loads

+ enables consideration of material properties

+ enables proper consideration of static and dynamic load portion

+ allows consideration of durability, endurance and over loads

+ provides consideration of many other influences e.g. welds, spot welds

- needs additional CPU-time