BICYCLE FRAME OPTIMIZATION BY MEANS OF AN ADVANCED GRADIENT METHOD ALGORITHM

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Content

- Introduction to bicycle frame design main aspects
- Finite Element model and validation
- Optimization algorithm
- Results
- Conclusions
Classical
(J. Anquetil, 1960)

1st unconventional
(F. Moser, 1984)

Pure fantasy
(G. Obree, 1993)
(L. Jalabert, 1994)

1996 NEW UCI RULES
Less fantasy, more physics
Introduction

• Aim of this activity has been the optimization of the shape of a modern carbon fiber frame and the evaluation of the most recent tools available for optimization.

• A bicycle frame should have low weight, high lateral stiffness and moderate vertical stiffness.

• Because of chain load, frame lateral deformation during pedalling is bigger when the rider pushes on right pedal (a pro rider may apply a force up to two times his weight).

• The optimization aim is to reduce the difference in frame lateral deformation during pedalling changing the shape of the frame.

• *Altair HyperWorks* software has been used for this activity.
Optimization cycle

- FEM model
- Model parameterization
- New constraints
- Objective, Constraints,

- Altair HyperMesh
- Altair HyperMorph
- Altair OptiStruct

- Evaluation of results
- Running Optimization

- Loads and Shape constraints
Load conditions

Pedalling:
- Sitting, push on right pedal
- Sitting, push on left pedal
- Standing, push on right pedal
- Standing, push on left pedal

Additional conditions:
- Surface irregularity
- Braking

Asymmetrical load conditions due to chain effect
Constraints and UCI rules

Constraints

UCI Rules

Wheel
Transmission
Crank
FEM model: validation and calibration

Comparison with experimental results

<table>
<thead>
<tr>
<th></th>
<th>Uz (case1)</th>
<th>Uz (case2)</th>
<th>Uz₁ - Uz₂</th>
<th>Uy</th>
<th>mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference (mm)</td>
<td>0.18</td>
<td>0.24</td>
<td>0.06</td>
<td>0.12</td>
<td>24g</td>
</tr>
</tbody>
</table>

The accuracy is adequate for the purpose of this job, considering the available information on the actual structure.
Shape optimization: general concepts

Shape optimization is based on mesh alteration and on the association of the alteration to a design variable.

The optimization solver finds the value of \( \alpha \), depending on objective and constraints.

This kind of shape optimization doesn’t create new geometry but alter the original shape using the perturbation vector created as design variables.

\[
\begin{align*}
X &= X_0 + \alpha PV \\
\alpha &\in [\alpha_1^*, \alpha_2^*]
\end{align*}
\]
Model Parameterization

In order to give a large freedom to the shape modification of the model more than 100 design variables have been created.

- Curvature on plane
- Curvature out of plane
- Cross-section reduction
- Local cross-section alteration
Optimization objective

Static analysis shows that the difference in lateral deformation is higher for standing pedalling.

OF (Objective Function)

\[ f_{\text{obb}} = \left| U_{z_{1\text{pedx}}} \right| - \left| U_{z_{1\text{pedx}}} \right| \]

Constraints

Mass \leq 990g(initial value)

Other constraints changing with the optimization attempts
**1st Run Results**

Result relative to a partial use of the parameterization are shown

First Optimization

**Objective:** Min(OF)

**Constraints:** Mass ≤ 990g (Initial value)

<table>
<thead>
<tr>
<th>Standing pedalling</th>
<th>Sitting pedalling</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>U_z R</td>
</tr>
<tr>
<td>δ</td>
<td>-0,18</td>
</tr>
<tr>
<td>δ%</td>
<td>-3,5%</td>
</tr>
</tbody>
</table>

Frame behaviour is more symmetrical, but **overall stiffness is reduced**
2nd Run Results

Result relative to a partial use of the parameterization are shown

Second optimization

**Objective:** Min(OF)

**Constraints:**
- Mass $\leq 990\text{g}$ (Initial value)
- $C_{pR} + C_{pL} \leq 8\text{J}$ (initial value) (ADDITIONAL CONSTRAINT)

#### Table: Standing pedalling vs. Sitting pedalling

<table>
<thead>
<tr>
<th></th>
<th>Standing pedalling</th>
<th>Sitting pedalling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$U_z \text{ R}$</td>
<td>$U_z \text{ L}$</td>
</tr>
<tr>
<td>$\delta$</td>
<td>-0.67</td>
<td>+ 0.57</td>
</tr>
<tr>
<td>$\delta%$</td>
<td>-13%</td>
<td>+ 31%</td>
</tr>
</tbody>
</table>

Frame behaviour is more symmetrical, and **overall stiffness is NOT reduced**
3rd Run Results

Result relative to a partial use of the parameterization are shown

Third optimization

Objective: Min(OF)

Constraints: Mass ≤ 990g (Initial value)

\[ C_{pr} + C_{pl} \leq 8J \] (initial value) (ADDITIONAL CONSTRAINT)

NEW LOAD CONDITION to include VERTICAL STIFFNESS in the optimization process

<table>
<thead>
<tr>
<th>Standing pedalling</th>
<th>Sitting pedalling</th>
<th>Vert stiff</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_z ) R</td>
<td>( U_z ) L</td>
<td>( F_{obb} )</td>
</tr>
<tr>
<td>( \delta )</td>
<td>( +0.18 )</td>
<td>( +1.19 )</td>
</tr>
<tr>
<td>( \delta % )</td>
<td>( -3.5% )</td>
<td>( +65% )</td>
</tr>
</tbody>
</table>

More lateral stiffness, More vertical comfort

Optimization allows for multi objectives optimization
Results stress analysis

The optimized shape shows a significant stress reduction in the optimized region

-17% stress
Conclusions

• Results show the effectiveness of computer aided optimization techniques

• Selection of proper Objective Function and constraints is strategic for a successful result

• The final shape reduces the frame different lateral deformation (-39%) without increasing mass and stresses

• UCI rules are not violated

• Multi objectives optimization are possible: more lateral stiffness combined with more vertical flexibility (comfort)

• Further development are possible using the “size” optimization technique