Influence Of Test Parameter Variations On The Flex GTR
Joint Project of ACEA and BASSt

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Bergisch Gladbach, Germany
Test Objective

- Determination of the influence of test parameter variations on the sensor outputs of the Flexible Pedestrian Legform Impactor Flex PLI, Version GTR, using the inverse test setup

- The influence of the following test parameters was investigated:
  - Impact angle (Rotation around z-axis)
  - Impact height
  - Impact velocity
# Test Programme

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<th>Test No.</th>
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Rotation around Z-axis

- Evaluation Diagrams
  - Results of tests with -10°
  - Results of tests with +10°
  - Comparison of average values
  - Quantification diagrams:
    - Tibia moments vs. rotation variation
    - Knee elongations vs. rotation variation
Rotation around z-axis:
Results of three tests with -10°

**Femur bending moments**

- CV: 0.2% - 2.0%
- CV: 1.9% - 5.3%
- CV: 0.3% - 1.6%

**Tibia bending moments**

**Knee elongations**

CV: 0.2% - 2.0%
Rotation around z-axis:
Results of three tests with +10°

Femur bending moments

Knee elongations

Tibia bending moments
Rotation around z-axis (-10°, 0, +10°): Comparison of average values

Femur bending moments

Knee elongations

Tibia bending moments
Rotation around z-axis:
Tibia Bending Moments

![Graph showing bending moments vs. rotation angles for Tibia A1, A2, A3, and A4.]

- **Tibia A1**: Linear equation: \( y = 0.0417x + 263.33 \)
- **Tibia A2**: Linear equation: \( y = 0.1067x + 246.6 \)
- **Tibia A3**: Linear equation: \( y = 0.0367x + 190.1 \)
- **Tibia A4**: Linear equation: \( y = -0.0217x + 106.74 \)
Rotation around z-axis: Knee Elongations

- **Polynomisch (MCL):** \[ y = -0.0113x^2 + 0.0067x + 20.667 \]
- **Polynomisch (ACL):** \[ y = -0.0132x^2 + 0.0383x + 11.733 \]

### Graph Details:
- **Z-Rotation [°]**
- **Elongation [mm]**
- **MCL**
- **ACL**
- **PCL**
- **Polynomisch (MCL)**
- **Polynomisch (ACL)**
- **Linear (PCL)**
Impact height variation

- Evaluation Diagrams
  - Results of tests with -10 mm
  - Results of tests with +10 mm
  - Comparison of average values
  - Quantification diagrams:
    - Tibia moments vs. height variation
    - Femur moments vs. height variation
    - Knee elongations vs. height variation
Impact height variation:
Results of three tests with -10mm

Three Tests w. Height = -10mm

Femur bending moments

CV: 1.1% - 2.5%

Knee elongations

CV: 0.1% - 4.9%

Tibia bending moments

CV: 2.0% - 2.8%

CV: 7.4%
Impact height variation:
Results of three tests with +10mm

Femur bending moments

Knee elongations

Tibia bending moments
Impact height variation (-10mm, 0, +10mm): Comparison of average values

Tests w. Height Variation - Comparison Of Mean Values

Femur bending moments

Knee elongations

Tibia bending moments
Impact height variation:
Tibia Bending Moments

Impact Height Variation [mm]

Bending [Nm]

y = -0.5667x + 261.14
y = -0.9883x + 245.12
y = -0.8067x + 187.99
y = -0.065x + 103.57
Impact height variation:
Femur Bending Moments

Impact Height Variation [mm]

Bending [Nm]

Femur A1
Femur A2
Femur A3
Linear (Femur A1)
Linear (Femur A2)
Linear (Femur A3)

y = 0.8283x + 197.36
y = 0.8567x + 148.72
y = 0.7333x + 85.267
Impact height variation:
Knee Elongations

\[ y = 0.0767x + 20.578 \]

\[ y = -0.0143x^2 + 0.0333x + 11.733 \]

\[ y = 0.0117x + 5.1111 \]
Impact Velocity Variation

- Evaluation Diagrams
  - Results of tests with -1.0 m/s
  - Results of tests with -0.5 m/s
  - Results of tests with +0.5 m/s
  - Results of tests with +1.0 m/s
  - Comparison of average values
  - Quantification diagrams:
    - Tibia moments vs. impact velocity
    - Knee elongations vs. impact velocity
Impact velocity variation: 
Results of four tests with –1.0 m/s

Femur bending moments

Knee elongations

Tibia bending moments

CV: 2,7% - 4,3%
CV: 8,7%
CV: 6,4%
CV: 3,0%
CV: 7,1%
CV: 0,3% - 1,6%
CV: 0,3% - 1,6%
Impact velocity variation:
Results of three tests with \(-0.5 \text{ m/s}\)

Three Tests w. Velocity = -0.5 m/s

**CV: 2.6% - 5.5%**

**CV: 0% - 3.9%**

**CV: 0.4% - 0.7%**

Femur bending moments

Knee elongations

Tibia bending moments
Impact velocity variation:
Results of three tests with +0.5 m/s

Femur bending moments

Knee elongations

Tibia bending moments
Impact velocity variation:
Results of three tests with +1.0 m/s

Femur bending moments

Knee elongations

Tibia bending moments

CV: 0.3% - 1.0%

CV: 0.7% - 2.2%

CV: 0.9% - 2.8%
Impact velocity variation (-0.5, -1, 0, +0.5, +1 m/s): Comparison of average values

Femur bending moments

Knee elongations

Tibia bending moments
Impact velocity variation:
Tibia Bending Moments

Impact Velocity Variation [mm] vs Bending [Nm]

- Tibia A1: $y = 22,781x + 8,8105$
- Tibia A2: $y = 17,594x + 50,588$
- Tibia A3: $y = 12,949x + 46,202$
- Tibia A4: $y = 6,8796x + 29,78$

(Tibia A1, Tibia A2, Tibia A3, Tibia A4, Linear (Tibia A1), Linear (Tibia A2), Linear (Tibia A3), Linear (Tibia A4))
Impact velocity variation:
Knee Elongations

Impact velocity variation [mm]
Elongation [mm]
MCL
ACL
PCL
Linear (MCL)
Linear (ACL)
Linear (PCL)

\[ y = 1.3983x + 4.413 \]
\[ y = 0.5271x + 4.8529 \]
\[ y = 0.4395x + 0.1927 \]
Summary of Results (1)

- Remarkable general effects due to the parameter variations including tests with higher loadings (velocity) or oblique impact angles:

  - No damages of the legform
  - No unexpected behaviour of the legform
  - No unexpected sensor output (peaks etc.)
  - Reproducibility seems to be good (only three tests each):
    CV < 5% for Tibia Moments, MCL, ACL and PCL in all cases, except:
    - PCL in tests with Z-rotation -10° (5,3%)
    - ACL in tests with impact height variation (7,4%; 7,3%)
    - ACL and PCL in tests with impact velocity -1 m/s (6,4%, 7,1%)
Summary of Results (2)

- Rotation around z-axis
  - No significant change of the tibia and femur bending moments due to rotations of +10° or -10°
  - No significant change of PCL either
  - MCL and ACL decrease during tests with rotations around z-axis of +10° and -10°:
    - Z-rot. = -10° => ACL = -15%
    - Z-rot. = -10° => MCL = -6%
    - Z-rot. = +10° => ACL = -8%
    - Z-rot. = +10° => MCL = -5%
  - (The reason for the differences with +10° or -10° is not obvious and should be further investigated)
Summary of Results (3)

- Impact height variation (1)
  - The tibia bending moments decrease with increasing impact height while the femur bending moments increase:
    - Femur A3: +0,7 Nm / mm
    - Femur A2: +0,9 Nm / mm
    - Femur A1: +0,8 Nm / mm
    - Tibia A1: -0,6 Nm / mm
    - Tibia A2: -1,0 Nm / mm
    - Tibia A3: -0,8 Nm / mm
    - Tibia A4: -0,1 Nm / mm
  - Obvious reason: With increasing impact height the legform loading goes from tibia top upwards towards the femur
Summary of Results (4)

- Impact height variation (2)
  - MCL increases with increasing impact height:
    - MCL: +0,8 mm / mm
    - Obvious reason: With increasing impact height the legform loading goes from tibia top upwards to the knee. (The maximum MCL value is expected in tests when the middle axis of the honeycomb is aimed to the centre of the knee)
  - ACL decreases when changing the impact height in either direction:
    - -10 mm => ACL = -15%
    - +10 mm => ACL = -9%
    - Obvious reason: The original configuration (upper edge of honeycomb aims at centre of knee) introduces the maximum shear loading between upper and lower part of the knee. (Reason for the differences between +10 mm and -10 mm not obvious)
  - No significant change of PCL due to the impact height variations
Impact velocity variation (1)

- Generally, all measurements increase at least slightly with increasing impact velocity:
  - Tibia A1: +2,3 Nm / 0,1 m/s
  - Tibia A2: +1,8 Nm / 0,1 m/s
  - Tibia A3: +1,3 Nm / 0,1 m/s
  - Tibia A4: +0,7 Nm / 0,1 m/s
  - MCL: +0,14 mm / 0,1 m/s
  - ACL: +0,05 mm / 0,1 m/s
  - PCL: +0,04 mm / 0,1 m/s

- Obvious reason: The higher velocity applies a higher load to the legform.

- The effect on ACL as well as on Femur A2 and Femur A3 is not entirely clear because in spite of the above mentioned tendency the maximum values were observed in the tests without velocity variation.
Conclusions (1)

- Generally the effects of the investigated parameter variations occurred as expected.
- The quantifications have to be seen with respect to the particular test configuration used in this study.
- Some details require further investigations:
  - Rotation around z-axis:
    - Reason for different deviations with +10° and -10°
    - Effect in tests up to +/- 30° rotation
  - Impact height variation:
    - Effect on the measurements when impacting further upwards (e.g. centre of honeycomb in line with centre of knee or higher)
  - Impact velocity variation:
    - Effect on ACL because the highest value was not in the test with the highest velocity
Conclusions (2)

- The influence of other test parameters was not tested and should be investigated in a subsequent project:
  - Rotation around x-axis
  - Rotation around y-axis
  - Temperature
  - Combination of parameter variations (e.g. impact height and impact velocity)
Thank you!

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