First Technology Safety Systems

FLEX-PLI-GTR Development

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FTSS Europe

FLEX-PLI-TEG 5th meeting
BASt, Bergisch Gladbach, Germany
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- Design Review Results
- Input from FLEX-PLI-TEG
- Project Progress
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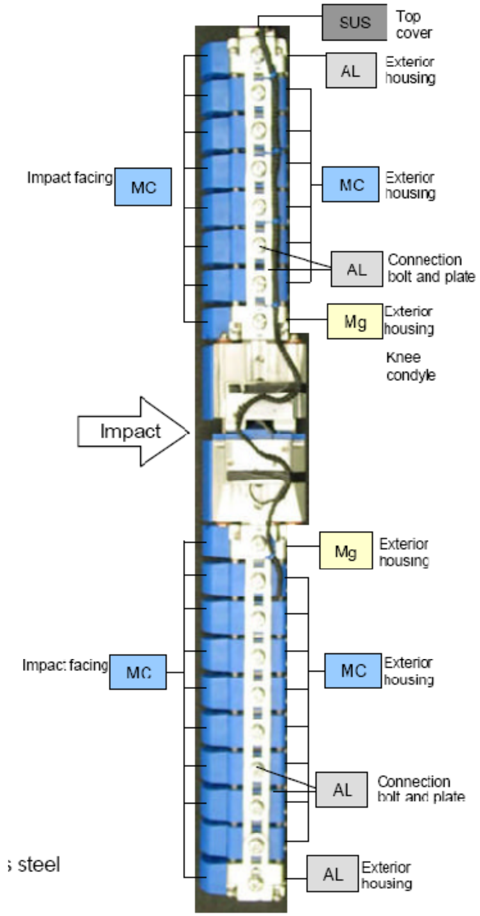
  - Comparison of versions GT-GTR

FLEX-PLI-GTR Development Project

- JAMA/JARI requested FTSS to develop the FLEX-PLI GTR version
  - Develop FLEX-GTR final design
  - Solve remaining issues
  - Global supplier FLEX-PLI-GTR
- Starting point of GTR Development is a Design Review by FTSS
  - List of found issues was discussed
  - JARI and JAMA accepted found items
- Conceptual design December 07
- Design Freeze February 08
- Delivery 3 FLEX-PLI-GTR prototypes by October 2008



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Design review

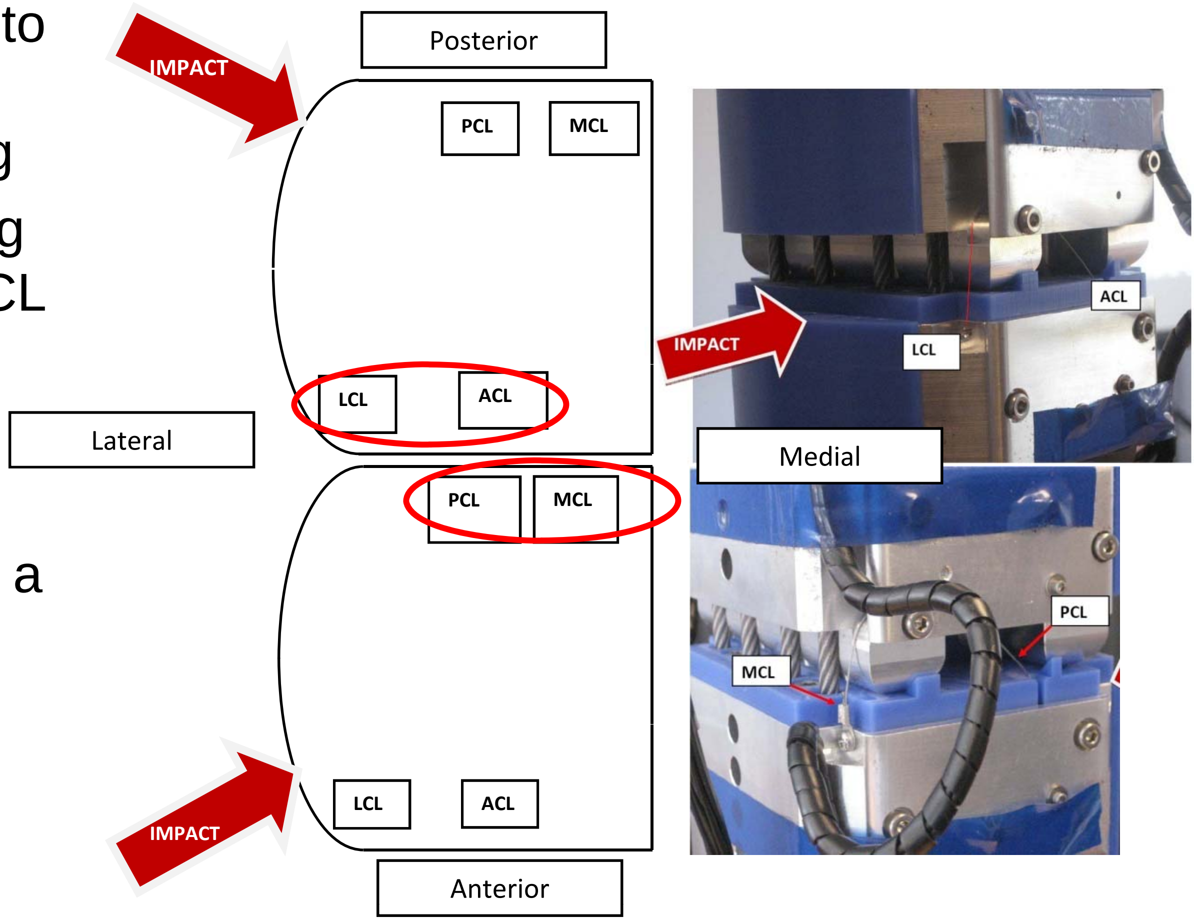
- FTSS held design review of the FLEX-PLI-GT
- April 3-4, 2007 at BASt
- To assess:
  - control of dummy response, measurement accuracy, manufacturability, durability, procedures and documentation
- Findings were reported
- 47 action items were found

Results Design Review

- The durability has not been extensively tested so far, as only well performing vehicles were tested
- The overload capacity beyond the injury threshold may be insufficient for vehicle development programs
  - OEM's and test houses should set a design requirement.
- A-symmetric sensitivity of MCL, ACL and PCL measurements to LH-RH off axis loading
- Knee joint twist causes inaccuracy in ligament elongation measurements
- Evaluation of bending moment calibration method
- The dynamic calibration test is not representative for the loading during vehicle tests and the input pulse is not controlled
- Internal wiring protection should be improved
- Control of free flight trajectory influenced by large umbilical (higher channel count)
- Temperature sensitivity of strain gauges
- Durability issues
- Material specifications and sourcing may be a problem
- Completion of documentation needs attention

Results Design Review (cont.)

- A-symmetric sensitivity to off axis loading due to potential Y-axis bending
- Lateral-Posterior loading will engage LCL and ACL
- Lateral-Anterior loading will engage PCL and MCL
- On a symmetric vehicle a RH impact may give a different response from LH impact



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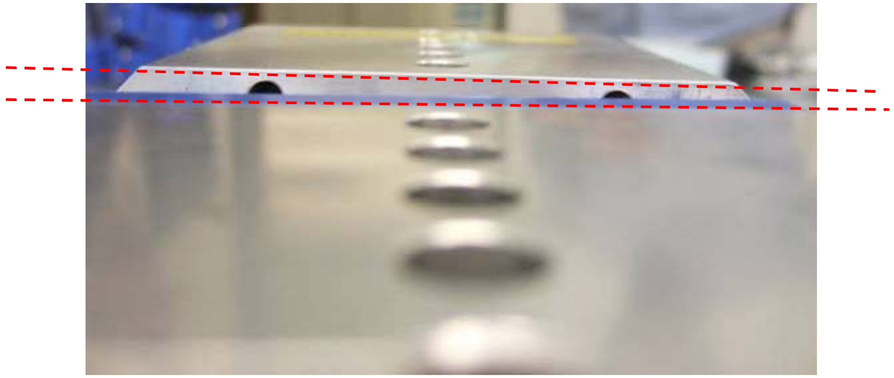
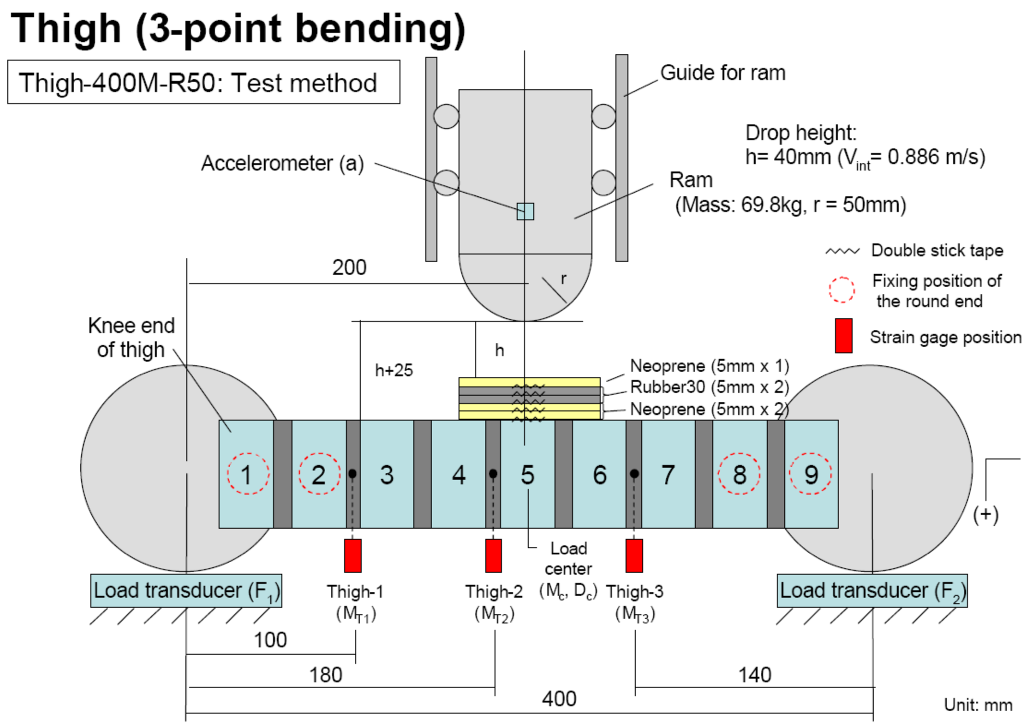
Results Design Review (cont.)

- Knee joint twist causes inaccuracy in ligament elongation measurements
- Cruciate ligaments exert a twist moment (z-axis along bone) between femur and tibia
- Correct angle is maintained by friction only
- Rotation between femur and tibia is likely to occur
  – Inaccurate ligament elongation measurement likely



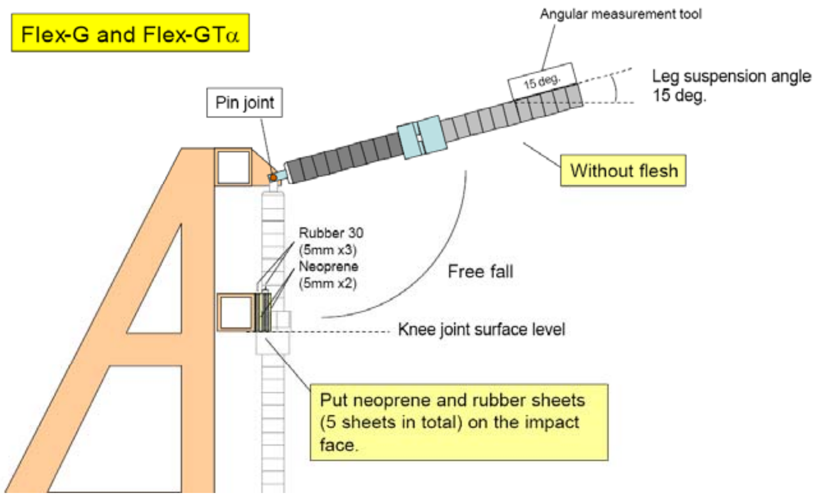
Results Design Review (cont.)

- Evaluate calibration method of bending moment strain gauges
- Dynamic test?
- Accuracy of position of strain gauges with respect to load transducers?
- Displacement of supports during bending?
- Tensile loading in z-axis?



Results Design Review (cont.)

- Dynamic calibration method for control of dynamic response
- Impact pulse controlled by neoprene and rubber sheets
- Neoprene and rubber sheet material may deteriorate over time: not controlled
- No feedback on severity of impact pulse
- Test is not representative for the loading during vehicle tests



Results Design Review (cont.)

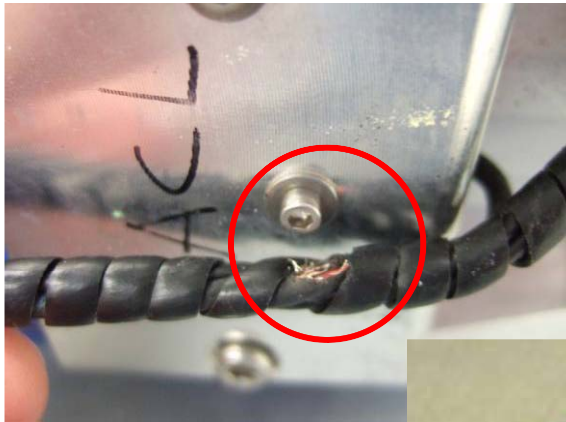
- Review Dynamic Calibration Results
- A limited comparison was done between car test and calibration test results to evaluate how well calibration test represents the vehicle test
  - Tibia calibration loading lower then vehicle testing
  - Femur bending is closer (but still lower then) to vehicle tests
    - Femur is not assessed for injury
  - Conclusion: Calibration procedure seems not to match with vehicle test results

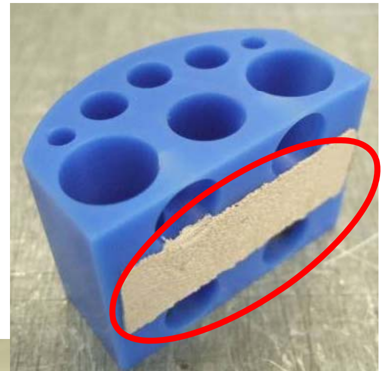
	1box	**sport**	**calibration**	**Difference**
Femur A3	130-190	110-240	120-130	Low match
Femur A2	110-200	180-250	100-110	Lower
Femur A1	80-120	110-150	75-85	Low match
Tibia A1	180-230	80-150,	110-120	Low match
Tibia A2	180-260	100-170	90-100	Lower
Tibia A3	160-230	110-180	60-70	Much Lower
Tibia A4	100-150	130-160	30-40	Much Lower
MCL	10-19	9-19	12-14	Match
ACL	4-7	6-9	2-4	Lower
PCL	6-10	3-11	2-4	Lower

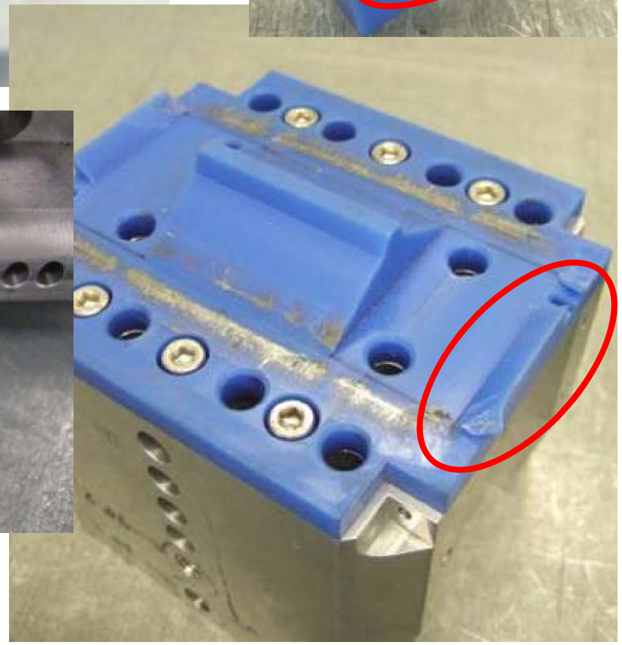
Results Design Review (cont.)

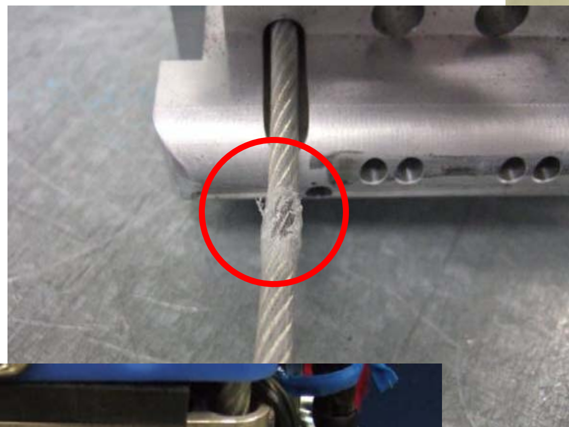
Durability issues:

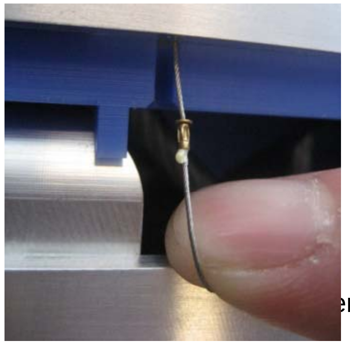
- Internal wiring
- Cable plastic sleeving
- Double side tape bonding
- Blue nylon liner damaged
- Innerside of neoprene skin sheets
- Stringpot stop

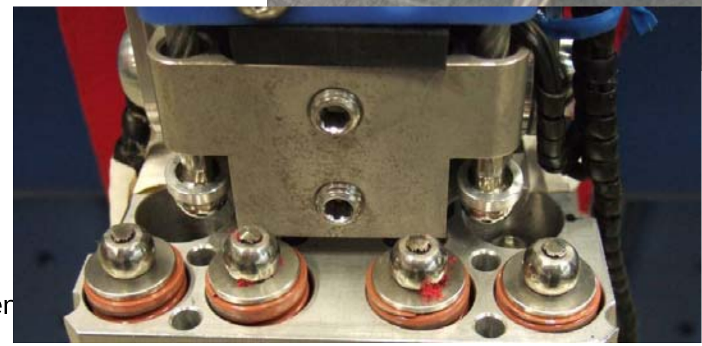










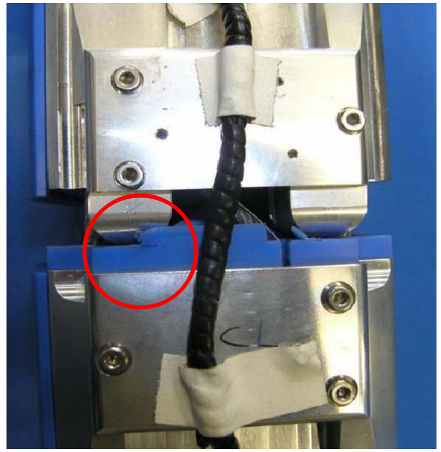


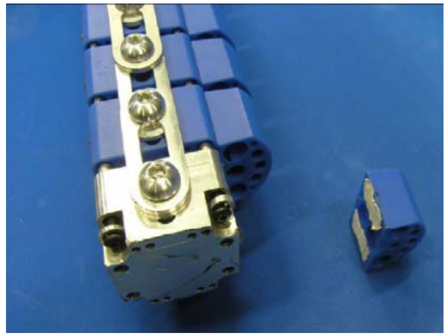
Input from other sources

- **ACEA**
  - Robustness of test wiring is not acceptable
  - Function on a "marginal" performing vehicle has to be checked
  - ACL and PCL results are dependent on the side of the vehicle that is impacted, thus making pedestrian test results asymmetrical
  - Certification and calibration procedures for the components of the legform and the sensors should be defined
  - Bending moments measurement strain gauges should be full bridge configuration
    - Directly attached to the bone elements
    - To avoid strain gauge elongation due to temperature variations

Input from other sources

- **BGS/BASt**
  - Edged shape of the legform’s impact surface seems to increase rotation around z-axis during impact: possible reason for scatter in ACL and PCL results
  - Cables likely to be damaged when the impactor falls on them
  - Influence of cables on the flight behaviour
  - Cable guiding with sharp angles and around sharp edges, cables likely to be damaged near the impactor
  - Tibia surface plate damage
  - Neoprene skin: Zippers very sensitive, skin gets caught in spring ends, skin damaged by sharp edges of knee
  - Separation of lowest segment impact face





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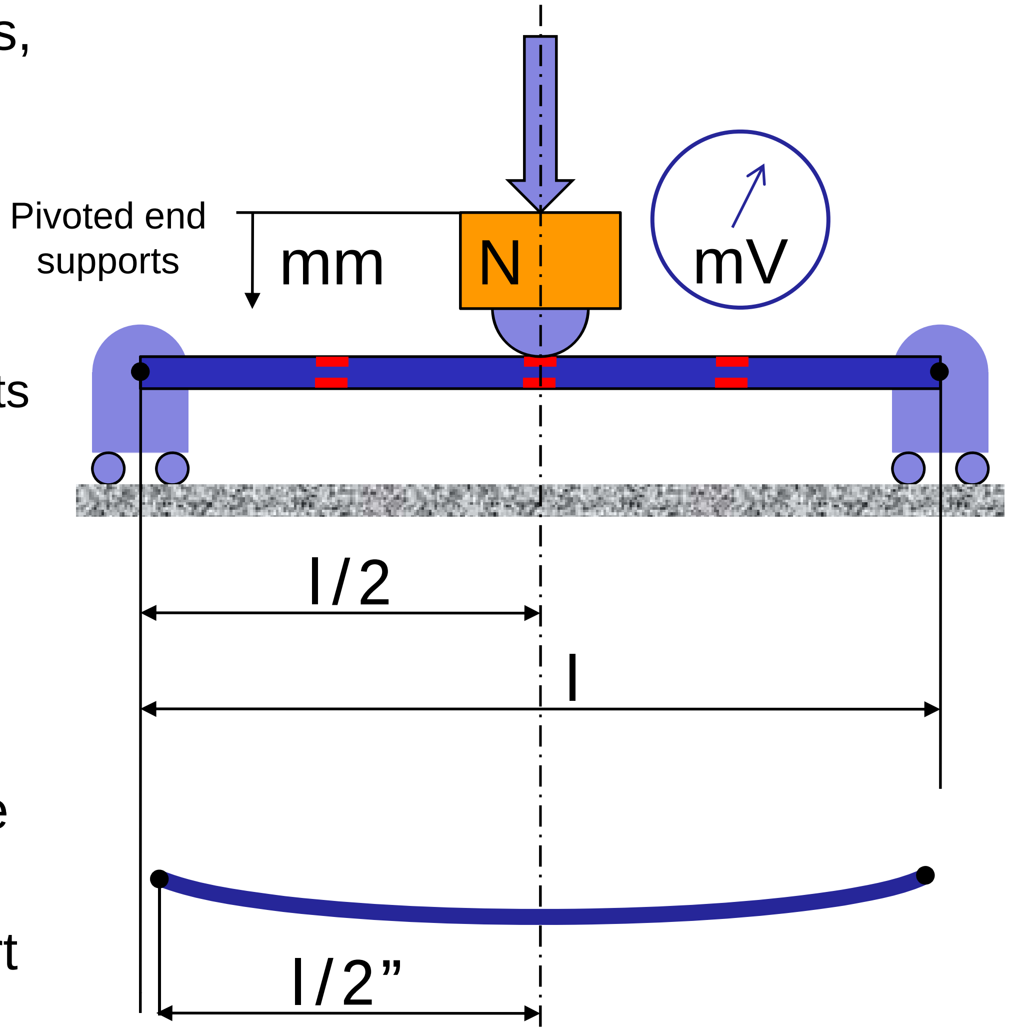
FLEX-GTR Development Progress

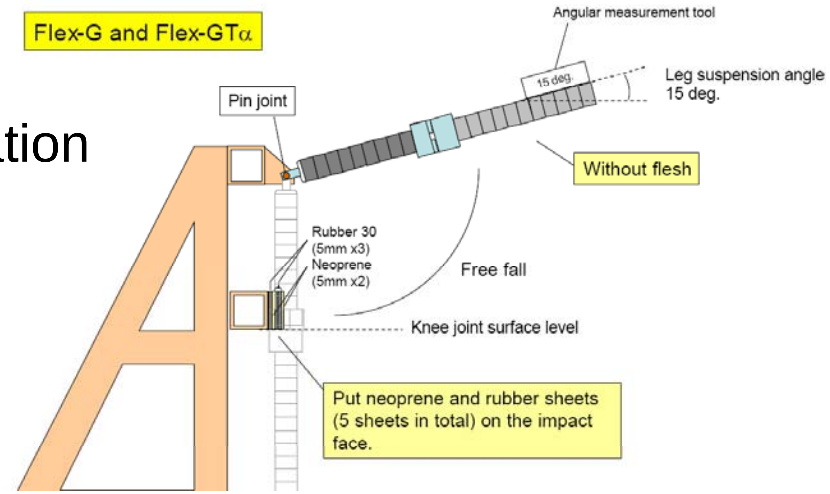
Calibration of Bending Moment

- Proposed procedures for bones, knee & ass'y will be followed
- Quasi static test
  - Loading rate t.b.d.
- Calibration of bone only
  - Supply of calibrated spare parts
- Measurement of test force, deflection and strain gauge voltage
- Accurate control of probe and support distance l and l/2
- Roller end support to annihilate tension / compression in bone
- Analytical correction for support distance change l/2" due to bending



Dynamic Calibration Procedure

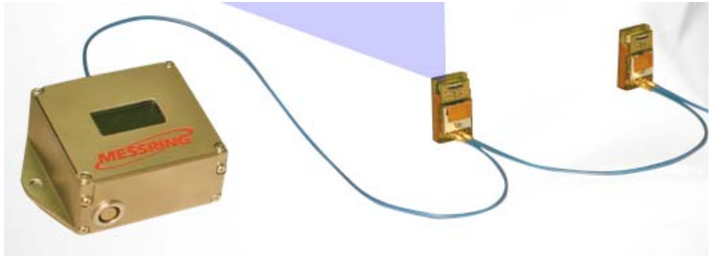
- Use current test fixture and drop height
- Use Aluminium honeycomb deceleration material
- Control input pulse with x-acceleration
- Control parameters
  - Drop height
  - Ax
  - MCL, ACL, PCL (and LCL)
  - Tibia bending moments
  - Femur bending moments
  - Target corridor ±10% from average



Dynamic Calibration Procedure Development

- FTSS will investigate possibilities to achieve better match with vehicle loading in certification testing
  - Increasing input pulse (raise the pendulum)
  - Mounting additional mass to lower end of assembly during certification
  - Turn upside down the test set up to load tibia higher (pivot on the tibia in stead of on the femur)
  - Lower the striking surface to impact the top of the tibia
  - Combination
- We could start development testing with FLEX GT to achieve earlier results

On Board Data Acquisition



- Improve free flight motion control
- Optional on board
  Data Acquisition System standard
- Messring M=BUS selected
  - Most compact system currently available
  - http://www.mbus-sensor.de
- 2 units 6 channel Loggers
  - 6 channel logger
  - 15 grams
  - 40*25*14mm
  - Internal battery
  - 20kHz sampling
  - 16 bit resolution
  - Signal conditioning
  - Etc.

Figure 1 M=BUS®

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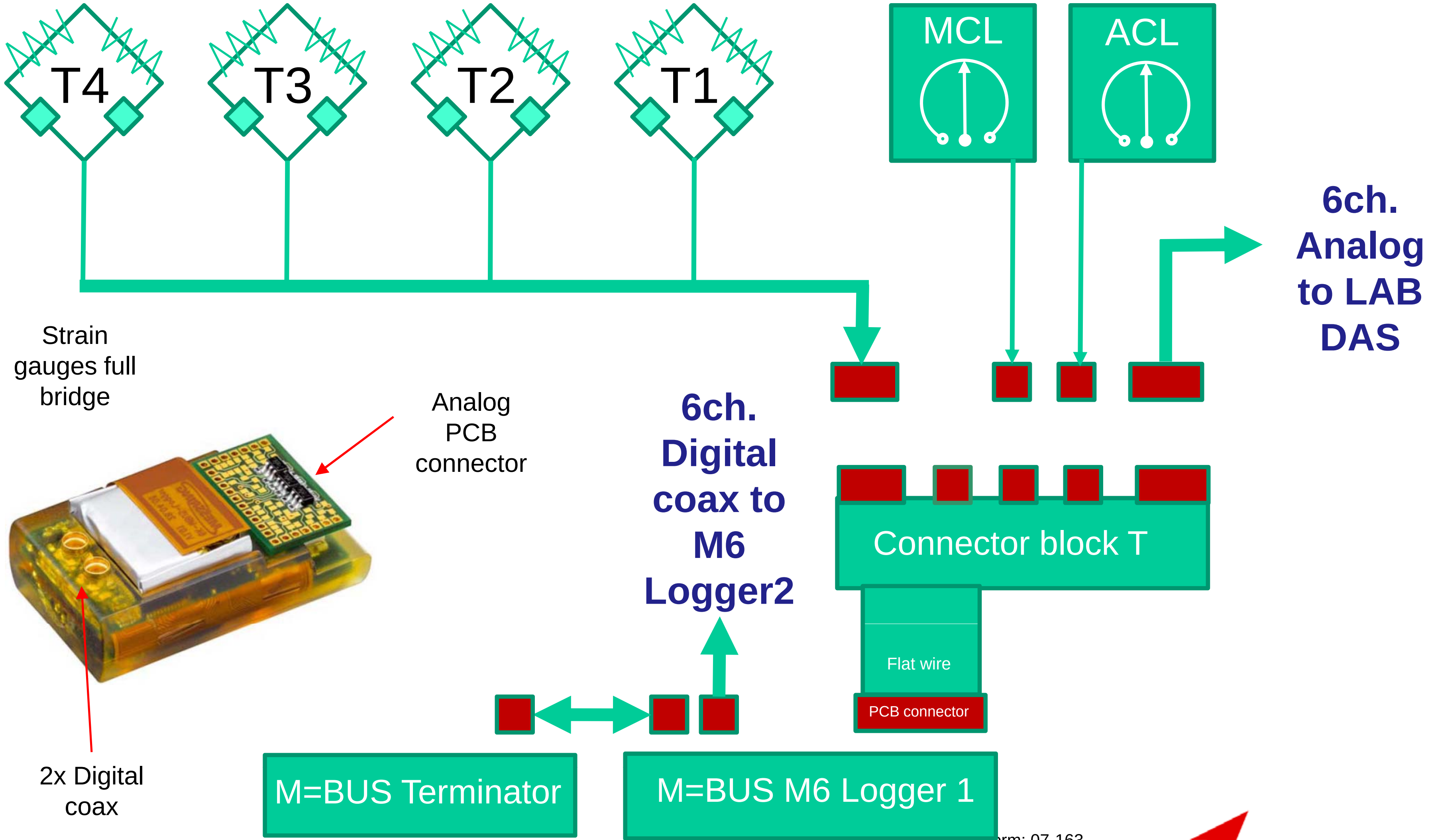
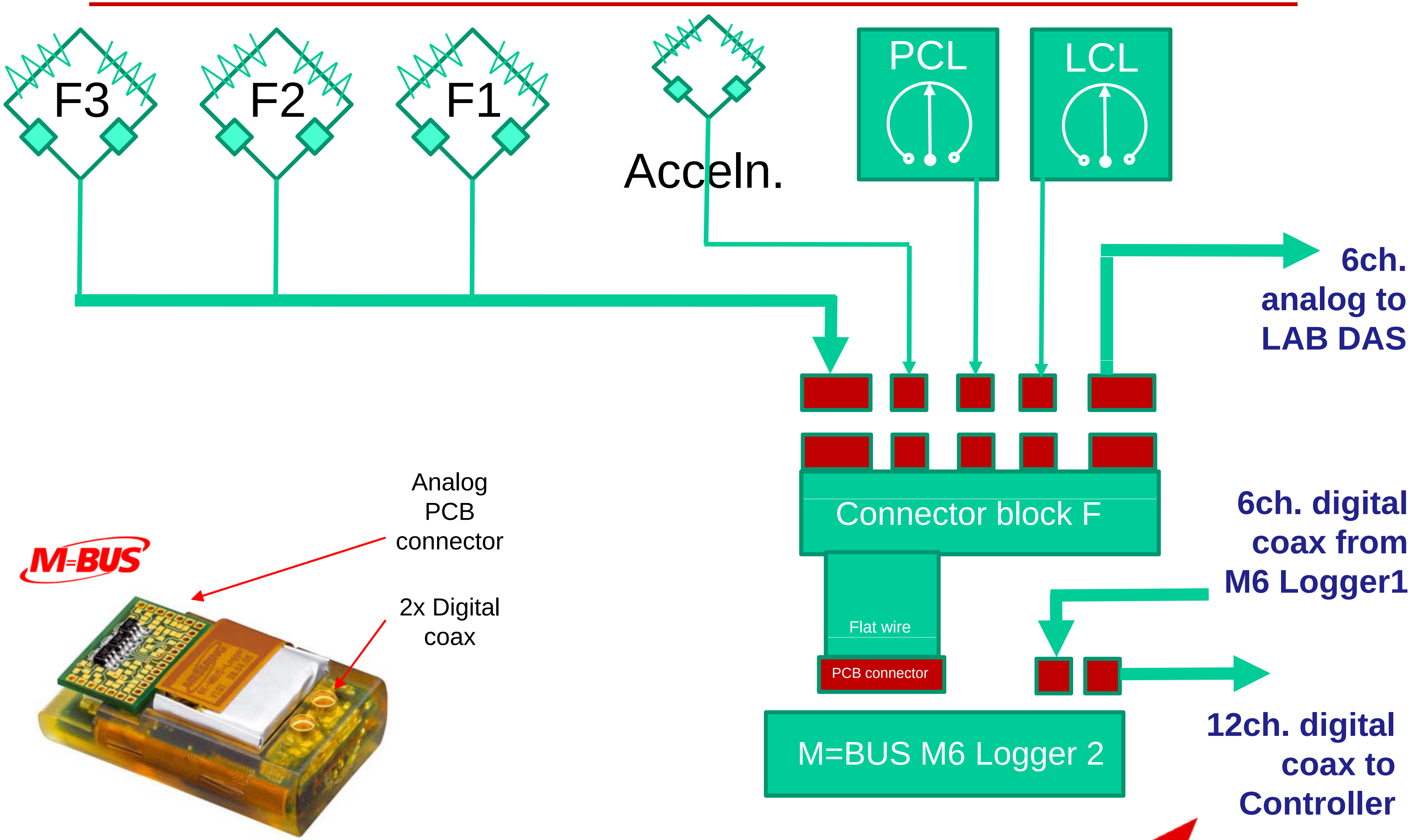
Wiring Diagram Tibia

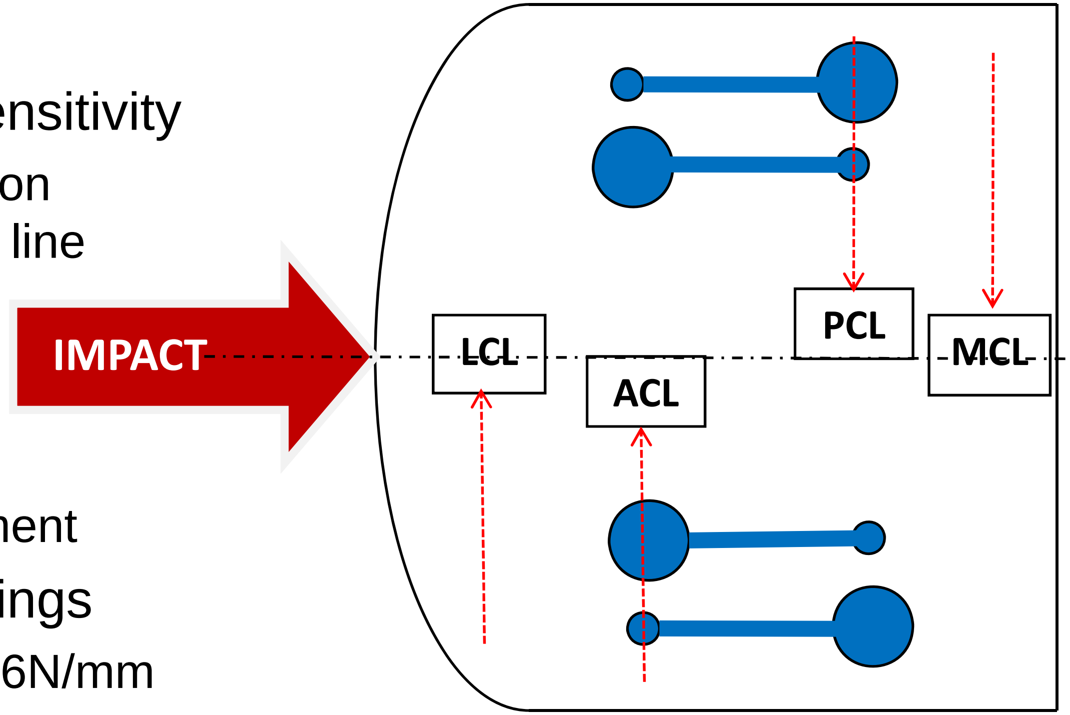


Wiring Diagram Femur



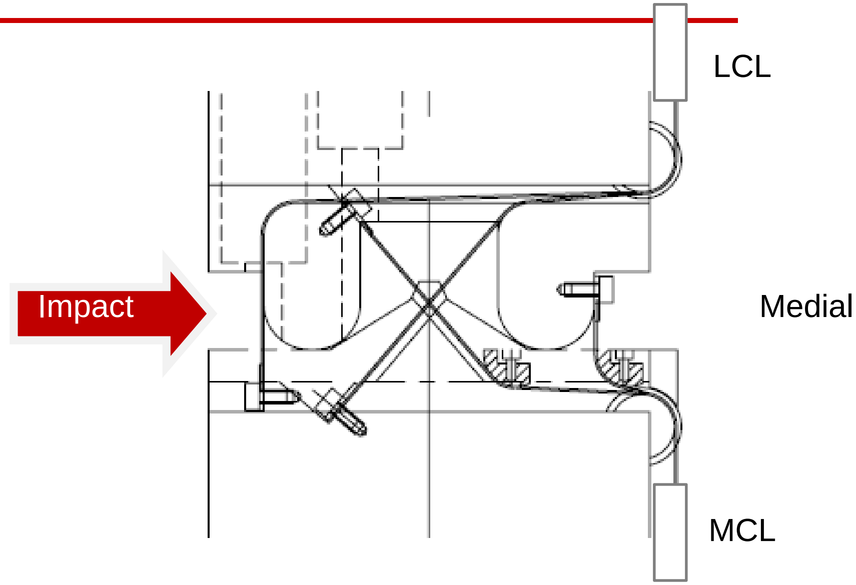
Conceptual design

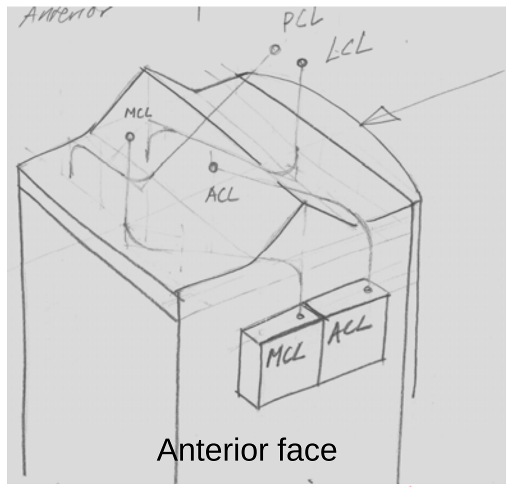
- To avoid A-symmetric sensitivity
  - Move ligament elongation measurement to centre line
- To avoid knee twist
  - Use two sets of cruciate ligaments
  - To neutralize twist moment
- Cruciate ligaments 8 springs
  - DBØ12xØ6x40mm; 71.6N/mm
  - May need to go Ø3mm cable
  - Optimized space for DAS & connector
- Lateral ligaments 16 springs same
  - DBØ18xØ9x80mm; 76.7N/mm



Conceptual design (cont.)

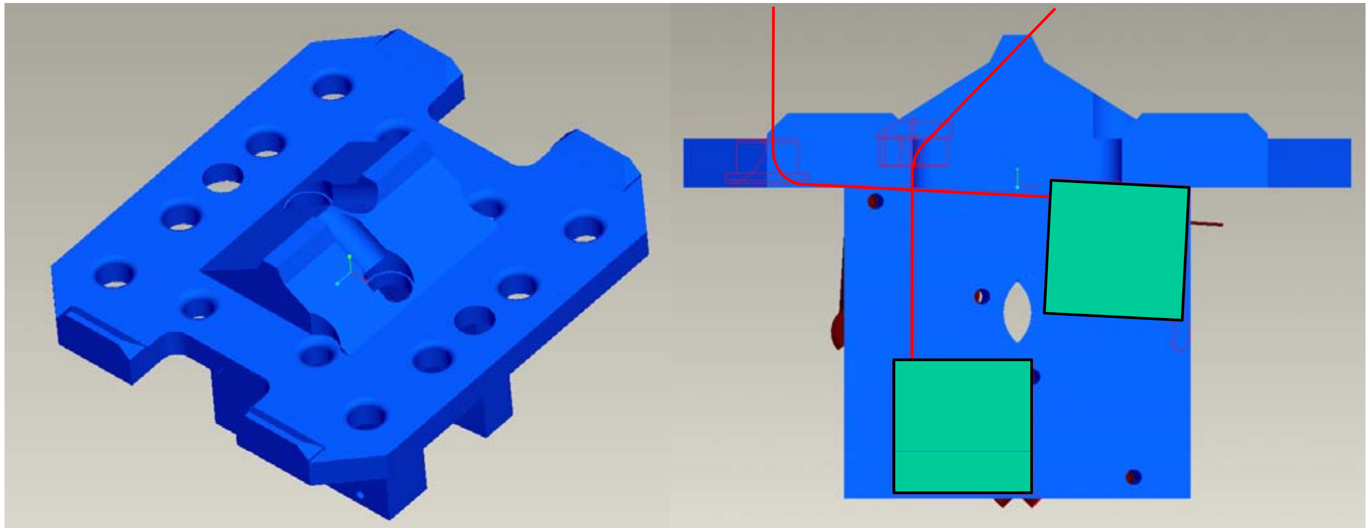
- Position of ligament elongation sensors on centre line
- Various concepts were investigated
  - On medial face
  - On anterior-posterior faces
  - In the centre tibia cavity
- Centre tibia cavity selected
  - Best control manufacturing tolerance
  - Best protection to sensors
  - Least angle string routing
  - Provides more space for DAS, connectors and wiring

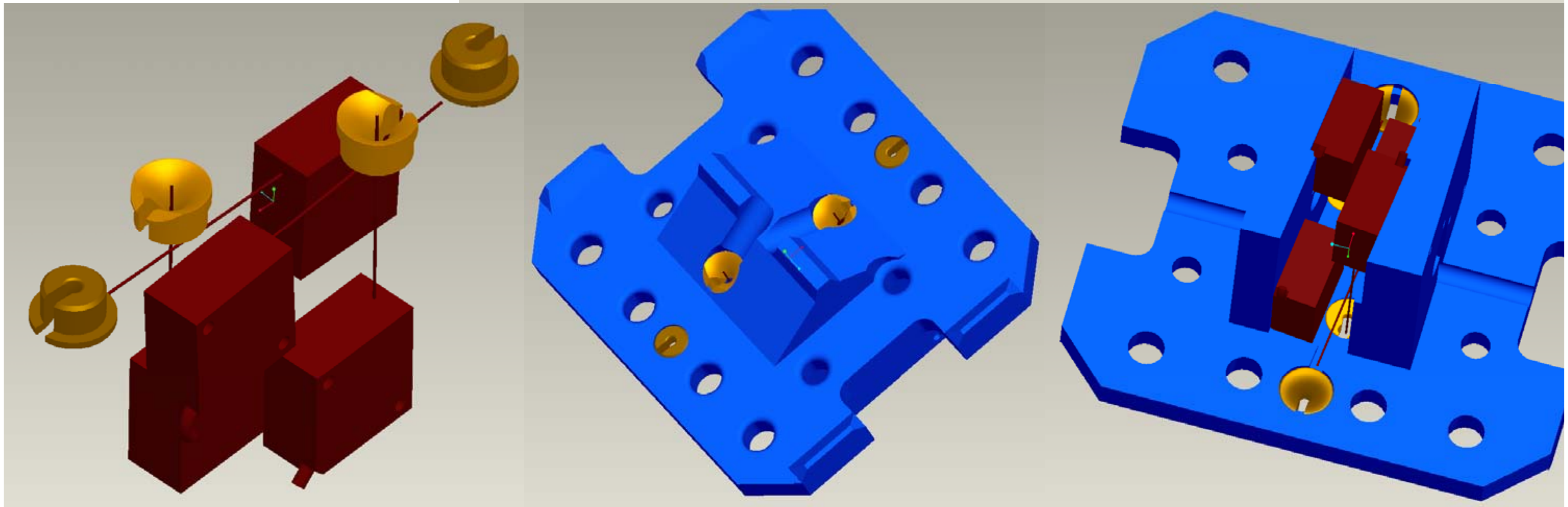




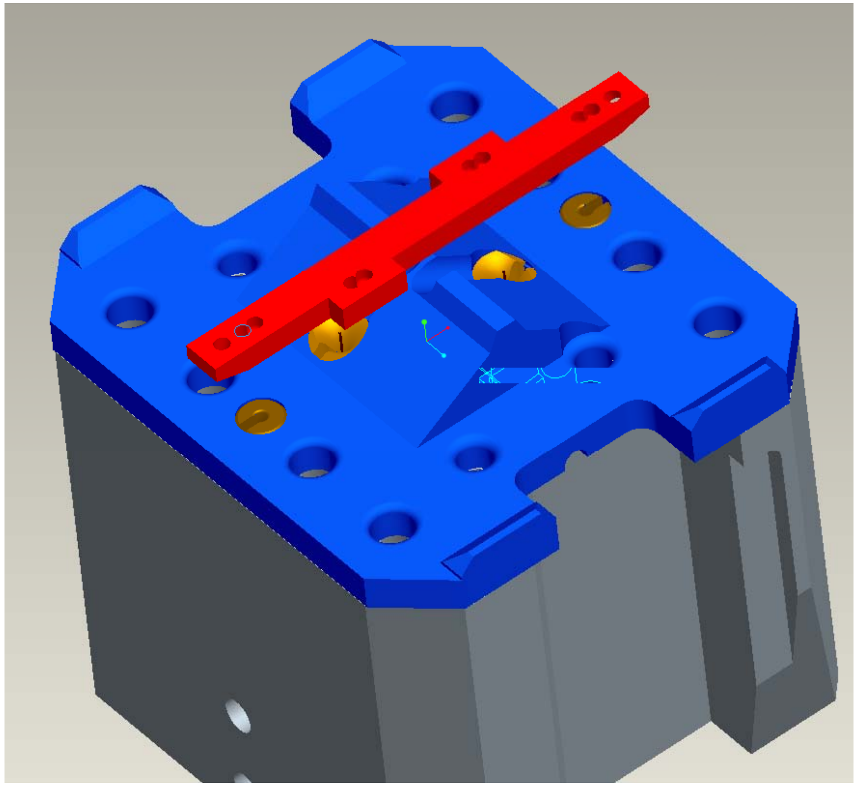
Conceptual design (cont.)

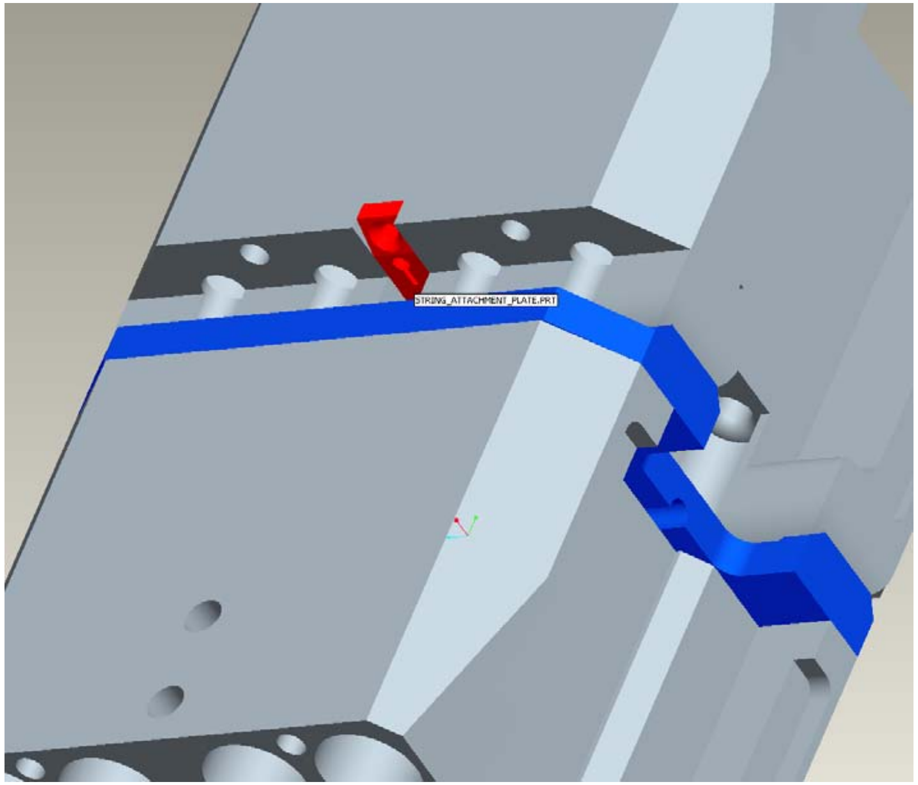
Space Age Control
150 series
19*19*10mm
49G acceleration
38mm stroke
2xLH & 2xRH pull
Bronze wire guides



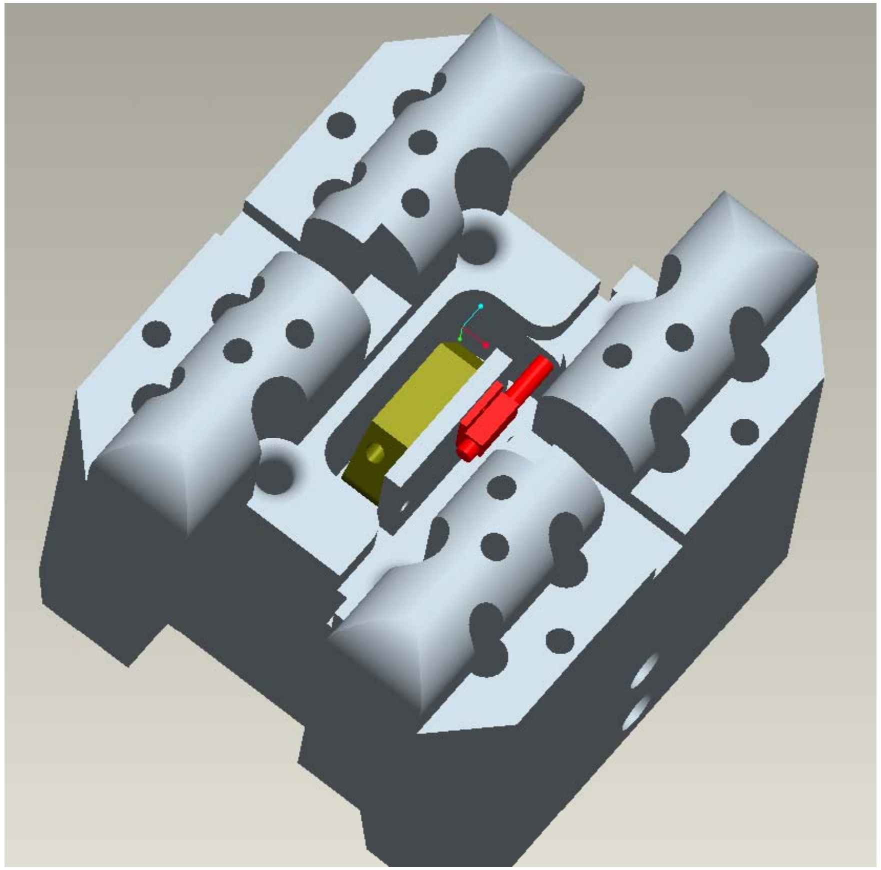


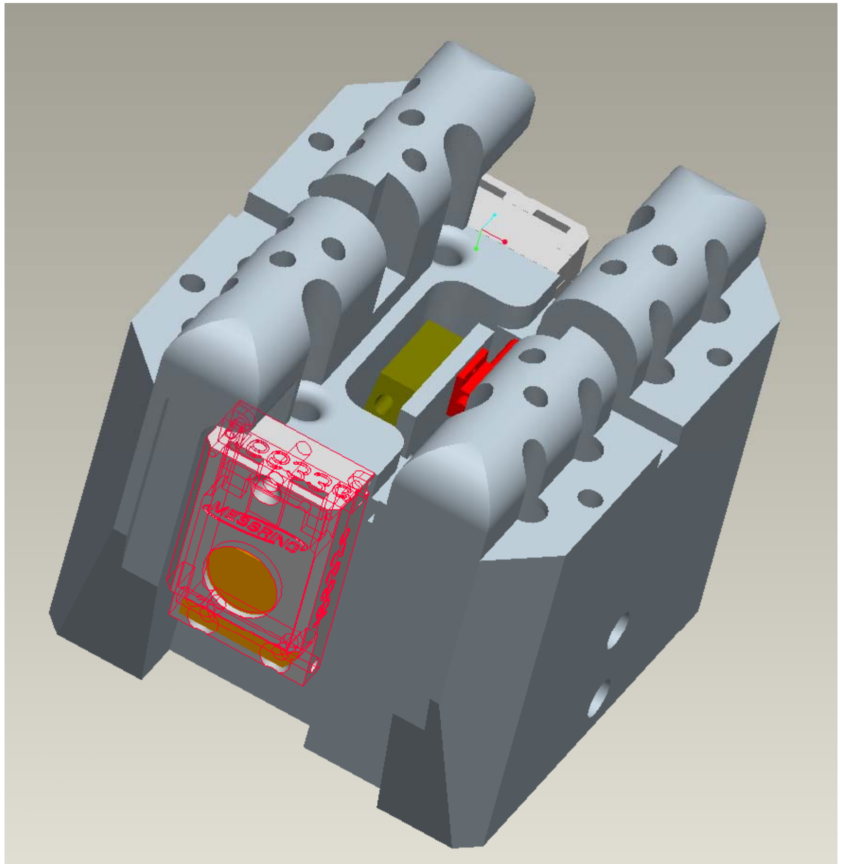
Conceptual design (cont.)



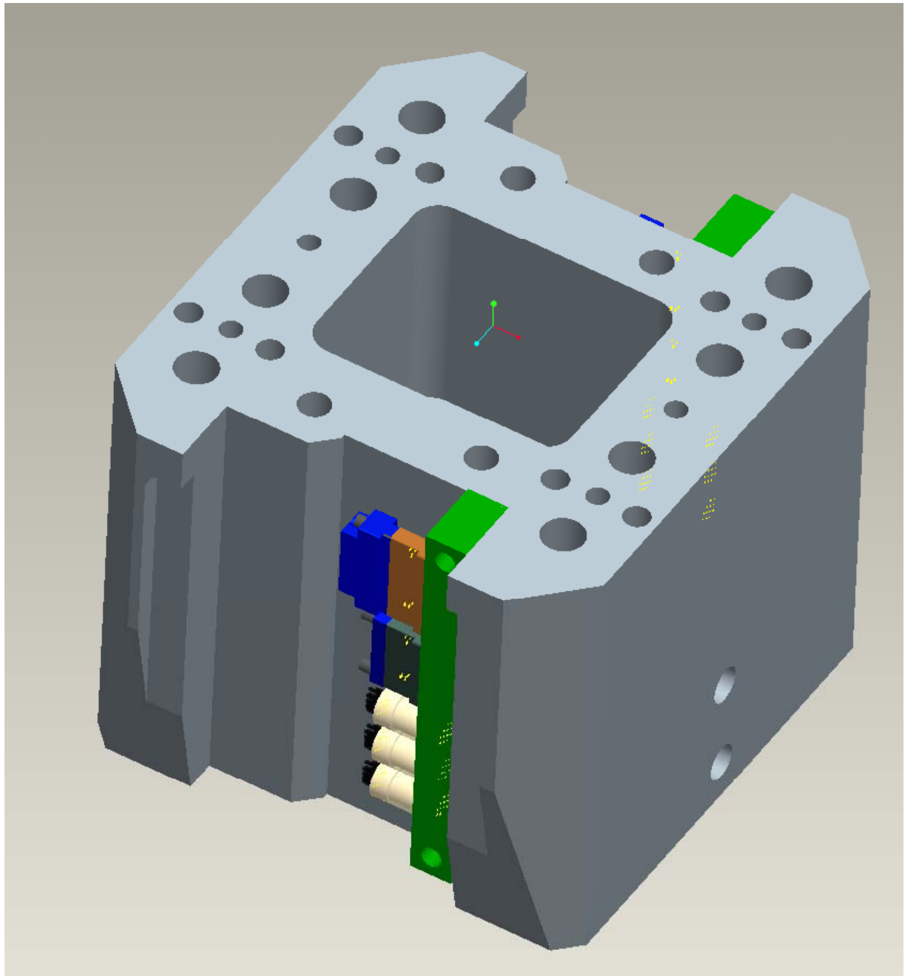


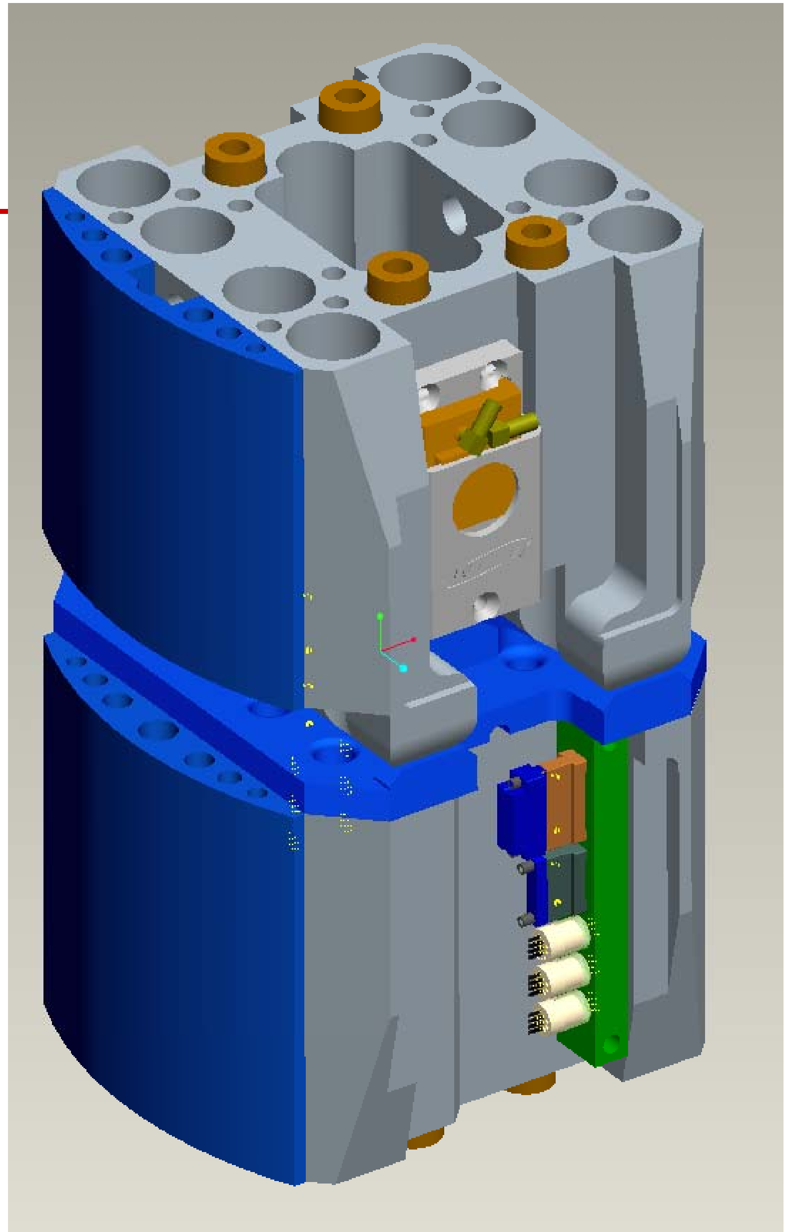
Conceptual design (cont.)



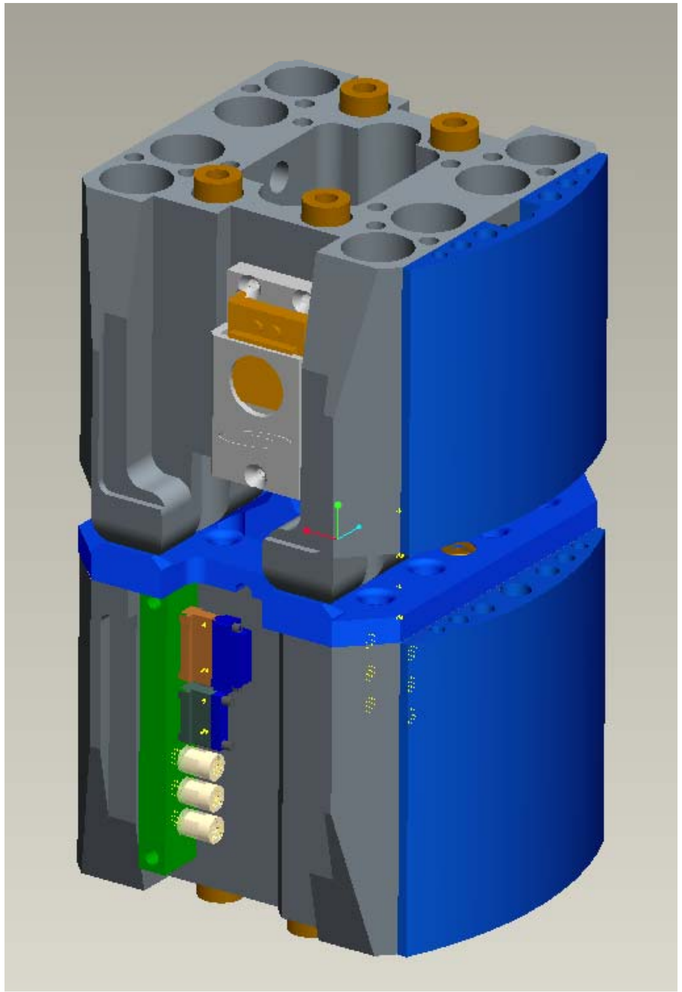


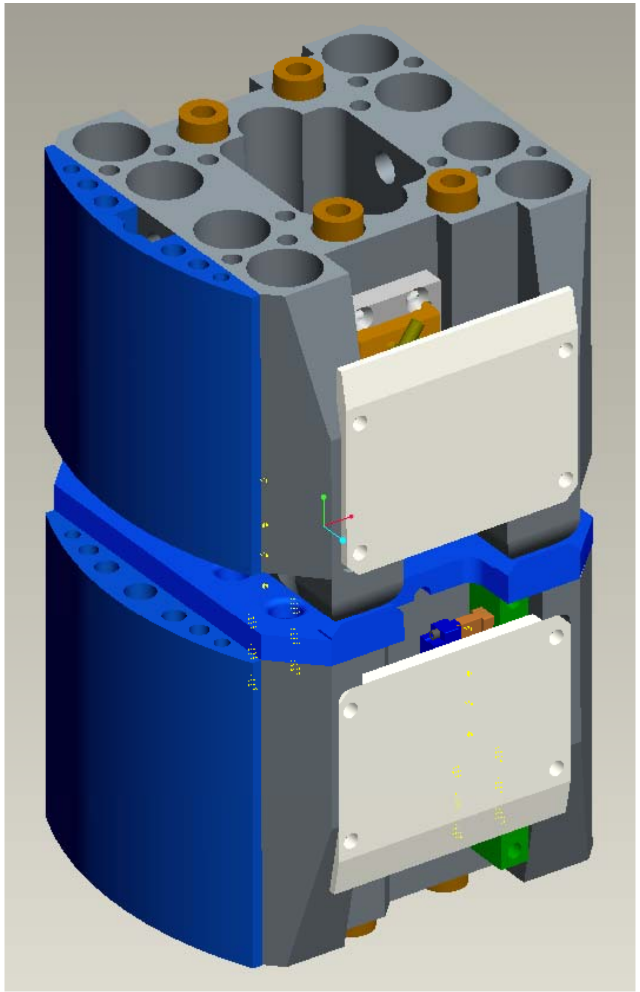
Conceptual design (cont.)





Conceptual design (cont.)





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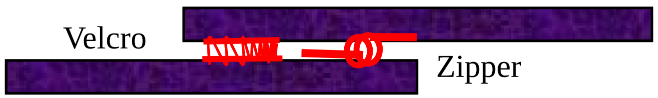
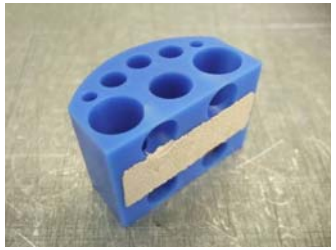
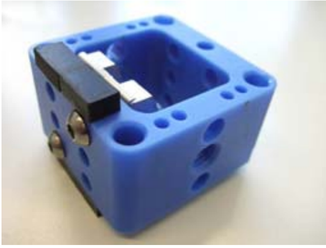
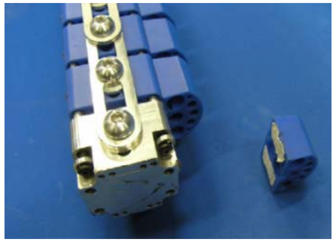
Conceptual design (cont.)



- Skin zipper protection
- Wear resistant material on skin
  - Inside - outside?
  - Schoeller Keprotec, www.schoeller-textiles.com
- Integration of inner and outer segment into one component
  - Bottom Tibia segment one piece aluminium?
  - Access holes for screws acceptable?
- Mark bone for assembly position reference
- Round all sharp edges in wire route
- Redesign FLEX-PLI link to calibration fixture
- Hex or flat on ligament cable ends for easy spring adjustment
- Wear of ligament cable sleeves
  - Remove plastic sleeves from cables?
  - Apply bronze bushing in meniscus?







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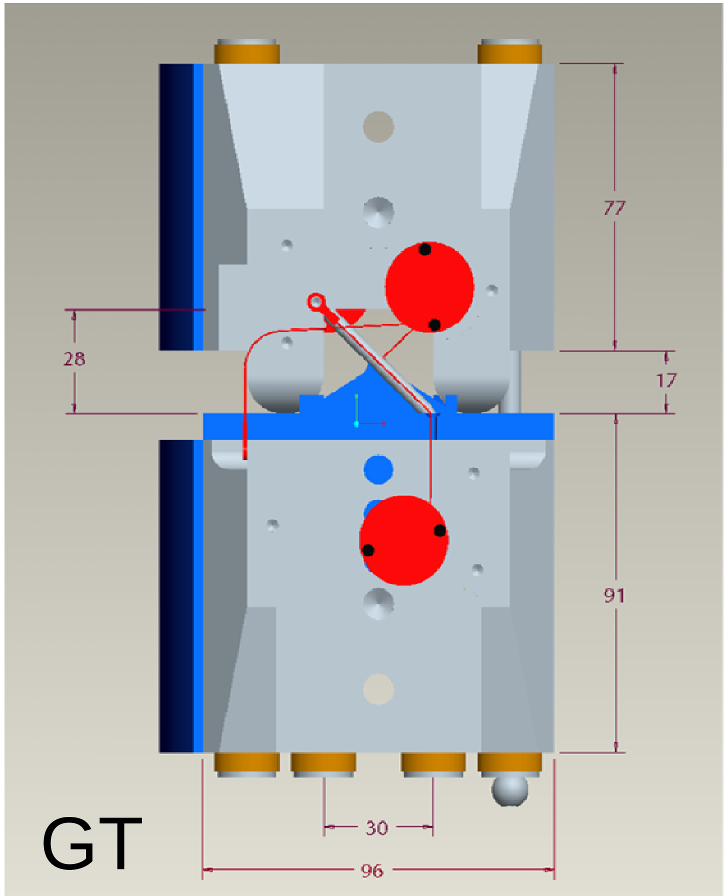
Further Activities

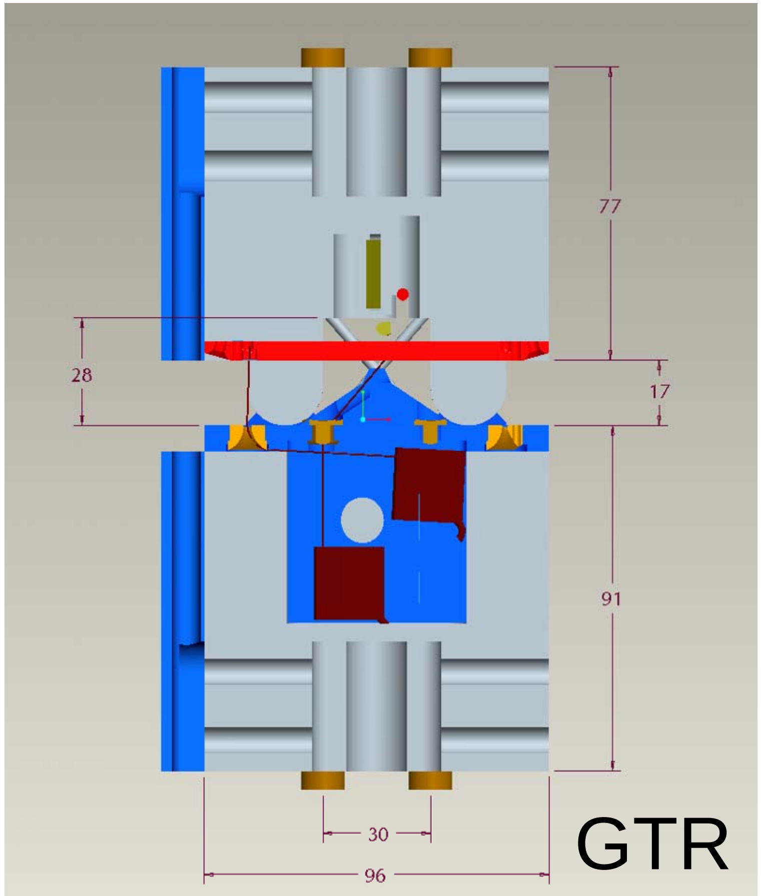
- Development of User Manual, including procedures, training, etc.
- Material tests
  - Characterize dynamic response of current and new source materials
    - Neoprene, Synthetic rubber 30 Shore A, 45 Shore A
- Temperature sensitivity tests
  - Calibration at various temperatures
- Anything else that needs addressing? Any concerns?
- Possible usefull Options?
  - Film targets?
  - Angular Rate Sensors to track free flight motion/rotation?
  - Three axis accelerometers: Tibia? Femur?

Comparison GT - GTR

- The project aims at keeping the dynamic response of the GTR as close as possible to current GT version
- GTR aimed to maintain GT Mass and Mass distribution
  - FLEX-GT mass breakdown study was performed
- GTR aimed at maintaining GT dynamic response
  - FTSS will perform material characterization tests
  - GTR materials will be as close as possible
  - Bone material and dimensions will remain the same
- Changes in the knee will not affect bending moment
  - Lateral Ligaments and springs and spacing in y- direction (impact) remain the same
  - Cruciate ligaments total force may slightly change, spacing in y-direction and pull direction remain the same
  - Elongation sensors MCL, PCL, ACL, LCL remain in line with ligaments, position projected to mid knee position

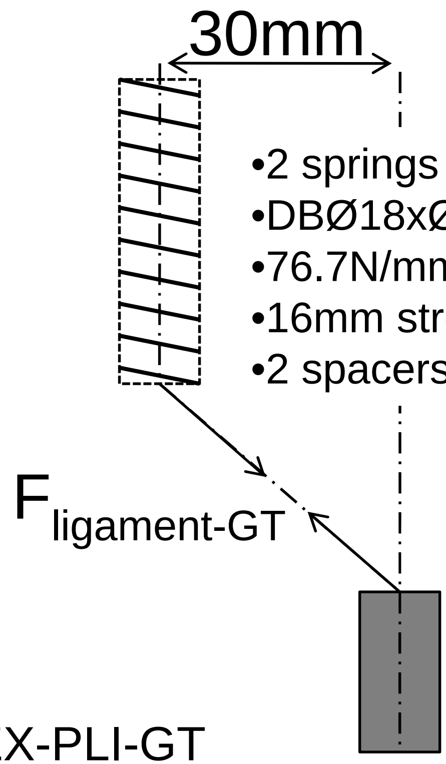
Comparison GT - GTR



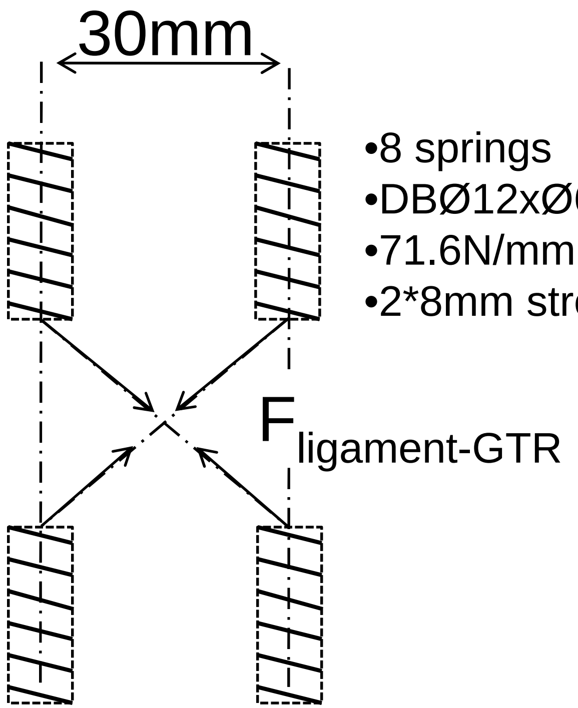


- GT and GTR cruiciate ligament and spring location remain the same
  - All dimensions and interactive geometry remain the same
- Accommodation connectors and DAS -> larger space in the side -> mass compensated

Cruciate Ligament Springs



- 2 springs
- DBØ18xØ9x80mm
- 76.7N/mm rate
- 16mm stroke
- 2 spacers



- 8 springs
- DBØ12xØ6x40mm
- 71.6N/mm rate
- 2*8mm stroke

- FLEX-PLI-GT
- $F_{ligament\ GT}$ = 76.7*16 = 1227N
- Total $F_{ligament\ GT}$ = 2 * 1227 = 2454N
- 8 Lateral ligaments DBØ18xØ9x80mm

- FLEX-PLI-GTR
- $F_{ligament\text{-}GTR}$ = 71.6*8 = 573N
- Total $F_{ligament\text{-}GTR}$ = 4*71.6*8 = 2292N
- Lateral ligaments unchanged

- Cruciate ligaments contribute ~20% to bending moment
- Effect ~-1.3%

Further Activities

- CAE model development
  - FTSS proposes to develop a Flex-PLI-GTR CAE model through a consortium project parallel to the hardware development
  - FTSS offers to take the responsibility to develop the models and co-ordinate the project
  - The model(s) will become part of the FTSS model database and will be maintained and further enhanced accordingly
  - The consortium members will fund the consortium project and will receive a free license allowing to use the model in the next 3 years

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