TEG-071

First Technology Safety Systems

FLEX-PLI-GTR Development

Prototypes

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FTSS Europe

7th FLEX-TEG meeting December 8, 2008
BASt, Bergisch Gladbach, Germany

Content

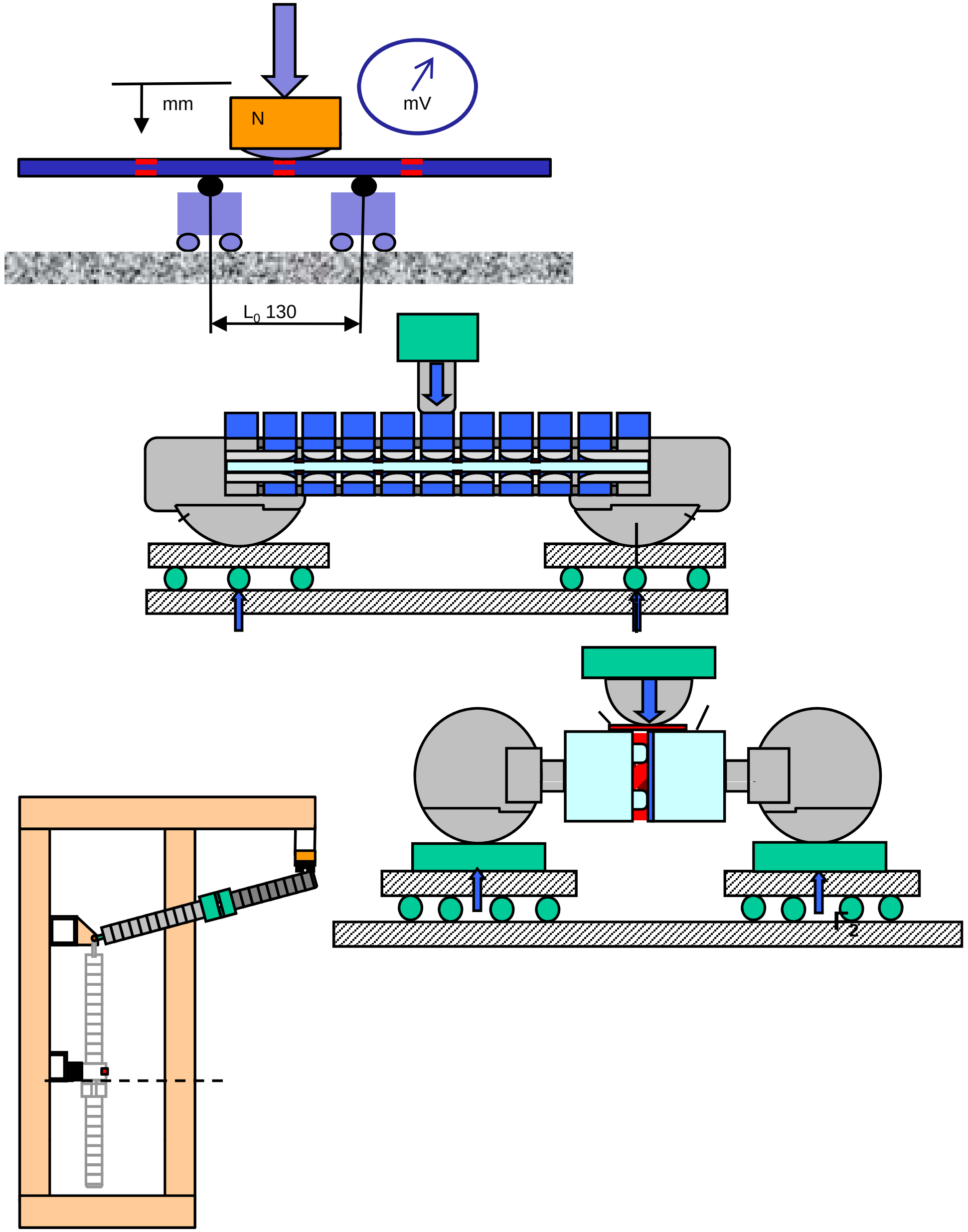
- Prototypes build according agreement design freeze
- Photos taken during assembly
- Calibration results
- Status CAE model development
- Further steps

Prototypes

- 3 FLEX-PLI-GTR prototypes were delivered to JARI November 2008
- 1 version equipped with cables to off-board DAS
- 1 version equipped with on-board DAS Messring M=BUS
- 1 version equipped with on-board DAS DTS-Slice
- All standard 12 channel configuration
- Training and initial testing conducted 1st week December at JARI

Photos taken during assembly

Flex-GTR full calibration test procedures (overview)



Step 1: Bone core 7 tests
Quasi-static 3-point bending test
(femur bone core, tibia bone core)

Step 2: Femur and tibia 2 tests
Quasi-static 3-point bending test
(femur, tibia)

Step 3: Knee, 1 test
Quasi-static 3-point bending test

Step 4: Assembly 1 test
femur-knee-tibia
dynamic calibration test

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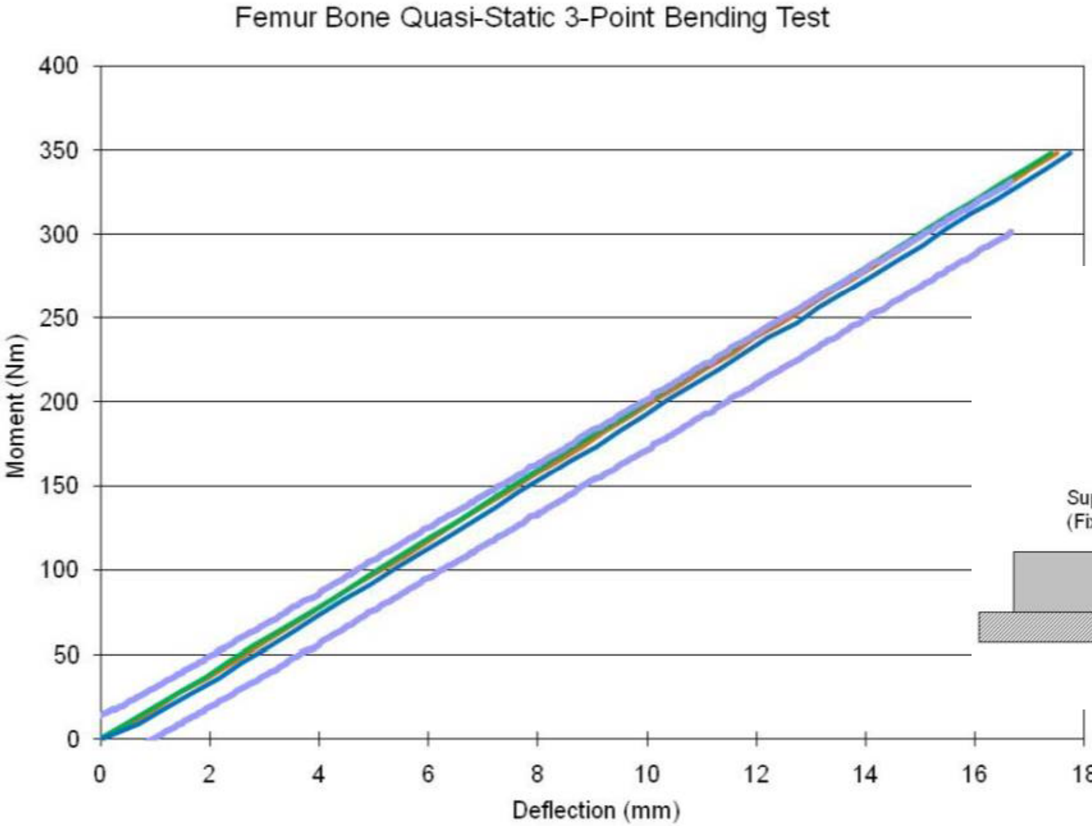
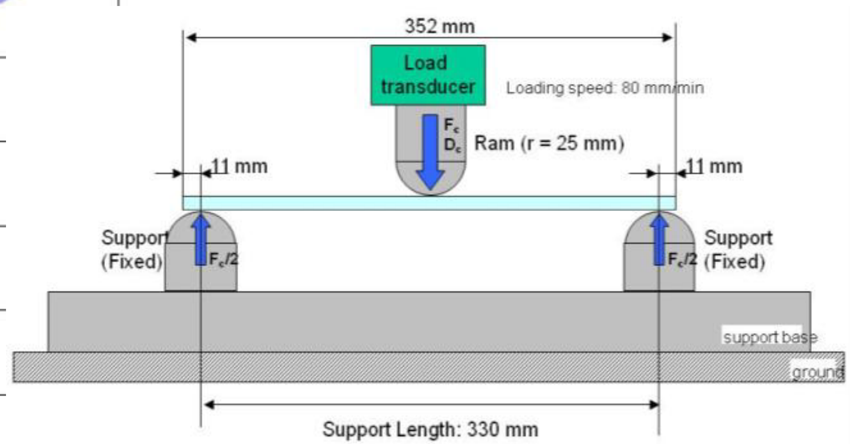
Step 1a
Bone Quasi Static 3-Point Bending

- This test was repeated 50 times on one femur and one tibia bone
- To check if any strain gage debonding occurred
- No strain gage debonding was observed (microscopic investigation)
- Strain gage resistance did not change after 50 tests





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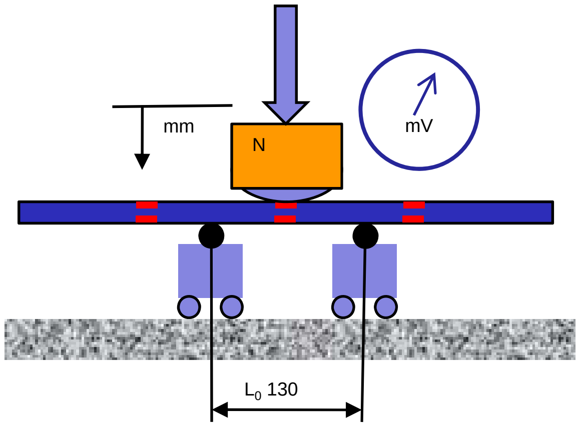
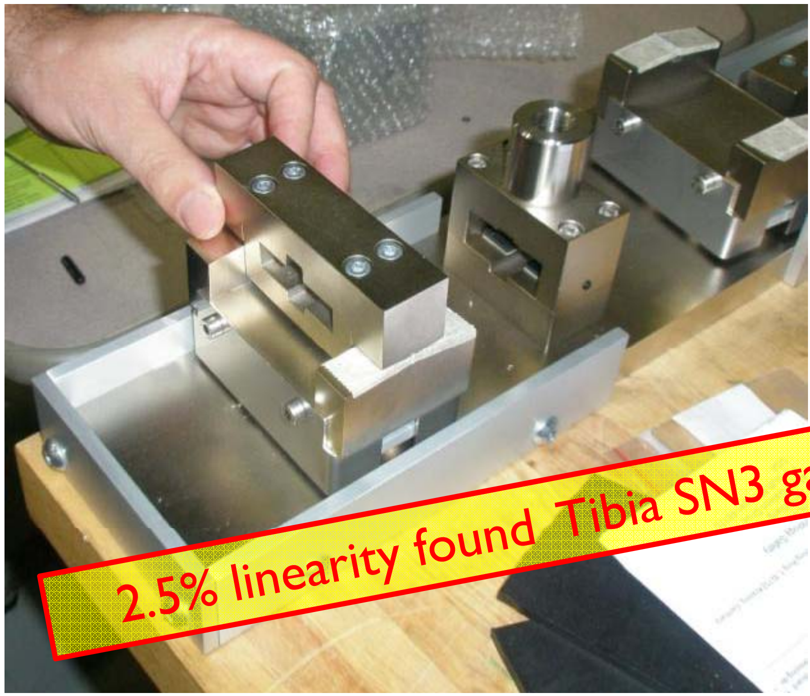
Step 1b - Bone calibration each gage

Femur	Offset	NonLinearity	Hysteresis
	mV/V	%Full Scale	%Full Scale
Average	0.00007	0.27	0.71
St.Dev.	0.00036	0.07	0.29

Tibia	Offset	NonLinearity	Hysteresis
	mV/V	%Full Scale	%Full Scale
Average	-0.0029	0.45	0.64
St.Dev.	0.0061	0.24	0.29

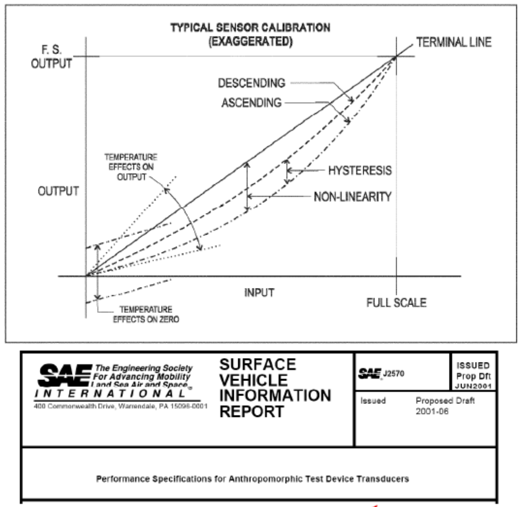




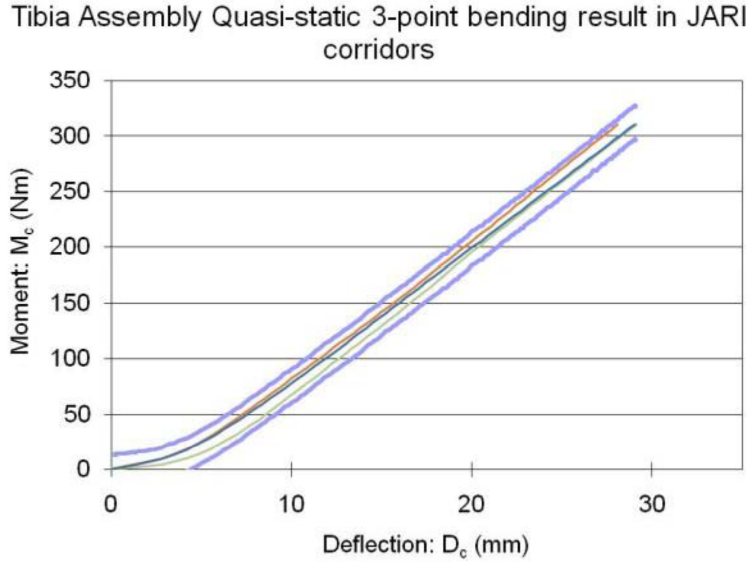
2.5% linearity found Tibia SN3 gage 3 CHECK!!

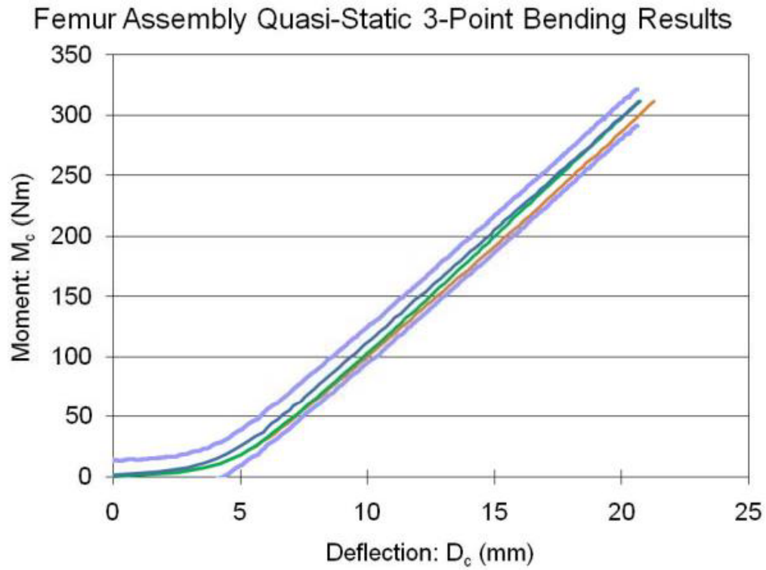
SAE J2570
Performance Specification Transducers

- Relevant criteria
  - Hysteresis ≤ 1% of full scale capacity
  - Non-linearity ≤ 1% of full scale capacity
- These are design goals!
- May be difficult to meet due to flexible nature of the bone
- Little experience with high deflection!



Step 2 – Tibia and Femur Assembly Quasi-static 3 point bending





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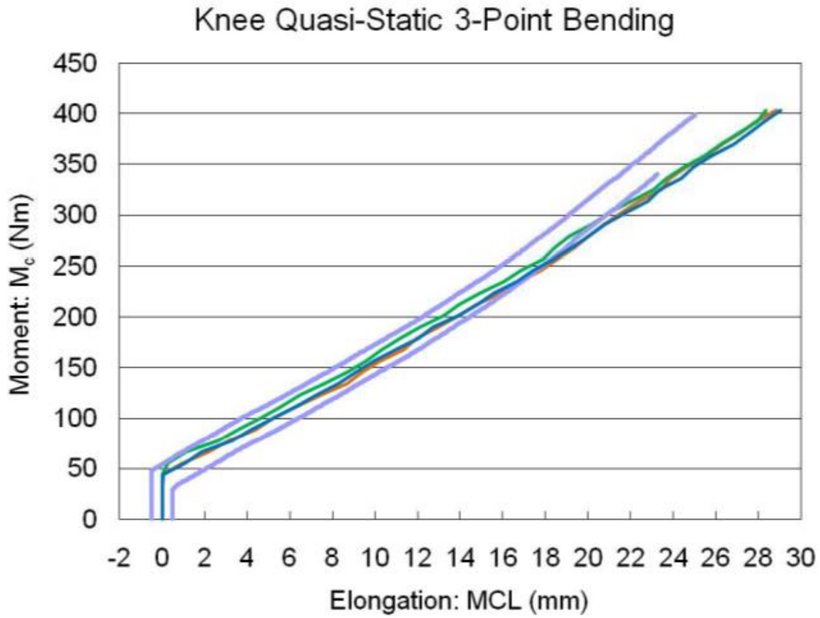
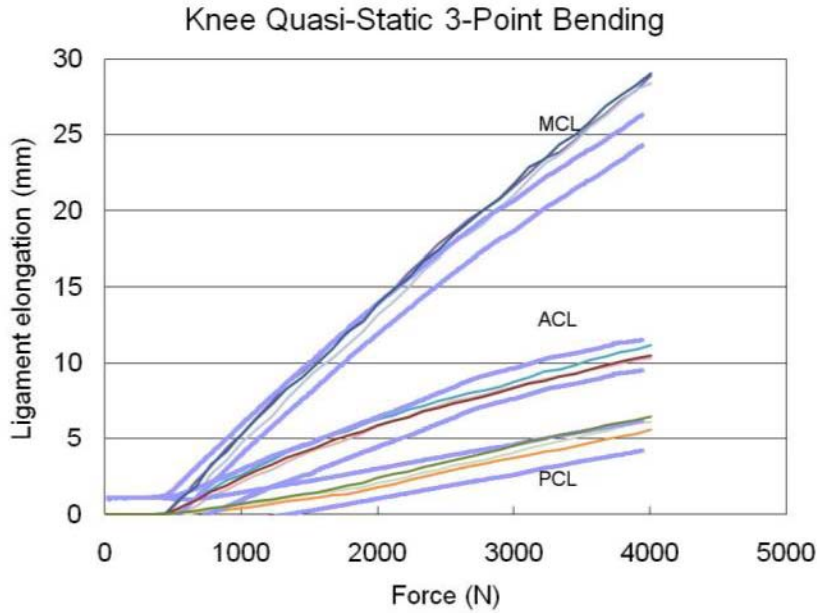
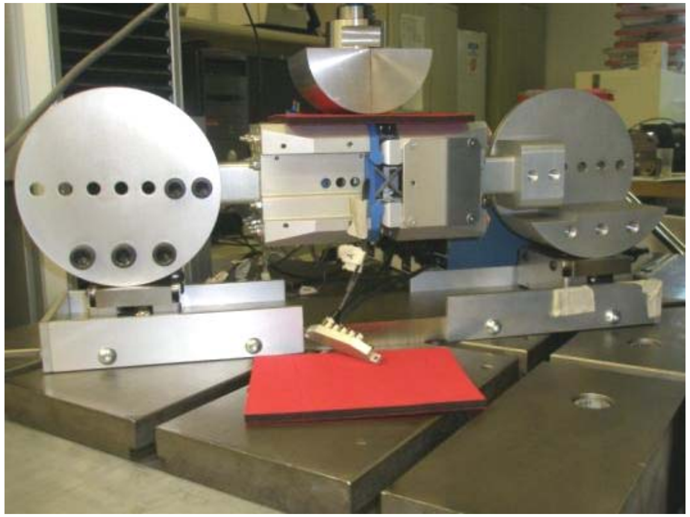
Step 3
Knee Quasi-Static 3-Point Bending







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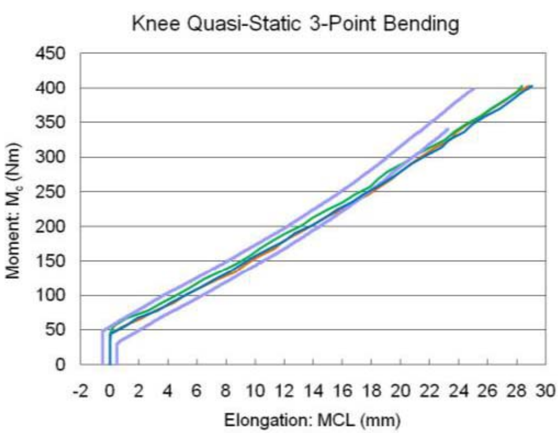
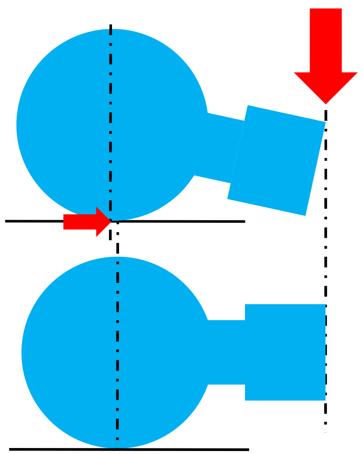
Step 3

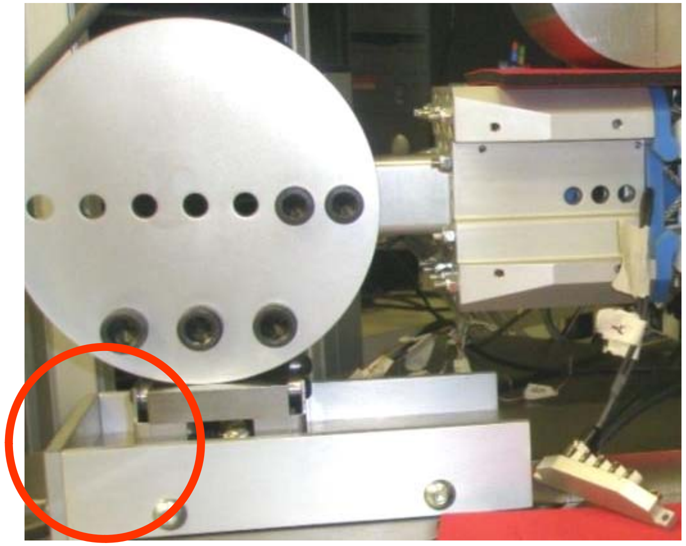
Cross Check GTR knee in GT procedure!

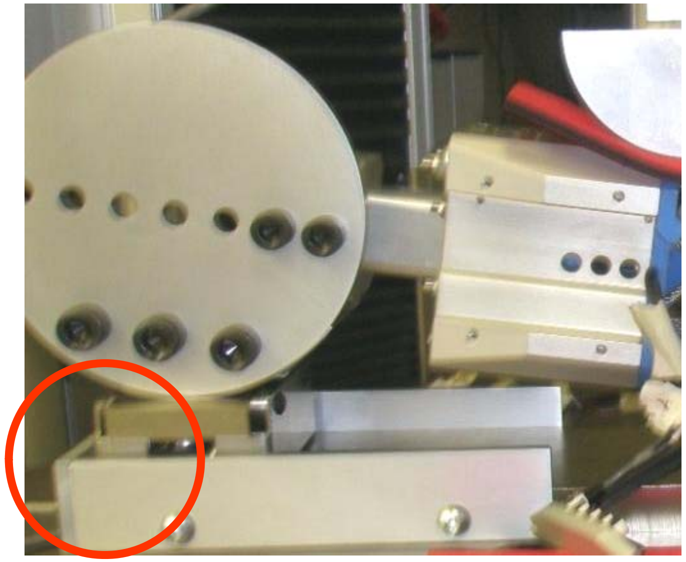
Knee Quasi-Static 3-Point Bending

- knee bending response appears slightly different from GT
- Cruciate ligament spring changed, estimated -1.2%
- Two springs per ligament allow to bend up to 28mm MCL before ACL-PCL bottom out
- Cruciate ligament friction reduced
- Test set-up changed with roller supports
  - The supports are significantly moving laterally
  - 4kN peak centre load induces support friction GT
  - GT Support friction induces additional moment
  - Estimate 4000*0.1*0.075=30Nm at peak load
- Absence of friction reduces GTR knee moment



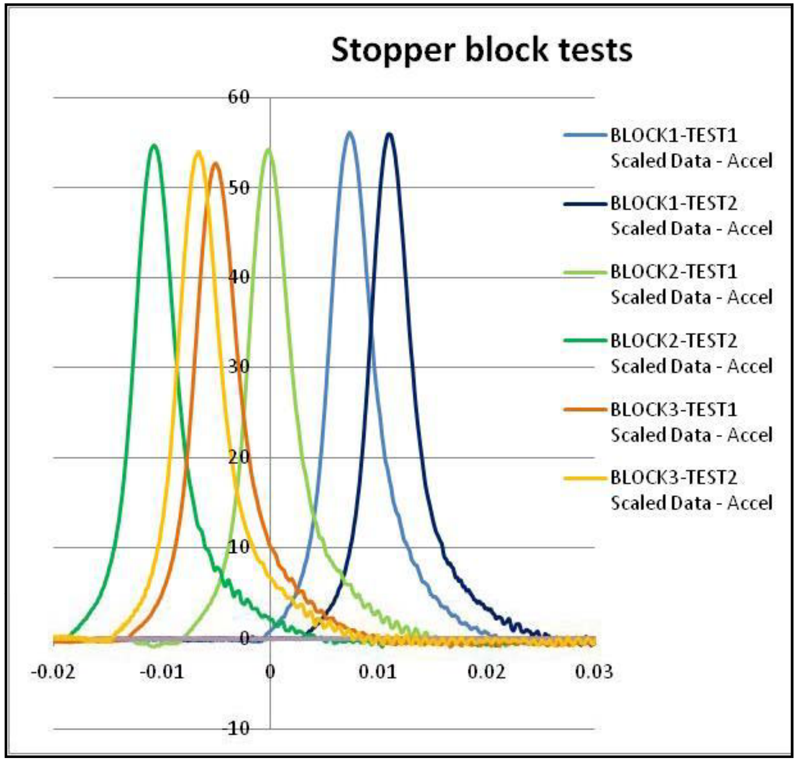






Dynamic stopper block test

- Drop test 200mm, 2m/s
- Drop mass 7.00kg steel bar, Ø50mm, rounded edge
- Record drop mass acceleration
- Stopper block as used in dynamic calibration test
  - 3 layers of Chloroprene rubber, 2 layers of Neoprene



block #1	56.2
	55.8
block #2	54.5
	54.2
block #3	52.7
	54.0
Average	54.6
St.Dev.	1.2
CV [%]	2.1

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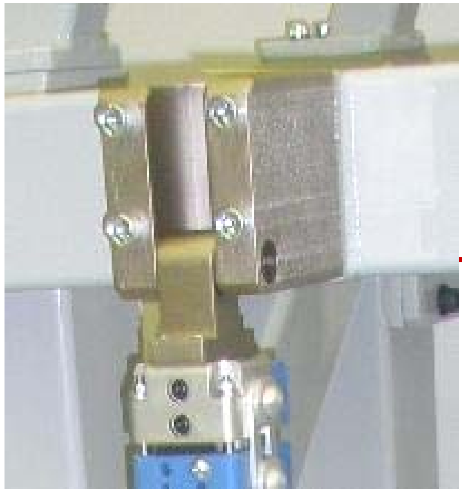
FLEX-PLI-GTR dynamic calibration set-up



Disassembly for transport

Top bar and release mechanism

Top pivot minimum play

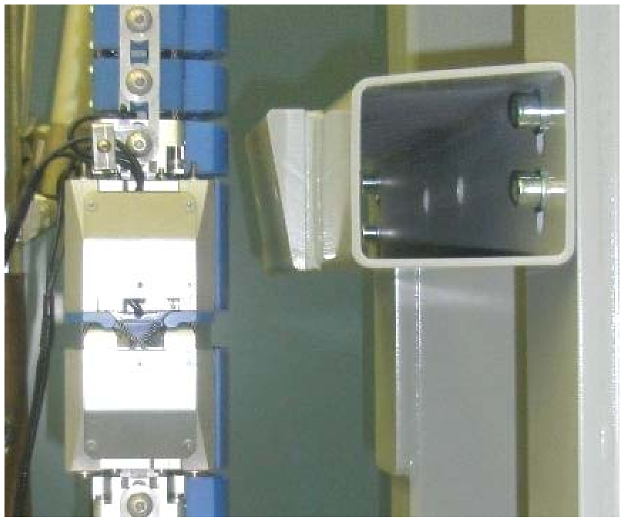
Accurate shoulder bolt

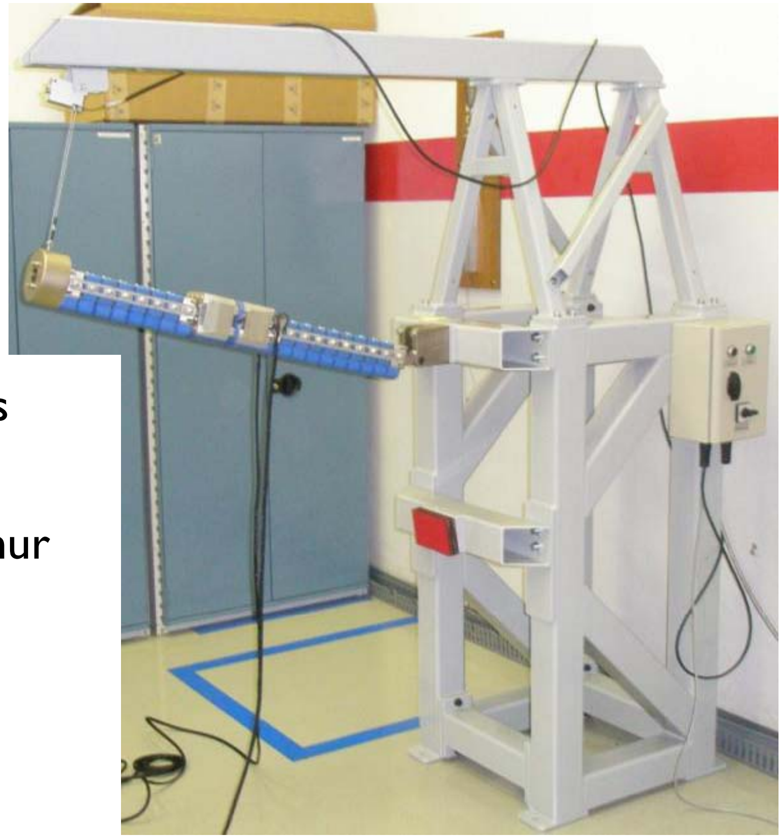
Tibia top pivot

Hinged brackets off board cables

10 deg inclined stopper bar

5kg calibration mass bottom femur





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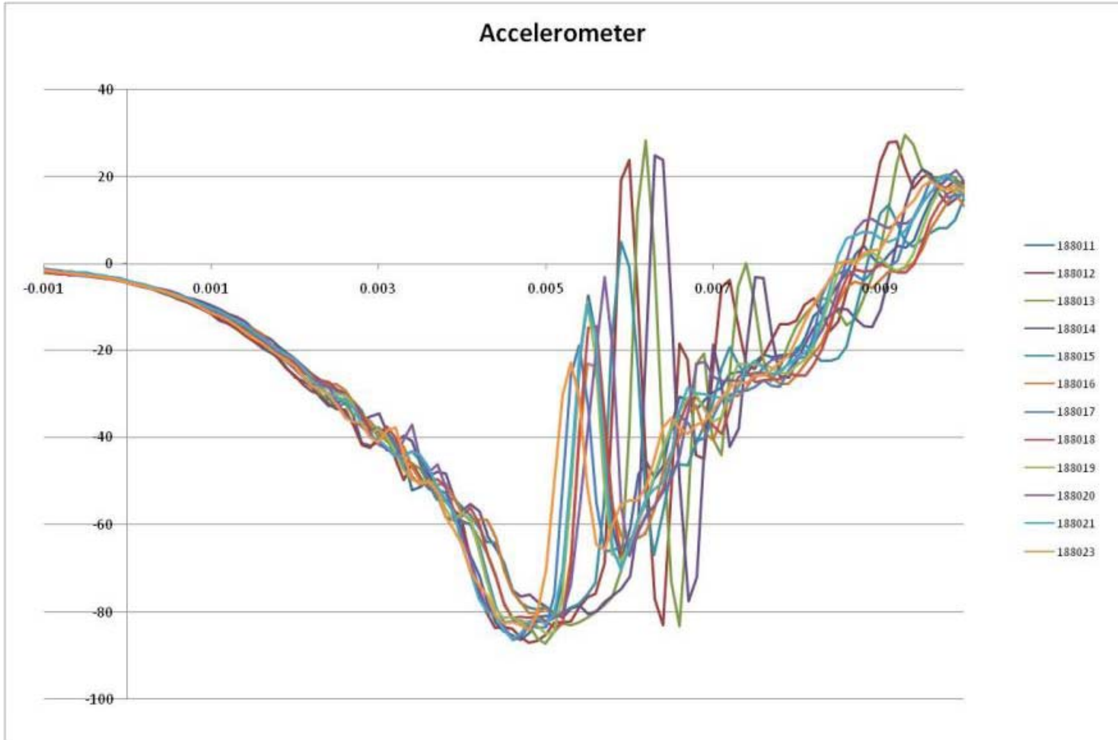
FLEX-PLI-GTR dynamic calibration

188011.02	TEST #1 on Leg assemble #1
188012.02	TEST #2 on Leg assemble #1
188013.02	TEST #3 on Leg assemble #1, stopper block #1
188014.02	TEST #4 on Leg assemble #1, stopper block #2
188015.02	TEST #1 on Leg assemble #2, stopper block #2
188016.02	TEST #2 on Leg assemble #2, stopper block #1
188017.02	TEST #3 on Leg assemble #2, stopper block #2
188018.02	TEST #4 on Leg assemble #2, stopper block #1
188019.02	TEST #5 on Leg assemble #2, stopper block #1
188020.02	TEST #1 on Leg assemble #3, stopper block #1
188021.02	TEST #2 on Leg assemble #3, stopper block #2, (sol 2, 15.1 deg)
188023.02	TEST #4 on Leg assemble #3, stopper block #1, (sol 2, 15.1 deg)

Summary dynamic calibration

TEST #1 Leg #1	75.1	177	135	90	246	201	160	108	8.03	22.4	4.29	4.99
TEST #2 Leg #1	82.9	181	138	92	247	201	160	109	8.59	22.5	4.33	4.41
TEST #3 Leg #1, block #1	82.2	179	136	91	245	200	159	108	8.61	22.4	4.30	4.37
TEST #4 Leg #1, block #1	78.7	175	135	90	241	195	156	106	8.64	22.5	4.24	4.38
TEST #1 Leg #2, block #2	74.0	175	134	90	235	197	152	106	8.16	22.2	4.30	4.85
TEST #2 Leg #2, block #1	69.2	177	135	92	241	199	153	107	7.79	22.4	4.42	5.26
TEST #3 Leg #2, block #2	71.6	181	137	94	245	204	158	111	7.89	22.4	4.46	5.25
TEST #4 Leg #2, block #1	72.1	176	135	92	241	199	153	107	7.84	22.4	4.44	5.22
TEST #5 Leg #2, block #1	73.3	183	140	96	248	205	158	110	7.87	22.5	4.48	5.18
TEST #1 Leg #3, block #1	77.2	183	138	91	239	204	170	107	8.34	22.3	4.34	4.90
TEST #2 Leg #3, block #2	75.3	183	138	91	241	205	171	108	8.30	22.4	4.40	4.95
TEST #4 Leg #3, block #1	71.8	183	138	91	242	204	171	109	8.17	22.4	4.43	5.12
GTR Dynamic calibration results	Acceln. knee	Femur Gauge 1	Femur Gauge 2	Femur Gauge 3	Tibia Gauge 1	Tibia Gauge 2	Tibia Gauge 3	Tibia Gauge 4	Peak ACL	Peak MCL	Peak LCL	Peak PCL
Average	75.3	179.4	136.7	91.6	242.5	201.1	160.0	108.0	8.19	22.4	4.37	4.91
St.Dev	4.2	3.1	1.9	1.7	3.7	3.3	6.8	1.5	0.3	0.1	0.1	0.3
CV[%]	5.6	1.7	1.4	1.9	1.5	1.6	4.3	1.4	3.8	0.3	1.8	7.0
Criteria		300	300	300	300	300	300	300	11	20	20	11
St.Dev/ Criteria [%]		1.0	0.6	0.6	1.2	1.1	2.3	0.5	2.8	0.4	0.4	3.1

Knee accelerations



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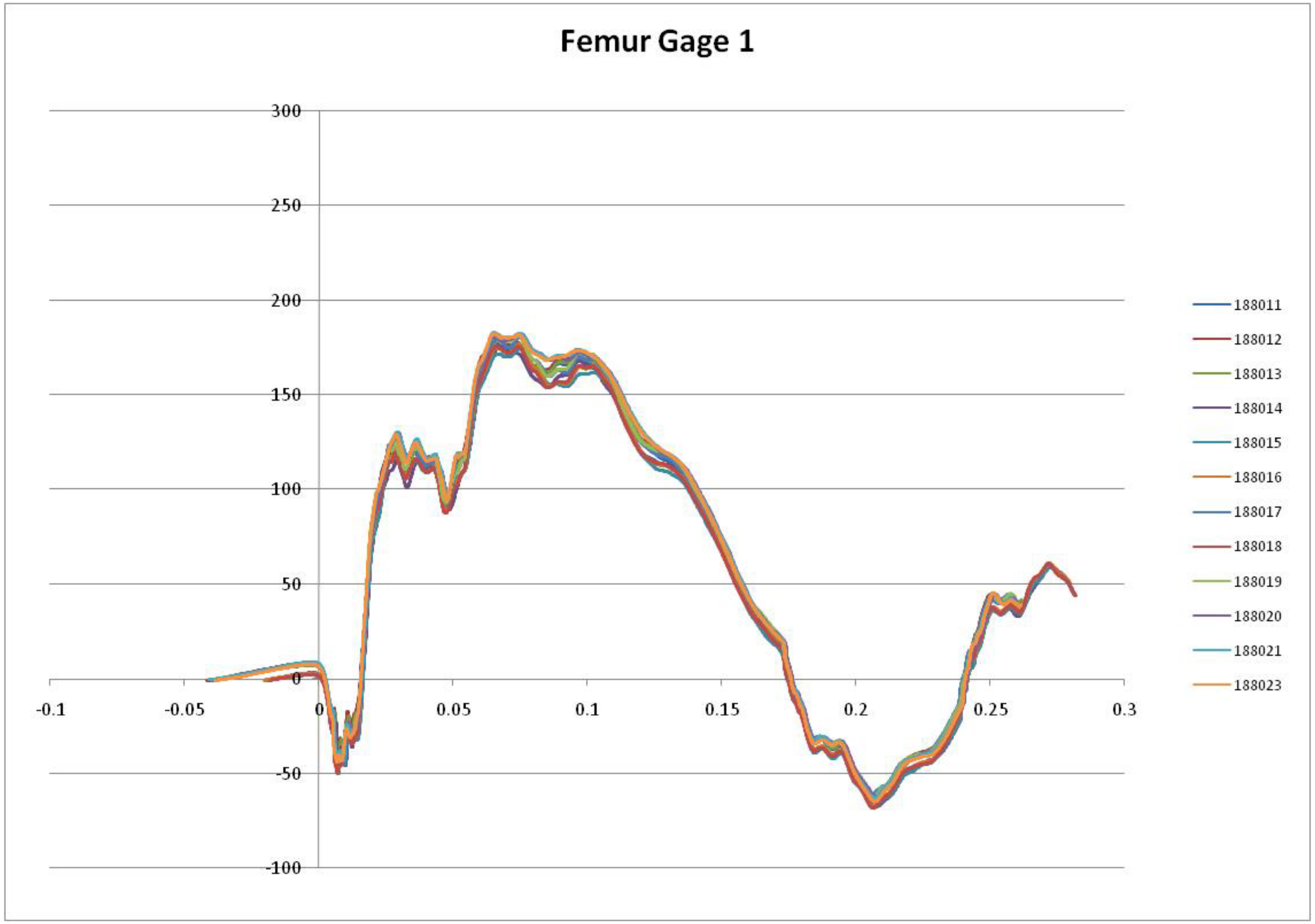
Femur moment 1



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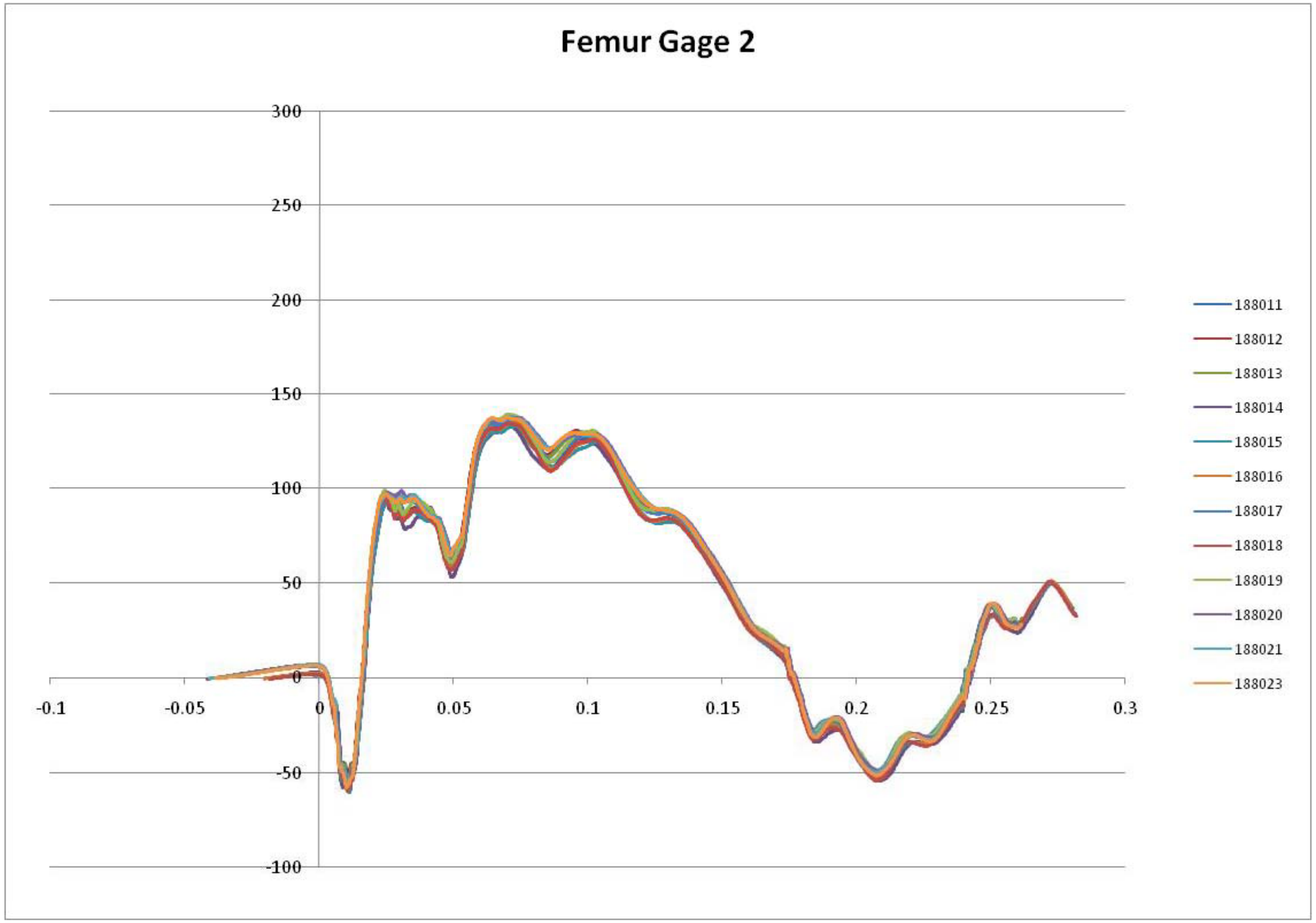
Femur moment 2



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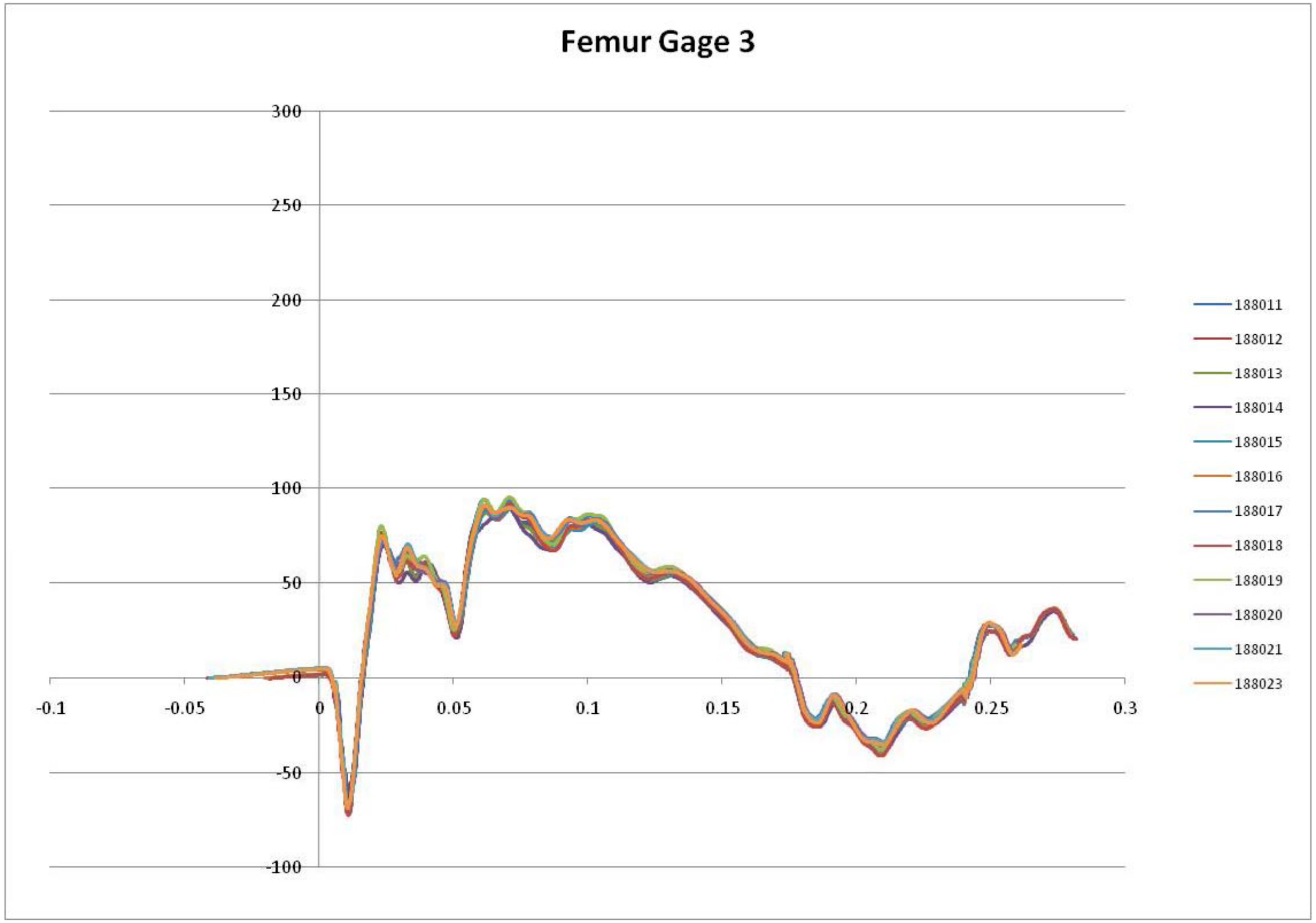
Femur moment 3



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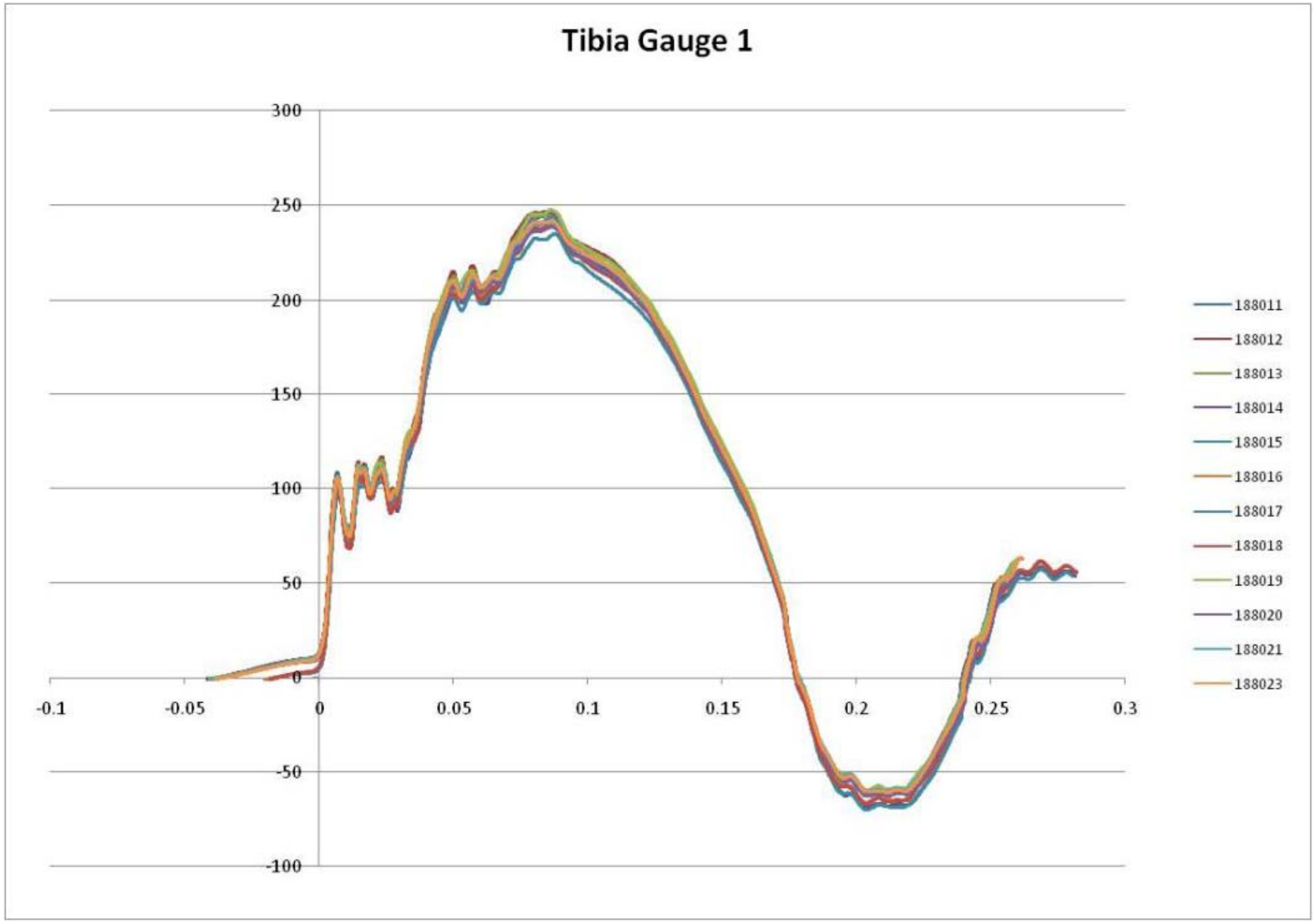
Tibia moment 1



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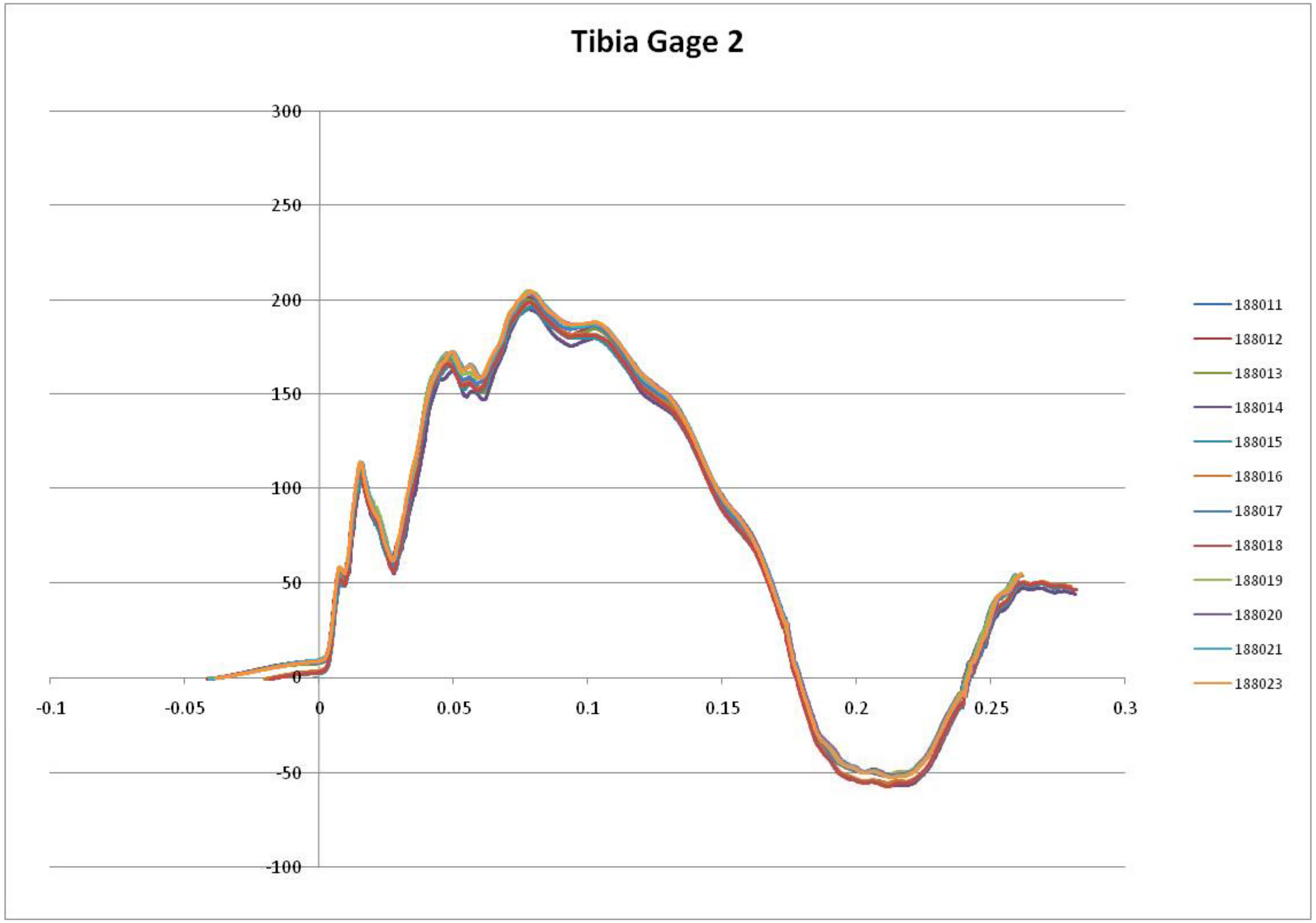
Tibia moment 2



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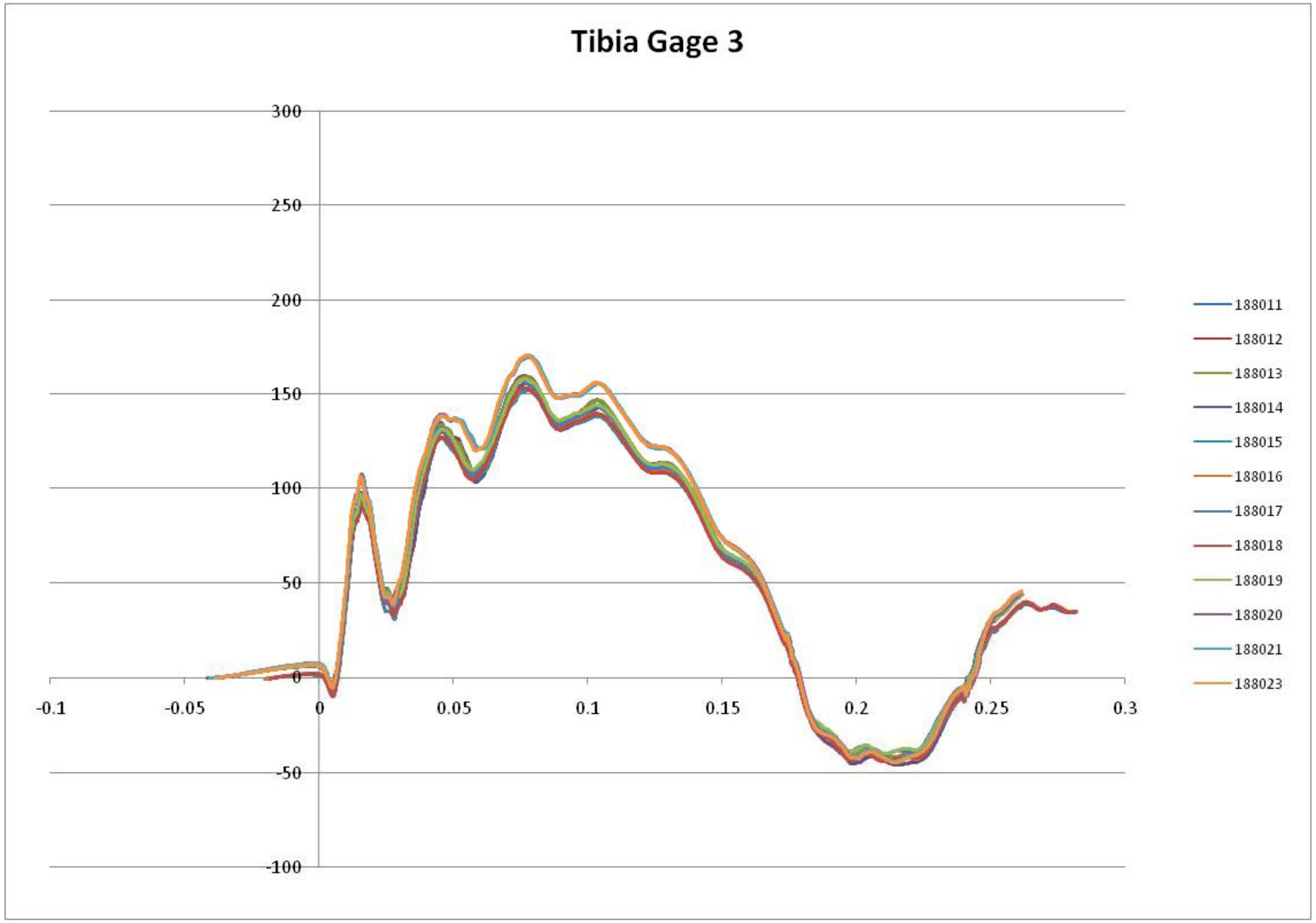
Tibia moment 3



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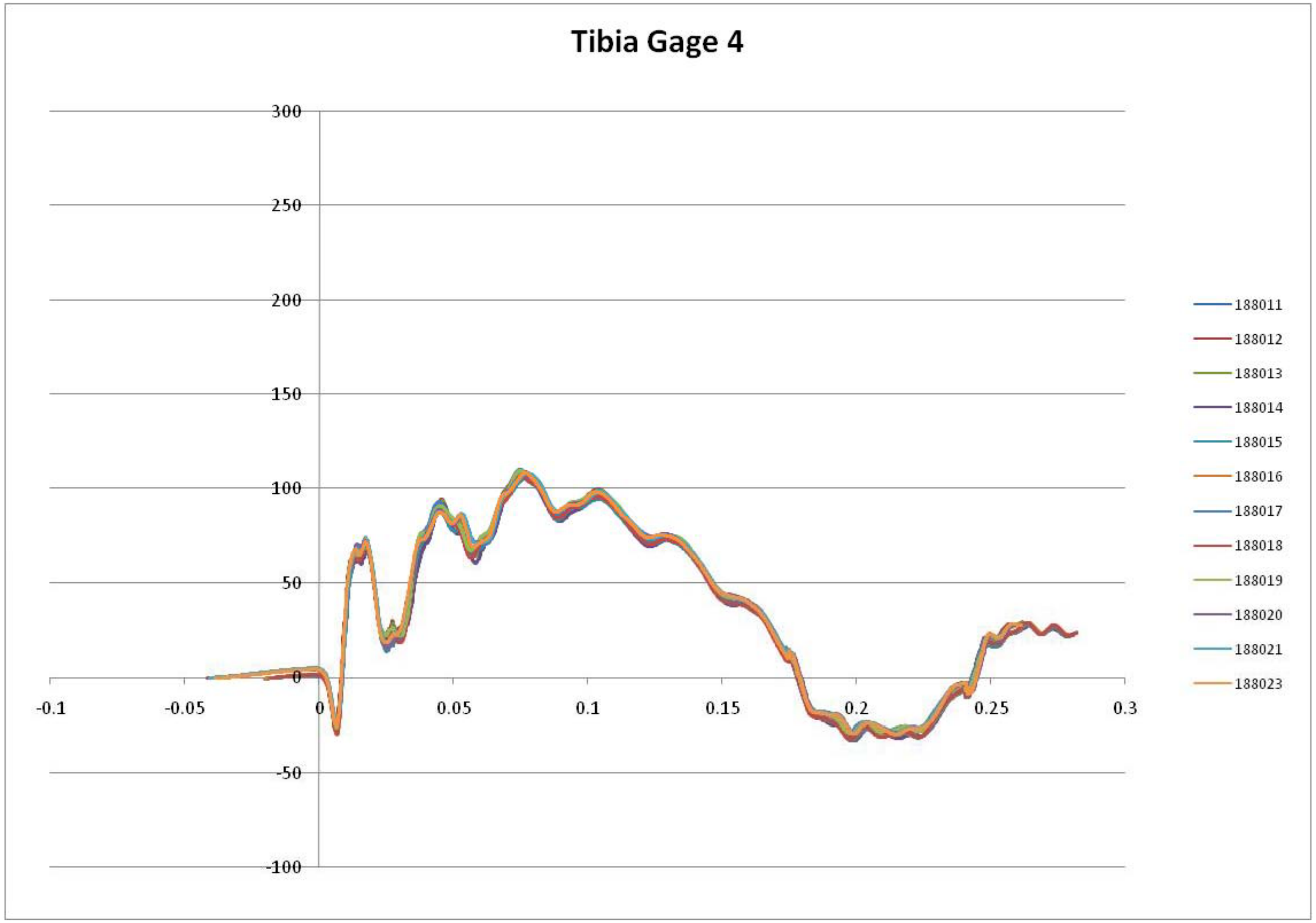
Tibia moment 4



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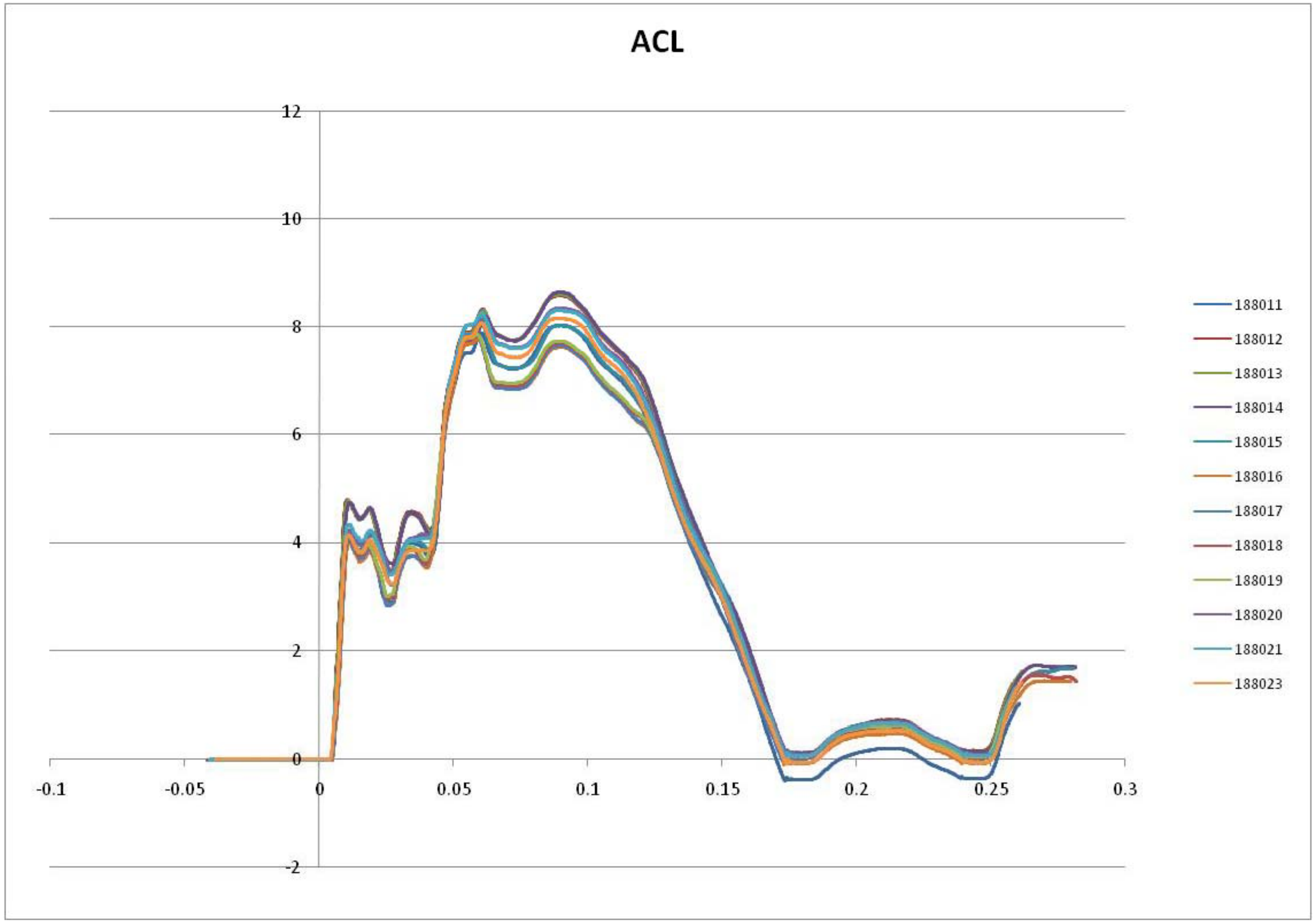
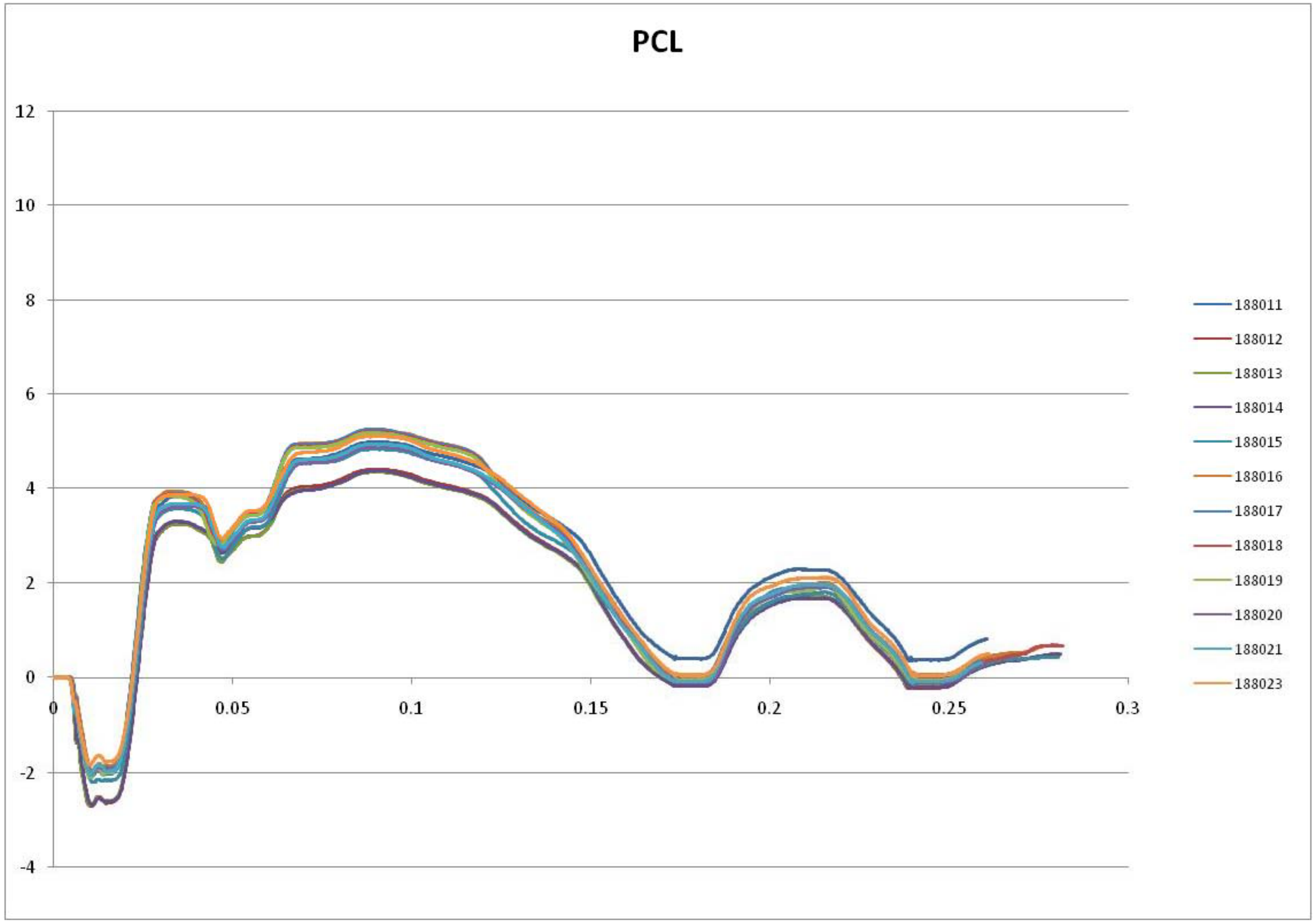
ACL elongation



PCL elongation



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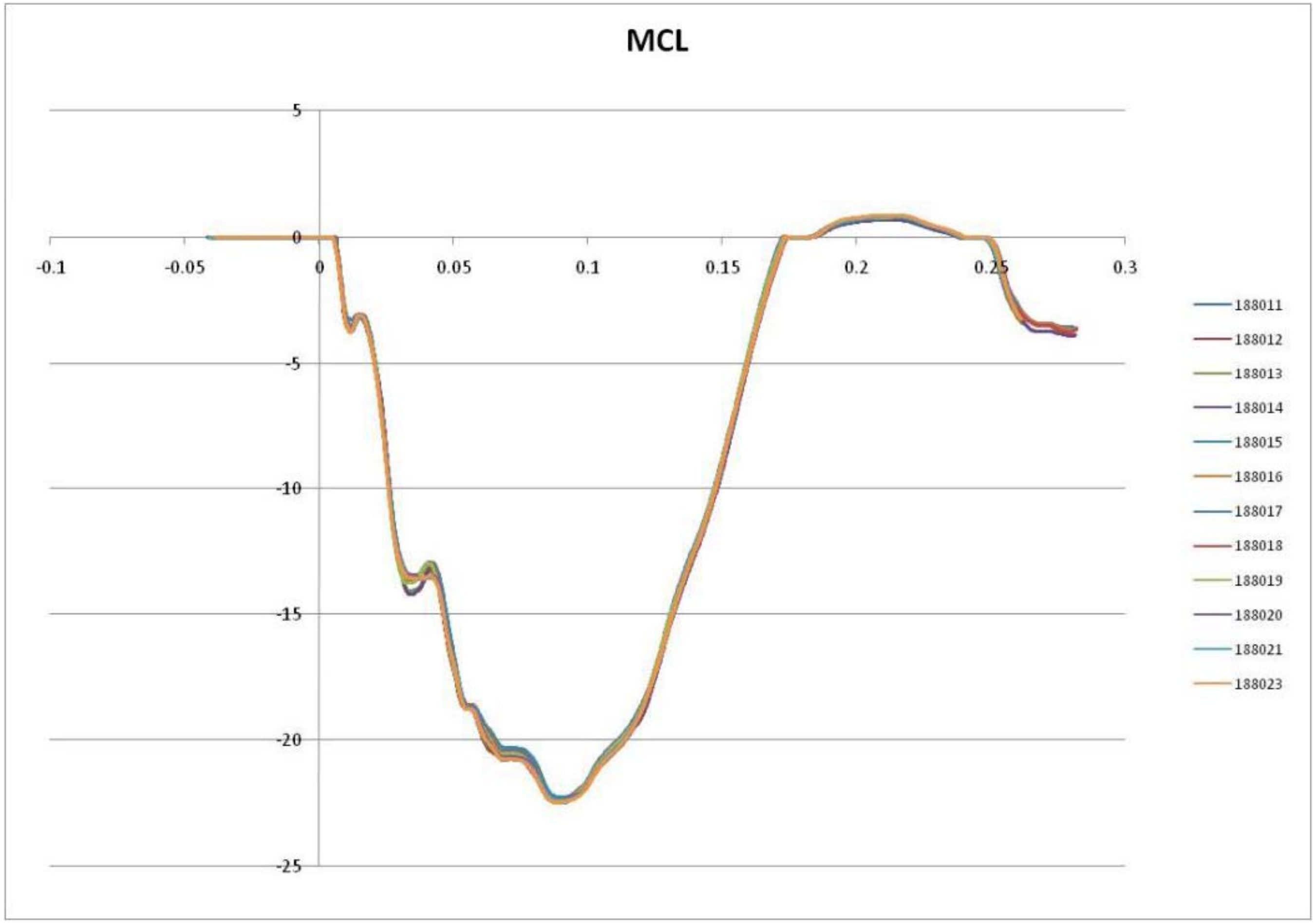
MCL elongation



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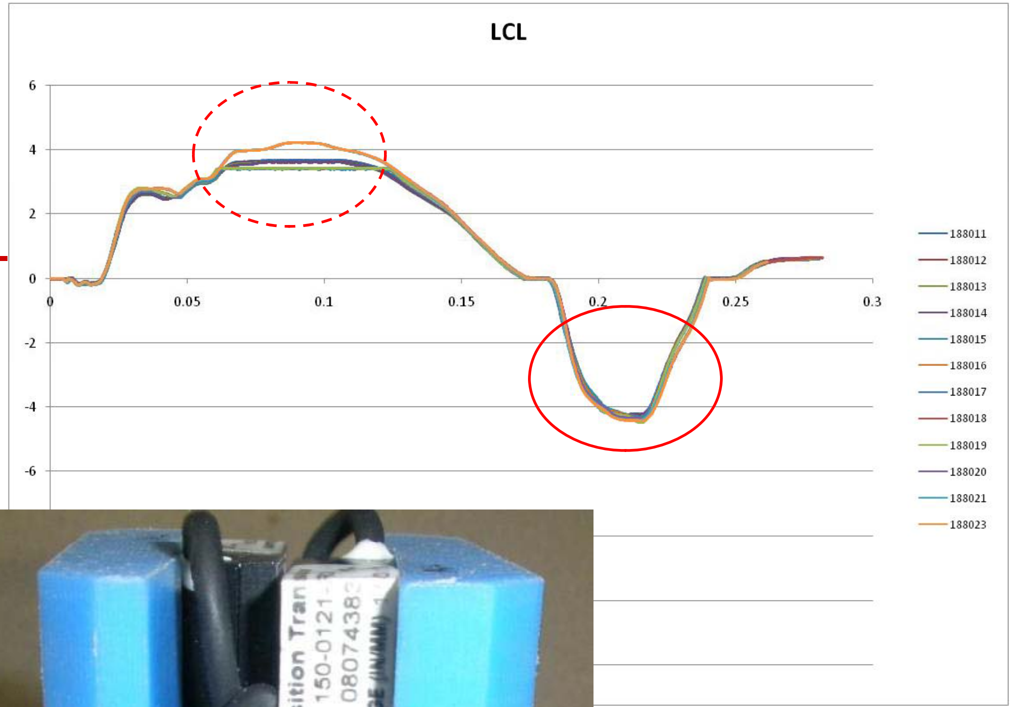
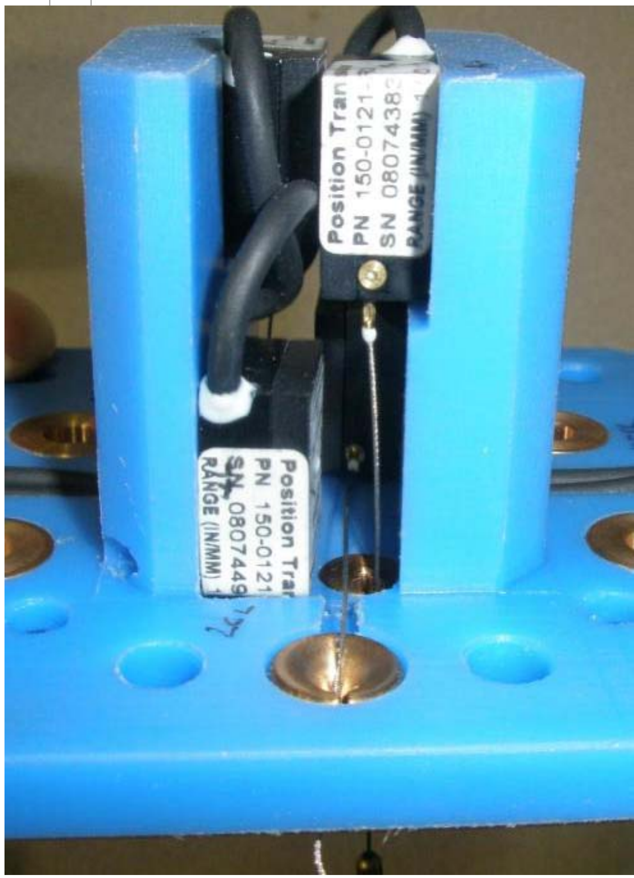
LCL elongation

- LCL ‘compresses’ (=shortening) during 1st peak of dynamic calibration
- LCL shortening is limited to about 3-4mm by the string potentiometer cable stop
- Used first rebound peak LCL
- Rebound LCL is more appropriate as we need to control for elongation





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On-board Data Acquisition System

- Onboard DAS in FLEX-PLI was initiated in GTR Development
- Cable damage frequently experienced with GT version
  - FLEX-PLI Tool is launched at 40km/h and in free flight for a short time
  - Due to elasticity in the system (FLEX-PLI bone, rubber skin, ligament springs and test object) the rebound after impact is very violent
  - Rebound trajectory and landing on floor is highly unpredictable
  - Damage of electrical cable to off-board DAS is very likely and frequently occurred
- Thicker – heavier cable affects free flight trajectory
  - The FLEX-PLI has a higher instrumentation count than TRL-PLI
  - 12 channels FLEX vs. 3 channel TRL
  - FLEX electrical cable consequently thicker and heavier
- Advantages On-Board DAS
  - Cable is disconnected at launch
  - No cable damage, all components and cables well protected inside
  - Stable free flight trajectory, not influenced by cable
  - Allows to hit target impact location most accurately
  - Least variability test results
  - Advantages operational costs

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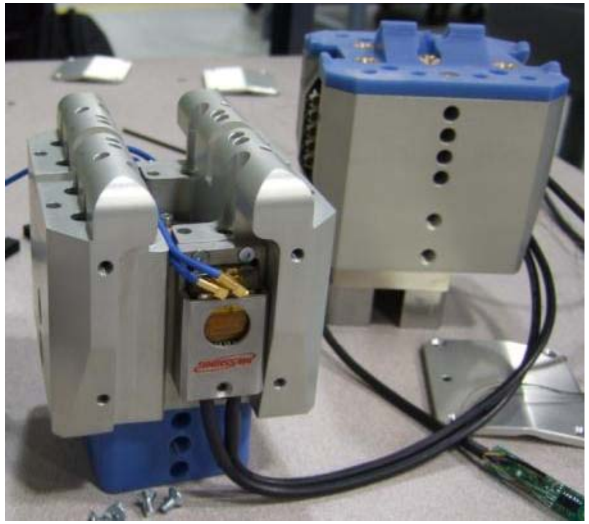
Integration of On-Board DAS systems

- FTSS recommends to offer FLEX-PLI with an on-board DAS system
- FTSS willing to work with any DAS manufacturer to integrate system requested by customer
  – DTS
  – Messring
  – KT
  – others
- FTSS will ensure fit and function and conformity to Regulation



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Mass comparison

Assembly mass [kg]	GT	GTR Off-board	GTR On-board M=BUS	GTR On-board Slice	GTR On-board
femur	2.432	2.426	2.426	2.450	2.426
knee	4.176	4.169	4.286	4.271	4.286
tibia	2.608	2.631	2.631	2.631	2.631
flesh	3.723	3.589	3.589	3.589	3.589
12 optional accels	-	-	-	-	0.33**
total	**12.94***	**12.82***	**12.93**	**12.94**	**13.26**
limits ±2%	13.20 12.68		13.19 12.67	13.20 12.68	

*Without off-board cable
**Estimate

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CAE Model Development

- FLEX-PLI-GTR Model Consortium Kick-off meeting has taken place on November 20th in Munich

- Project objective:
  - Release of high quality LS-DYNA, PAMCRASH, ABAQUS and RADIOSS models

- Consortium members:
  1. AUDI AG – Germany
  2. BMW AG - Germany
  3. DAIMLER AG – Germany
  4. Dr. Ing. h.c. F. PORSCHE – Germany
  5. FORD Werke GmbH – Germany
  6. GENERAL MOTORS Europe – Germany
  7. HONDA R&D Americas, Inc. - USA
  8. HYUNDAI Motor Europe TC GmbH – Germany
  9. JAGUAR LANDROVER - UK
  10. VOLKSWAGEN AG – Germany
  11. First Technology Safety Systems - USA

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CAE Model Development

- Chairman : Bastian Keding (Porsche) and Robert Kant (FTSS)
- Project tasks have been discussed and defined
  - The first model requirements are specified
  - The definition of the validation program is being kicked-off
- The models will be made available outside the consortium during the project through the standard FTSS distribution channels

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Further steps

- Update drawing package things learned from prototype build
- Explore ideas PCB with shunt resistors
- 3 sets of bones with new bone material
- Build 1 or 2 for demonstration and internal training purpose
- Build more GTR's at customer order
- Production planning

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Thanks!