Humanetics Innovative Solutions, Inc.

TF-RUCC FLEX PLI TASK FORCE PRESENTATION

Comments BASt/BGS

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Introduction

- Show results of Humanetic's Flex PLI Static Leg studies.
- Make recommendations from the data results and on protocols for leg testing.
- To agree build procedure for round robin leg set up

Long rubber verses short rubber effects on the Pendulum and Inverse test

- Short rubber flesh was discovered to be used when Inverse corridors were developed.
- Tests were carried out to compare the difference.
  - The Long and Short rubber had more affect on the Inverse than the Pendulum tests.
  - The short rubber Tibia Inverse moments increase 3 – 6.4 Nm. The Pendulum short rubber Tibia moments increase .5 to 1.3Nm.
  - Very little effect on MCL, PCL and ACL

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Comment BASt/BGS:
The inverse corridors were established using test results from impactors with both, short as well as long rubber sheets.

Comment BASt/BGS:
Using which impactors ?
When ?
Where ? Which test lab(s) ?

Comment BASt/BGS:
It is the intention that the inverse test being sensitive to changes / possible malfunctions.

Comment BASt/BGS:
This is no surprise. The inverse test provides more degrees of freedom because the impactor is completely released during the impact.
During the pendulum impact the tibia is fixed at two positions
➔ only limited movement possible.

Long rubber verses short rubber effects on the Inverse test

Three test were run on short and long Rubber. The difference is calculated from the average peaks

				Difference short to long rubber	% Difference from Mid Corridor
Pre Impact velocity	10.9	11.3	m/sec	0.0000	0.00%
Peak Moment @ T1	237	277	N-m	3.1300	1.13%
Peak Moment @ T2	223	269	N-m	5.0033	1.86%
Peak Moment @ T3	176	204	N-m	6.3733	3.12%
Peak Moment @ T4	98	120	N-m	5.8000	4.83%
Peak ACL Elongation	8.5	10.5	mm	0.4267	4.06%
Peak MCL Elongation	18	23	mm	0.2300	1.00%
Peak PCL Elongation	4.5	6	mm	0.0300	0.50%
Temperature	18	22	degC		
Humidity	10	70	%		

Comment BASt/BGS:
These are the corridors !
Where are the test results ? (peak loadings and time history curves are both needed for in depth investigation)
Which impactors have been used ? Where were the tests conducted ?
How were the impactors checked during the tests ?

Long rubber verses short rubber effects on the Pendulum test

Three test were run on short and long Rubber. The difference is calculated from the average peaks

				Difference short to long rubber	% Difference from Mid Corridor
Peak Moment @ T1	235	272	N-m	0.7400	0.27%
Peak Moment @ T2	185	211	N-m	0.5400	0.26%
Peak Moment @ T3	135	160	N-m	1.0667	0.67%
Peak Moment @ T4	94	108	N-m	1.2933	1.20%
Peak ACL Elongatio	9	11	mm	0.4367	3.97%
Peak MCL Elongatio	23	26	mm	0.2600	1.00%
Peak PCL Elongation	4	5.4	mm	0.1367	2.53%
Temperature	20.6	22.2	degC		
Humidty	10	70	%		

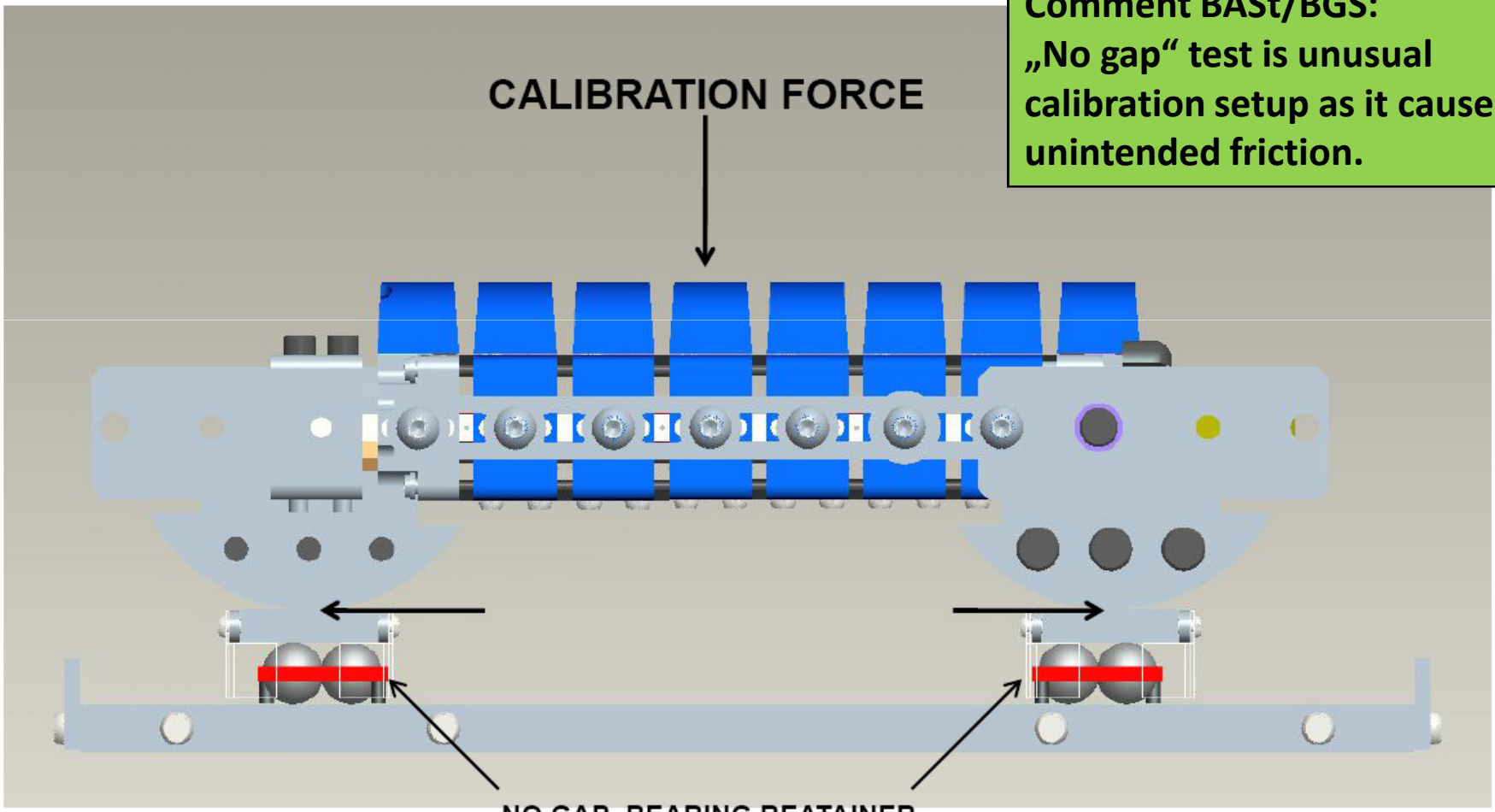
Comment BASt/BGS:
These are the corridors !
Where are the test results ? (peak loadings and time history curves are both needed for in depth investigation)
Which impactors have been used ? Where were the tests conducted ?
How were the impactors checked during the tests ?

PE sheet verses bearing assembly Summary

- No comparison was made between roller bearings and the original JARI test set up with PE sheet before being agreed with the TEG
- Humanetics conducted Quasistatic Tests on a FLEX-PLI tibia assembly in the following conditions:
  - Humanetics fixture with “NO GAP” between carriage and bearing retainer plate
  - Humanetics fixture with a “GAP” between the carriage and bearing retainer plate
  - JARI Polyethelyne Sheet
- The observed responses are as follows.
  - The Humanetics fixture causes more variability in the responses than the PE sheet. The PE sheet is at least 10 times more repeatable than the bearing with Gap or no Gap.
  - The PE sheet is much easier to control in production and less liable to error.
- A tibia static assembly was run with the PE sheet at 300Nm, 350Nm, and 400Nm. The repeatability for all three loads was under a 0.3%.

"NO GAP" BETWEEN BEARING RETAINER AND CARRIAGE SKIRT INSIDE WALL

Comment BASt/BGS:
„No gap" test is unusual calibration setup as it causes unintended friction.



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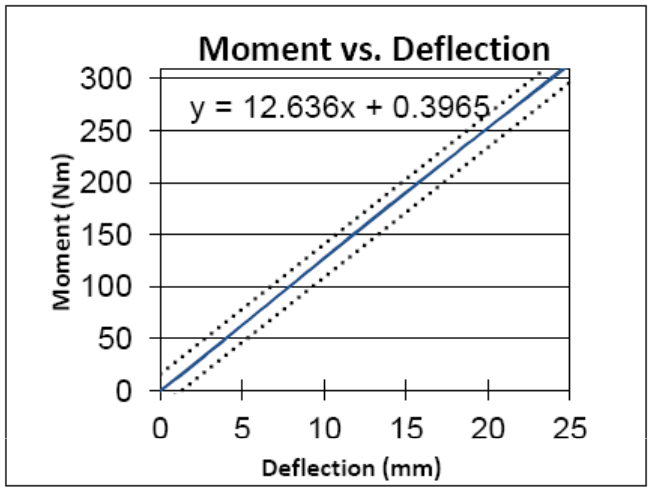
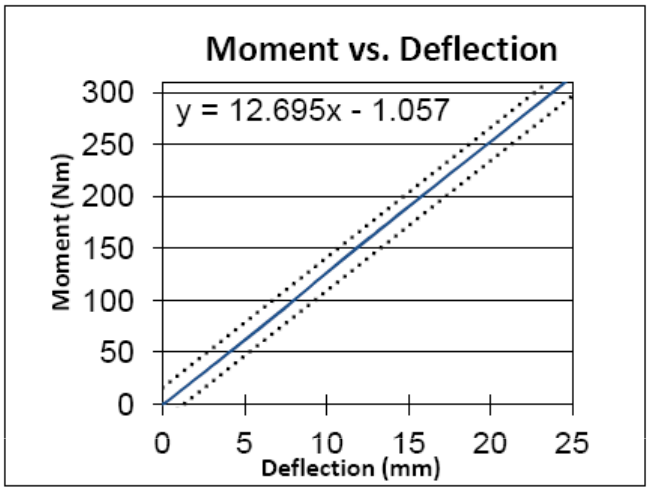
"NO GAP" CONDITION-CARRIAGE SKIRT CONTACTING BEARING RETAINER

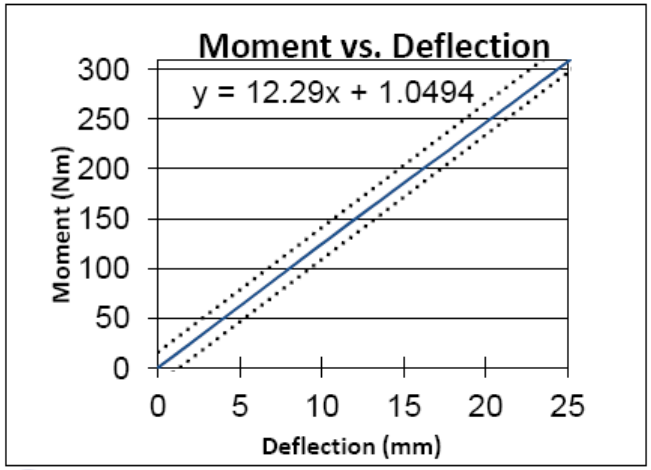
TEST 1



TEST 2



TEST 3



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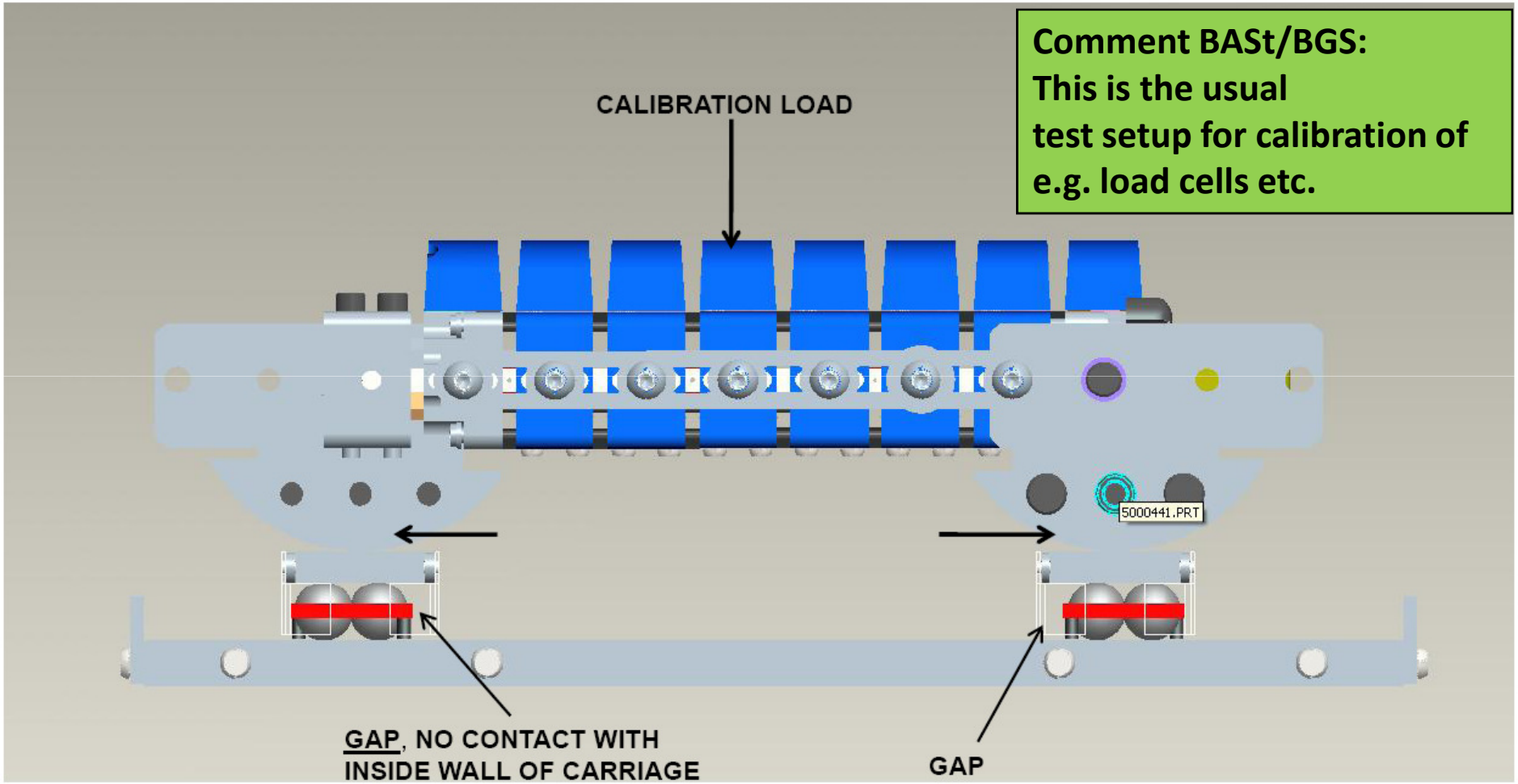
"GAP" BETWEEN BEARING RETAINER AND INSIDE CARRIAGE SKIRT WALL



Comment BASt/BGS:
This is the usual test setup for calibration of e.g. load cells etc.

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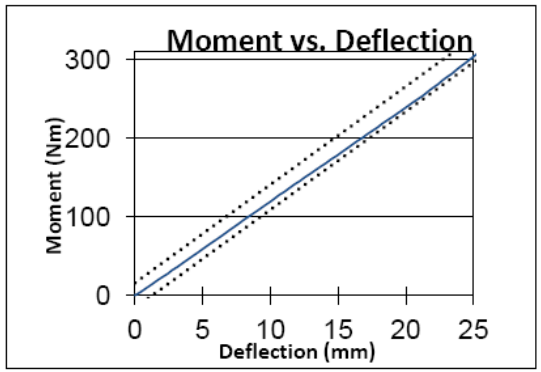
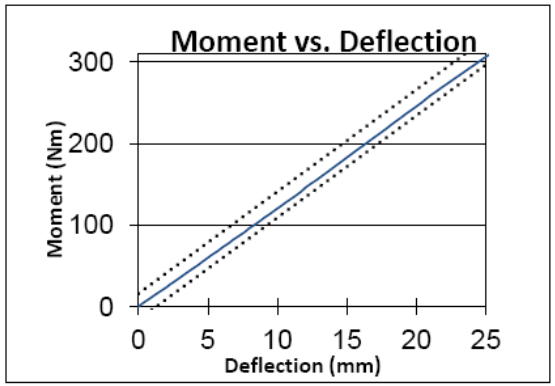
Gap Condition-Carriage NOT Contacting Bearing Retainer

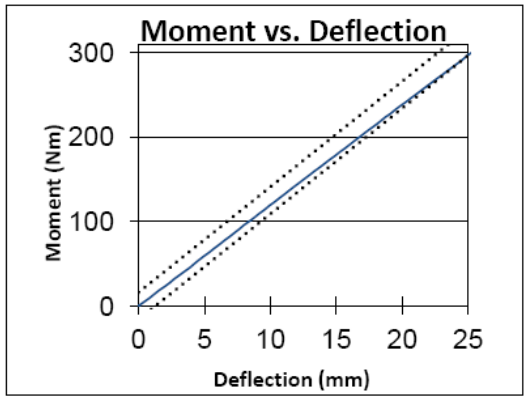
TEST 1



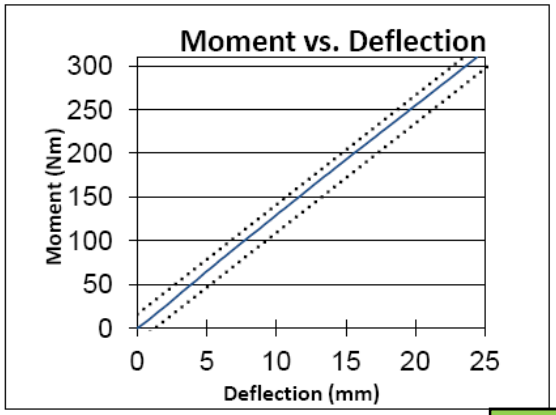
TEST 2



TEST 3



TEST 4 comparison no gap



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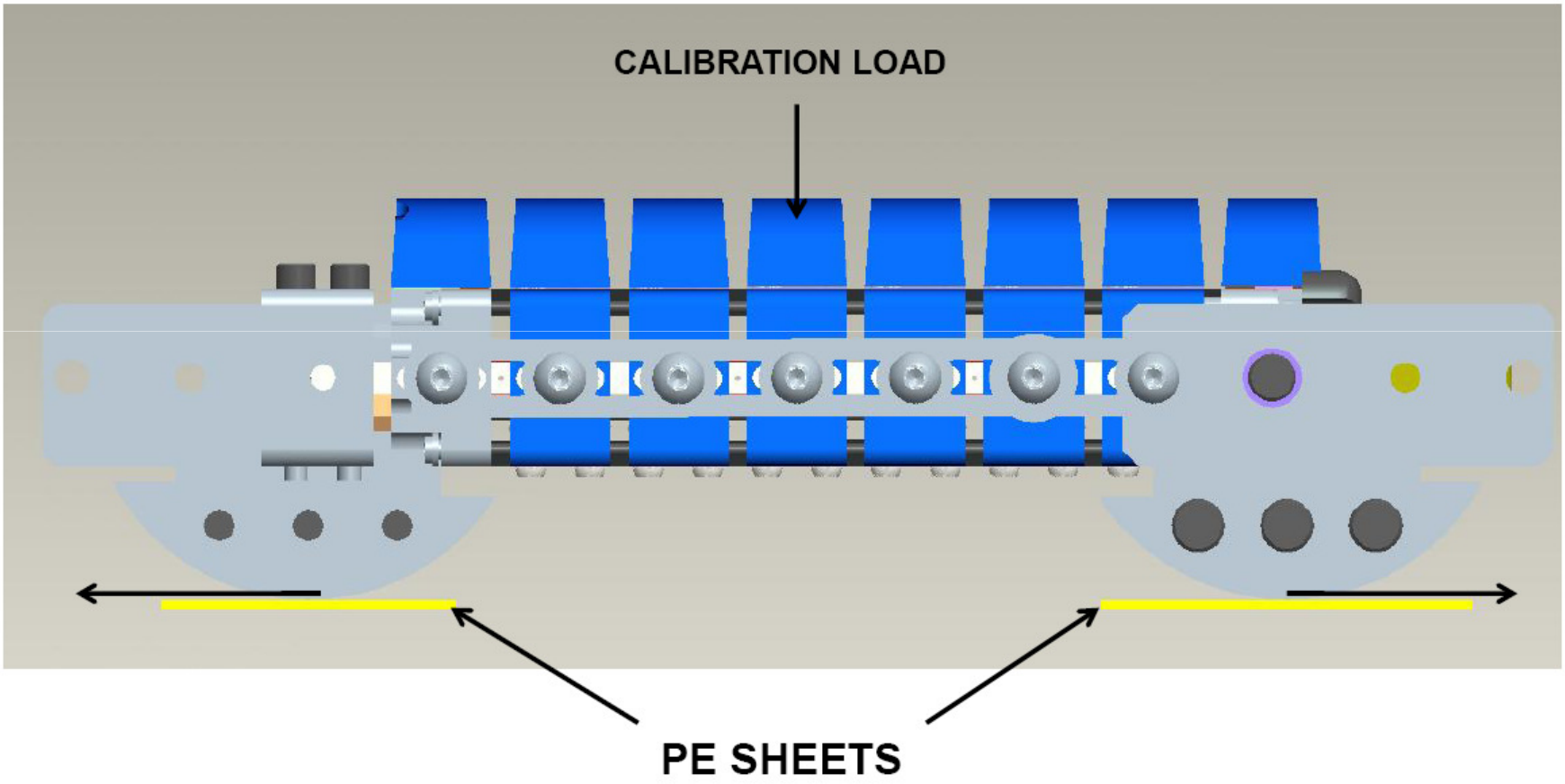
TEST 4: **NO GAP**; SHIFTS CURVE TOWARD UP IN CORRIDOR

Comment BASt/BGS:
Of course !
„No gap“ test setup causes unintended friction !

POLYETHYLENE SHEETS



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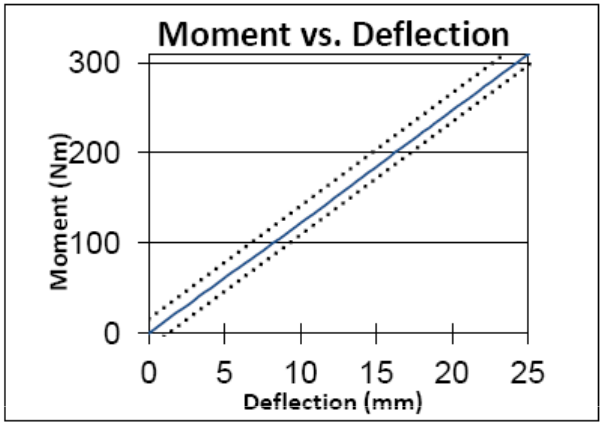
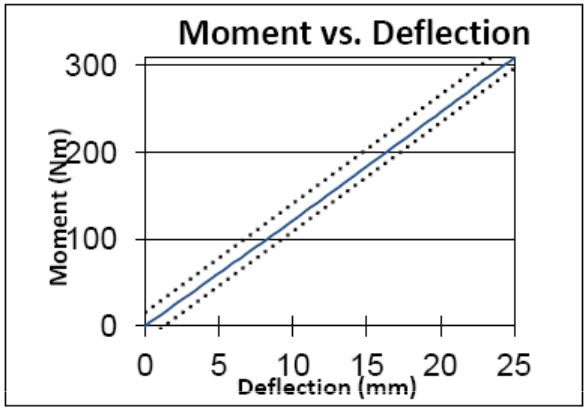
Polyethylene Sheet

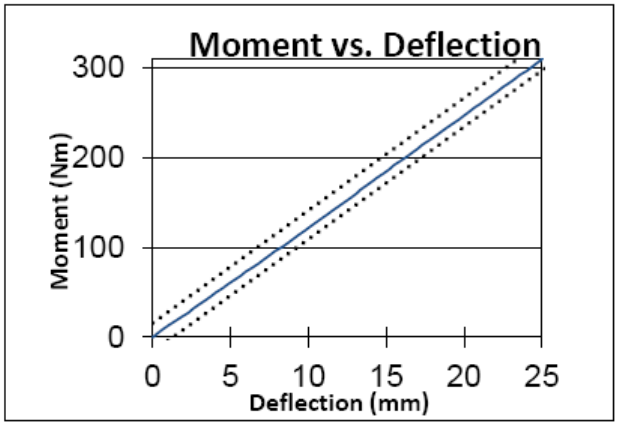
TEST 1



TEST 2



TEST 3



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Repeatability PE Sheet, Bearings Gap, Bearing no Gap

Bone snDH5239 B2 Bone PE sheet

	Test 1 (mV/V)	Test 2 (mV/V)	Test 3 (mV/V)
	13-Dec-11	13-Dec-11	13-Dec-11
Tibia G1	2.8252	2.8121	2.8088
Tibia G2	6.8432	6.833	6.8255
Tibia G3	8.8224	8.8069	8.8
Tibia G4	4.8693	4.8613	4.855

Max	Min	STDEV	AVERAGE	REPEATABLITY
2.8252	2.8088	0.0087	2.8154	0.31%
6.8432	6.8255	0.0089	6.8339	0.13%
8.8224	8.8000	0.0115	8.8098	0.13%
4.8693	4.8550	0.0072	4.8619	0.15%

Bone snDH5239 B2 bone No Gap

	Test 1 (mV/V)	Test 2 (mV/V)	Test 3(mV/V)	Test 4 (mV/V) *
	13-Dec-11	13-Dec-11	13-Dec-11	13-Dec-11
Tibia G1	2.6091	2.639	2.9735	2.6146
Tibia G2	6.6423	6.6836	6.8648	6.6508
Tibia G3	8.626	8.6711	8.8616	8.6734
Tibia G4	4.6629	4.6815	4.7924	4.6865

Max	Min	STDEV	AVERAGE	REPEATABILITY
2.9735	2.6091	0.1768	2.7091	6.53%
6.8648	6.6423	0.1045	6.7104	1.56%
8.8616	8.6260	0.1047	8.7080	1.20%
4.7924	4.6629	0.0586	4.7058	1.25%

* Test 4 was performed with a gap

Bone snDH5239 B2 bone With Gap

	Test 1 (mV/V)	Test 2 (mV/V)	Test 3 (mV/V)
	13-Dec-11	13-Dec-11	13-Dec-11
Tibia G1	2.993	2.7031	3.0612
Tibia G2	6.9039	6.8685	7.0549
Tibia G3	8.8937	8.8659	9.0449
Tibia G4	4.8508	5.0088	5.1084

Max	Min	STDEV	AVERAGE	REPEATABILITY
3.0612	2.7031	0.1901	2.9191	6.51%
7.0549	6.8685	0.0990	6.9424	1.43%
9.0449	8.8659	0.0963	8.9348	1.08%
5.1084	4.8508	0.1299	4.9893	2.60%

Comment BASt/BGS:
Test more sensitive
- **no friction**
- **higher degree of freedom**
- **higher influence of long bone properties**
- **higher values**
- **better assessment**

Conclusion:
- **Higher repeatability of „PE test“ no argument for type of test to choose**
- **Quite the contrary: PE test and „no gap“ test not sensitive enough**

➔ **„With gap“ test needed as calibration test !**

Repeatability PE Sheet testing 310, 350, & 400Nm

Bone snDH5255 B4 Bone PE sheet 310Nm

	Test 1 (mV/V)	Test 2 (mV/V)	Test 3 (mV/V)			
	1/17/2012	1/17/2012	1/17/2012	STDEV	AVERAGE	REPEATABLITY
Tibia G1	2.6867	2.6949	2.6982	0.0059	2.6933	0.220%
Tibia G2	6.4230	6.4312	6.4299	0.0044	6.4280	0.069%
Tibia G3	8.2923	8.3078	8.3073	0.0088	8.3025	0.106%
Tibia G4	4.5694	4.5785	4.5790	0.0054	4.5756	0.118%
					AVERAGE	0.128%

Bone snDH5255 B4 Bone PE sheet 350Nm

	Test 1 (mV/V)	Test 2 (mV/V)	Test 3 (mV/V)			
	1/17/2012	1/17/2012	1/17/2012	STDEV	AVERAGE	REPEATABLITY
Tibia G1	3.0350	3.0488	3.0492	0.0081	3.0443	0.266%
Tibia G2	7.2428	7.2578	7.2584	0.0088	7.2530	0.122%
Tibia G3	9.3581	9.3729	9.3728	0.0085	9.3679	0.091%
Tibia G4	5.1602	5.1741	5.1739	0.0080	5.1694	0.154%
					AVERAGE	0.158%

Bone snDH5255 B4 Bone PE sheet 400Nm

	Test 1 (mV/V)	Test 2 (mV/V)	Test 3 (mV/V)			
	1/17/2012	1/17/2012	1/17/2012	STDEV	AVERAGE	REPEATABLITY
Tibia G1	3.4662	3.4561	3.4627	0.0051	3.4617	0.148%
Tibia G2	8.2435	8.2300	8.2442	0.0080	8.2392	0.097%
Tibia G3	10.6432	10.6330	10.6452	0.0065	10.6405	0.061%
Tibia G4	5.8755	5.8633	5.8731	0.0065	5.8706	0.110%
					AVERAGE	0.104%

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Comment BASt/BGS:

- **Please show this comparison using the „with gap“ testing method,**
- **The „with gap“ testing method is the most sensitive one and should be kept on being used.**

Bone sensitivity tests at 310Nm, 360Nm, and 400Nm

- Gage Sensitivities were calculated at 325Nm, 360Nm, and 400Nm for Tibia Bridge#3 for 4 separate bones.
- The greatest change in Nm due to the Sensitivities at 325Nm, 360Nm, and 400Nm is less than 1 Nm over all four bones.

Comment BASt/BGS:
No ! The difference is much higher (see slide no. 20)

BONE SN5255 SENSITIVITY

FLEX PLI BONE SENSITIVITY REPEATILIBILITY TEST

Test Bone DH5255			SENSITIVITY	SENSITIVITY	SENSITIVITY
Load	Output	SENSITIVIITY	325 Nm	360Nm	400Nm
325.0	-9.847	-0.03030	AVG	AVG	AVG
360.0	-10.936	-0.03038	-0.03030	-0.03036	-0.03029
325.0	-9.851	-0.03031			
360.0	-10.929	-0.03036	% DIFFERENCE	% DIFFERENCE	% DIFFERENCE
400.0	-12.111	-0.03029	325 to 360Nm	325 to 400Nm	360 to 400Nm
360.0	-10.925	-0.03035	0.00218	0.00028	0.00247
325.0	-9.846	-0.03030			
360.0	-10.934	-0.03037	STDEV	STDEV	STDEV
400.0	-12.118	-0.03030	0.000008	0.000010	0.000010
360.0	-10.934	-0.03037			
325.0	-9.846	-0.03030	REPEATILBILITY	REPEATILBILITY	REPEATILBILITY
360.0	-10.929	-0.03036	-0.027%	0.032%	-0.034%
400.0	-12.118	-0.03029			
360.0	-10.930	-0.03036			
325.0	-9.844	-0.03029			

DIFFERENCE BECAUSE SENSITIVITY LOAD CHANGE IN Nm AT MID CORRIDOR

T1	0.6337	T2	0.6066
T3	0.4685	T4	0.2688

Comment BASt/BGS: Please insert units

***Sensitivities are calculated at 325Nm, 360Nm, and 400Nm for Tibia Bridge#3.**

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BONE SN5239 SENSITIVITY

FLEX PLI BONE SENSITIVITY REPEATILIBILITY TEST

Test Bone DH5239

Load	Output	SENSITIVIITY
325.0	-10.466	-0.03221
360.0	-11.619	-0.03228
400.0	-12.856	-0.03214
360.0	-11.618	-0.03227
325.0	-10.474	-0.03223
360.0	-11.617	-0.03227
400.0	-12.844	-0.03211
360.0	-11.620	-0.03228
325.0	-10.466	-0.03220
360.0	-11.616	-0.03227
400.0	-12.856	-0.03214
360.0	-11.606	-0.03224
325.0	-10.469	-0.03221

SENSITIVITY 325 Nm	SENSITIVITY 360Nm	SENSITIVITY 400Nm
AVG	AVG	AVG
-0.03221	-0.03227	-0.03213
% DIFFERENCE 325 to 360Nm	% DIFFERENCE 325 to 400Nm	% DIFFERENCE 360 to 400Nm
0.00168	0.00258	0.00426
STDEV	STDEV	STDEV
0.000010	0.000015	0.000017
REPEATILBILITY	REPEATILBILITY	REPEATILBILITY
-0.032%	-0.046%	-0.053%

DIFFERENCE BECAUSE SENSITIVITY LOAD CHANGE IN Nm AT MID CORRIDOR

T1	0.6638	T2	0.6354
T3	0.4908	T4	0.2815

***Sensitivities are calculated at 325Nm, 360Nm, and 400Nm for Tibia Bridge#3.**

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Comment BASt/BGS:
Please insert units

BONE SN3490 SENSITIVITY

FLEX PLI BONE SENSITIVITY REPEATILIBILITY TEST

B4 Bone DI3490			SENSITIVITY	SENSITIVITY	SENSITIVITY
Load	Output	SENSITIVIITY	325 Nm	360Nm	400Nm
325.0	-9.862	-0.03035	AVG	AVG	AVG
360.0	-11.140	-0.03095	-0.03081	-0.03100	-0.03087
400.0	-12.339	-0.03085			
360.0	-11.158	-0.03099	% DIFFERENCE	% DIFFERENCE	% DIFFERENCE
325.0	-10.065	-0.03097	325 to 360Nm	325 to 400Nm	360 to 400Nm
360.0	-11.161	-0.03100	0.61%	-0.20%	0.41%
400.0	-12.350	-0.03088			
360.0	-11.168	-0.03102	STDEV	STDEV	STDEV
325.0	-10.062	-0.03096	0.000309	0.000027	0.000022
360.0	-11.165	-0.03101			
400.0	-12.356	-0.03089	REPEATILBILITY	REPEATILBILITY	REPEATILBILITY
360.0	-11.161	-0.03100	-1.002%	-0.087%	-0.071%
325.0	-10.062	-0.03096			

DIFFERENCE BECAUSE SENSITIVITY LOAD CHANGE IN Nm AT MID CORRIDOR

T1	0.5214	T2	0.4991
T3	0.3854	T4	0.2211

***Sensitivities are calculated at 325Nm, 360Nm, and 400Nm for Tibia Bridge#3.**

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BONE SN5239 SENSITIVITY

?

FLEX PLI BONE SENSITIVITY REPEATILIBILITY TEST

B3 Bone DH5242

Load	Output	SENSITIVIITY
325.0	-9.647	-0.02968
360.0	-10.992	-0.03053
400.0	-12.169	-0.03042
360.0	-11.000	-0.03056
325.0	-9.925	-0.03054
360.0	-11.015	-0.03060
400.0	-12.177	-0.03044
360.0	-11.010	-0.03058
325.0	-9.923	-0.03053
360.0	-11.012	-0.03059
400.0	-12.184	-0.03046
360.0	-11.009	-0.03058
325.0	-9.928	-0.03055

SENSITIVITY 325 Nm	SENSITIVITY 360Nm	SENSITIVITY 400Nm
AVG	AVG	AVG
-0.03033	-0.03057	-0.03044
% DIFFERENCE 325 to 360Nm	% DIFFERENCE 325 to 400Nm	% DIFFERENCE 360 to 400Nm
0.8[illegible]%	-0.38%	0.43%
STDEV	STDEV	STDEV
0.[illegible]00428	0.000024	0.000018
REPEATILBILITY	REPEATILBILITY	REPEATILBILITY
-1.411%	-0.[illegible]78%	-0.060%

DIFFERENCE BECAUSE SENSITIVITY LOAD CHANGE IN Nm AT MID CORRIDOR

T1	0.9748	T2	0.9331
T3	0.7207	T4	0.4134

***Sensitivities are calculated at 325Nm, 360Nm, and 400Nm for Tibia Bridge#3.**

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Comment BAS/BGS:
Relating these sensitivities to an output value of 300 Nm causes a difference of 9 Nm !

Round Robin test series Legs

- SN02, 03, Eng leg
- SN 01 from Ford (end of January)
- SN 05 (end of January)
- Ford U.S has offered to run round rob n testing on inverse only

Comment BASt/BGS:
These are by far the oldest impactors !
For performing comparative tests (and perhaps, if the results are promising, establishing new corridors later on) we need the latest, newest, unchanged, design-freezed and completely identical impactors with exactly identical design and parts !

Comment BASt/BGS:
We strongly recommend to NOT update SN02 !
SN02 is the last available reference tool that has been used for innumerable inverse and vehicle tests.
After the agreement on a final Flex-GTR design and the confirmation of a sufficient repeatability and reproducibility of test results there still will be a strong need for a comparison of test results obtained with the prototypes !

Round Robin Test Requirements Discussion

- Data to Record
- Inverse Test
  - Hexcell used
  - Velocity measurement system used
  - Record Impact location
  - Weight of probe
  - Describe system
    - Air, hydraulic
  - Pictures of set up
    - Preparation and post test
  - Movies, if possible
- Pendulum Test
  - Angle of drop
  - Weight of leg and additional mass
  - Confirm GTR rig dimension requirements

Comment BASt/BGS:
Why should the pendulum tests be less documented than the inverse ones ? For pendulum tests the set up pictures, movies, record of impact location etc. are required as well.

- Test Series
  - 5 Pendulum
  - 5 inverse test
  - Propose use onboard DAS, provide with each leg. This is how it is tested and gives more accurate result due to shorter cables.
  - Laptop/s can be provided with legs as option to run both DAS systems?
  - Which labs are willing to participate in RR testing?
  - Format for recording data?

Comment BASt/BGS:
As already indicated at the IG GTR9-PH2 meeting in Geneva, first of all we need:

<u>Step 0</u>

<u>In depth investigation of impactor repeatability</u>

- **2 impactors (latest built level)**
- **5 tests w/ each impactor**
- **tested at 2 labs – JARI and BASt (most experienced labs)**
- **2*5*2 = 20 tests in total**
- **identical honeycomb material**

If impactors prove to produce repeatable and reproducible results, a round robin test programme is to be developed, including more labs and impactors.

Proposed FLEX-PLI Round Robin Legs Receive and Build Structure

- Photograph contents of case on arrival.
- Document the serial numbers of all existing parts. Parts not being used for RR to be stored in dedicated box.
- Disassemble the knee, check condition of parts for wear or damage. Calibrate the GTR ligament strain pots. If any parts need replacement replace and add to dedicated box.
- Reassemble the knee. Adjust the spring so that washers are flush with knee block. Place knee calibration data, ligament calibration data and accelerometer calibration data in a folder and in its case.
- Fit onboard DAS and check and record weight and cg. Send to JARI for testing
- Prepare 6-10 sets of bone rigid corridor on JARI bone fixture
- Disassemble the tibia assembly. Place the original instrumented tibia bone in the returned parts box. Check condition of parts for wear or damage. Bag tibia parts and ship to JARI with new bones.

Proposed FLEX-PLI Round Robin Legs Receive and Build Structure continued

- JARI tests bones to check mid corridor stiffness
- JARI builds the tibia assembly as per manual instruction and calibrates. Assemblies then sent back to Humanetics.
- Humanetics rechecks component assembly and records tibia weight and cg on test rig
- Femur instruction to be as tibia above
- After parts have been calibrated assemble the leg as per manual instruction. Check and record leg total weight with flesh.
- Perform 5 dynamic pendulum tests.
- Perform 5 dynamic inverse tests
- After testing remove flesh from leg and box up so that it can be shipped to JARI

Tbd later

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Time Table

- January – February
  - Humanetics prepares 6 to 10 bone sets for JARI bone check and component testing including knee
  - Humanetics will need JARI bone fixture to confirm set up of bones in middle of corridor before sending.
- February –March
  - JARI checks bones are in the middle of the bone stiffness corridor, assemble and carry out component sub assemble test and set corridors as required.
- March-April
  - JARI sends component assemblies to Humanetics to retest and compare results
- April-June
  - Humanetics sends to JARI for dynamic testing. Start round robin. Humanetics and JARI analyze results and set corridors for agreement with Informal group

Tbd later

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CONCLUSIONS

- Propose use of PE sheet for static testing
- Propose gage sensitivity is calculated at 340 Nm to provide accurate result at injury threshold
- Send out revised manual for build and leg use

Comment BASt/BGS: „With gap test“ is needed as calibration test !

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