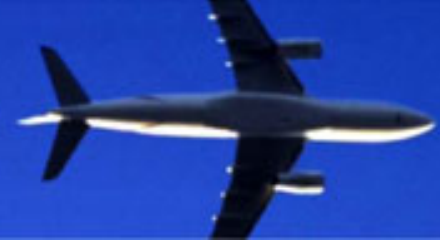




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Automation of Strain Gage Measurement on Full-Scale Aerospace Structures

Christoph Leser, Ph.D. & Dan Van Horn
MTS Systems Corporation

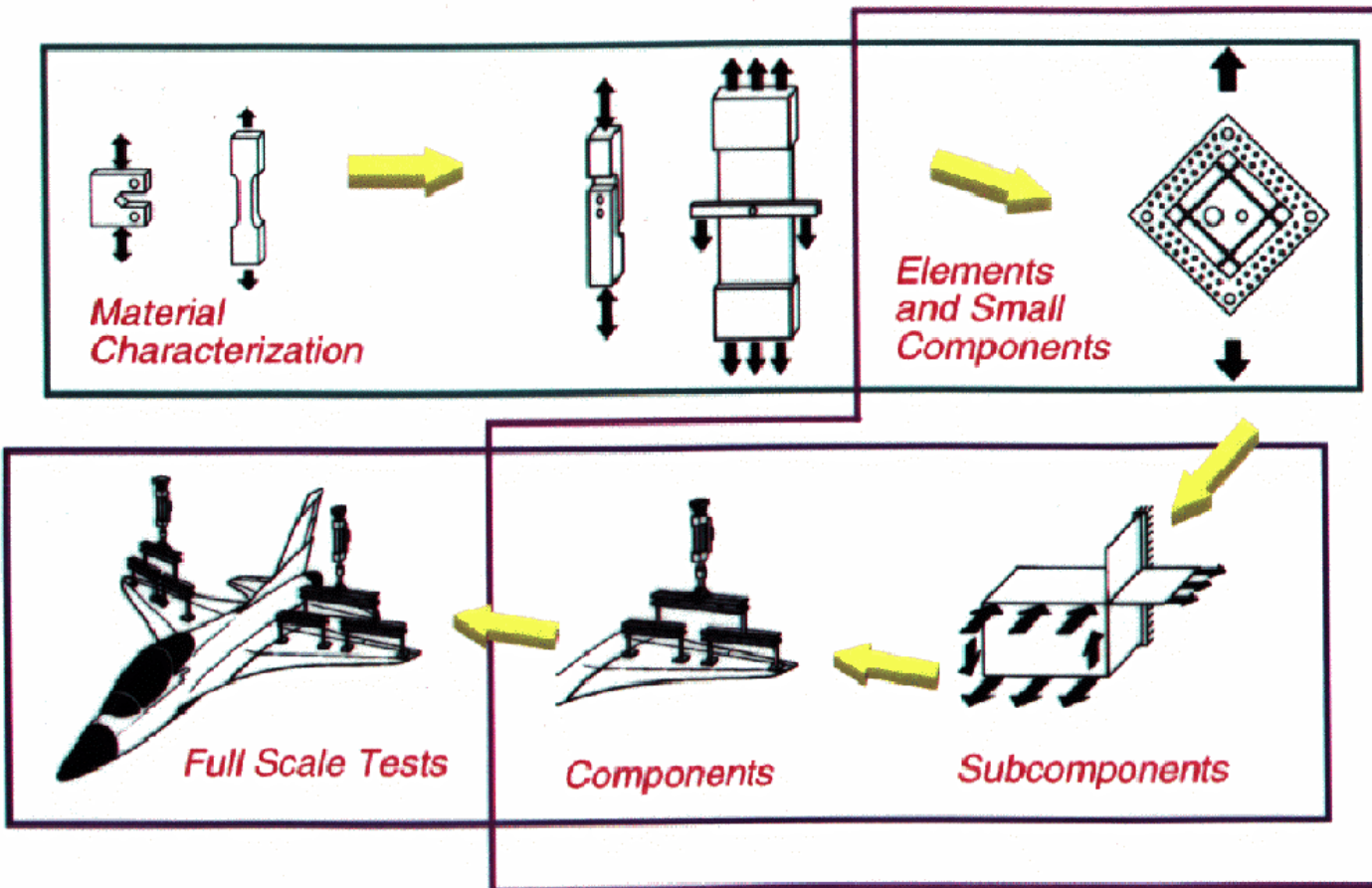
Aerospace Testing Expo, 2006
Hamburg, Germany
April 6, 2006



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System Development, from Material to Structure





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Full-Scale Test

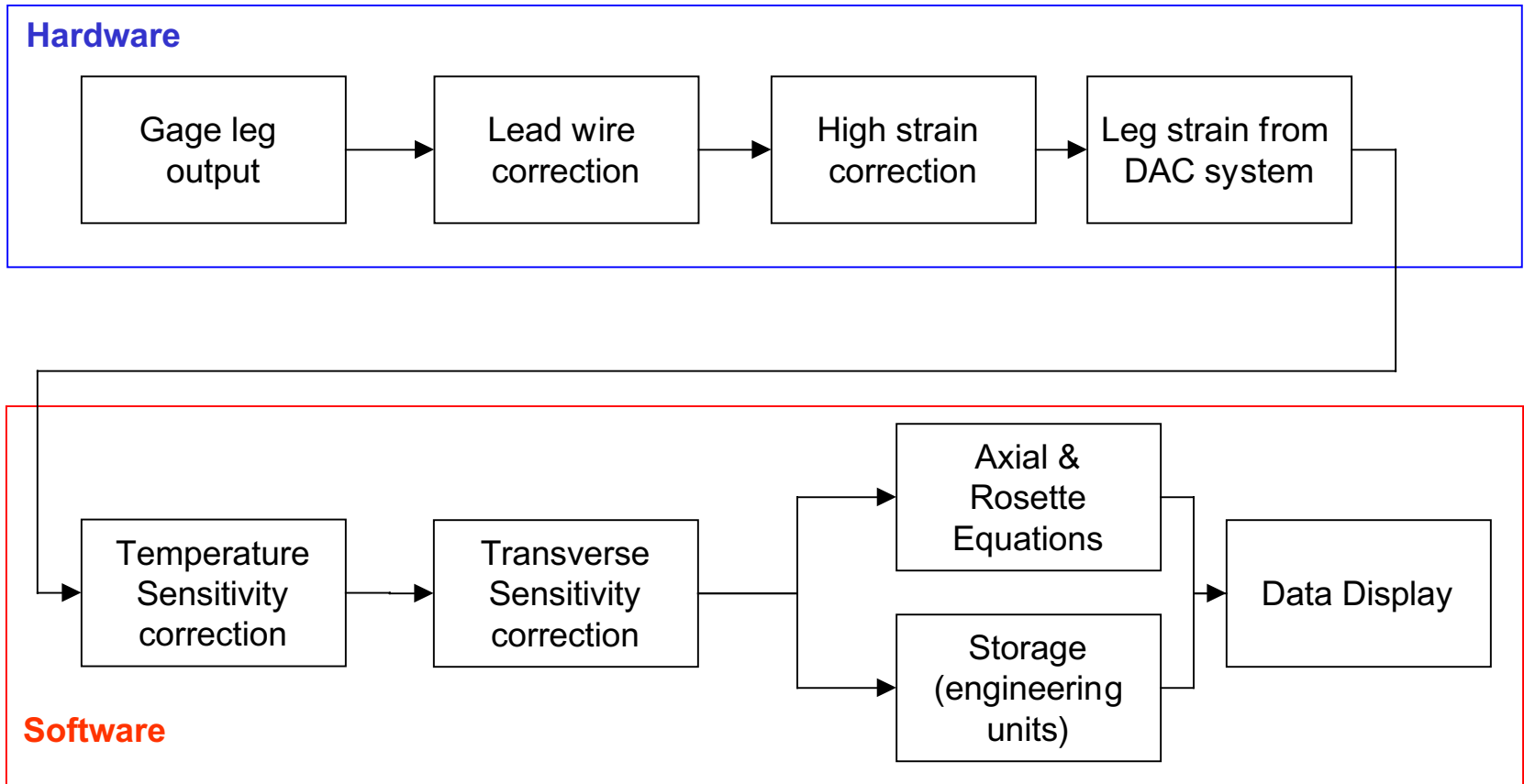
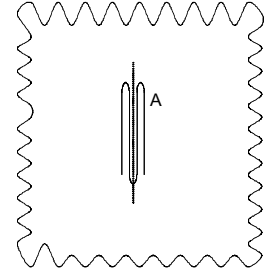




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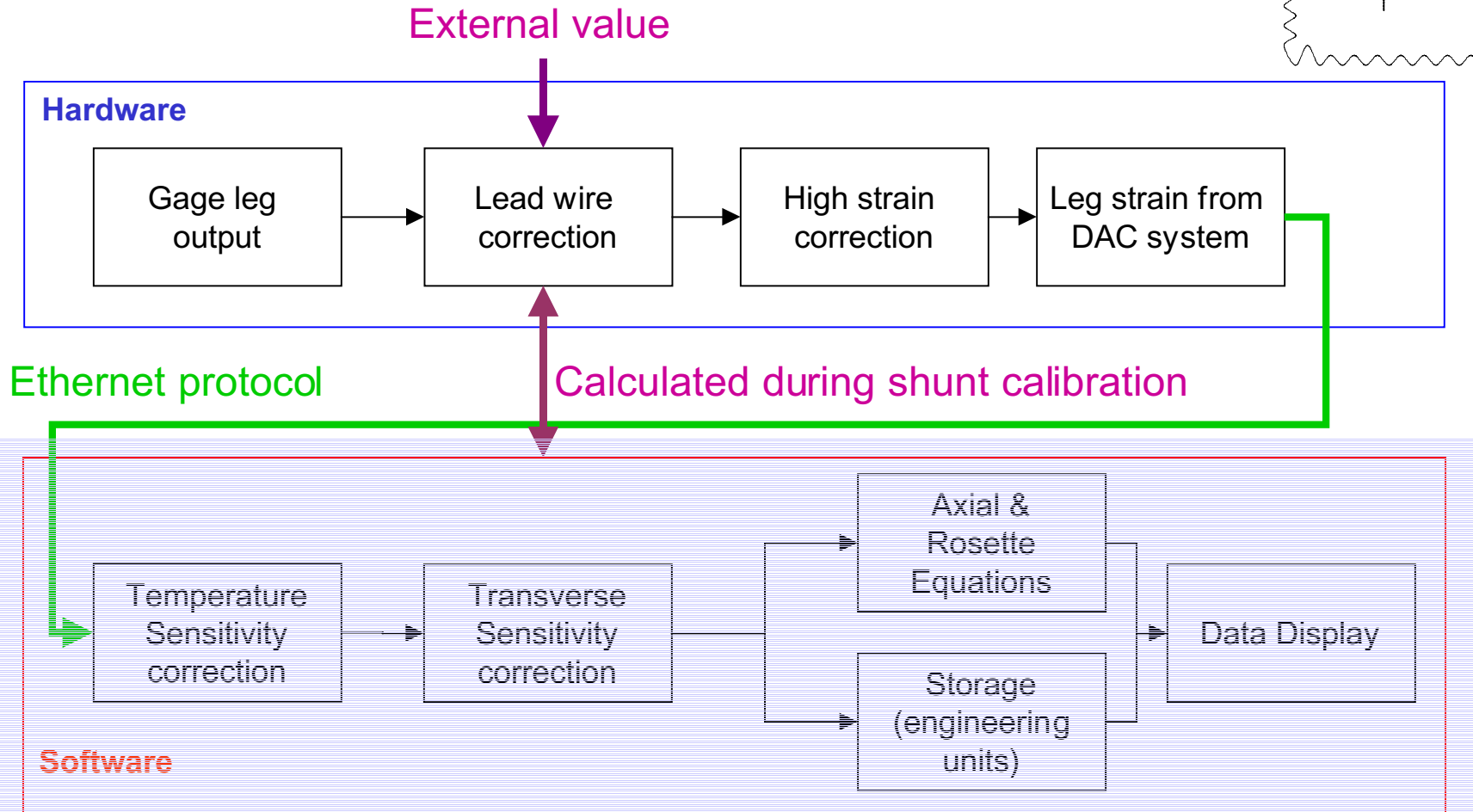
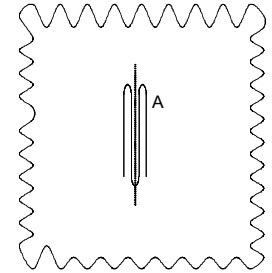


DAC System Schematic





Hardware / Software Interaction during Setup





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Software: Assist During Calibration

Tables - Data Acquisition Channels

Limits | Conditioners | Offsets | Filters | Calibration | **Shunt Verify** | Review Limits

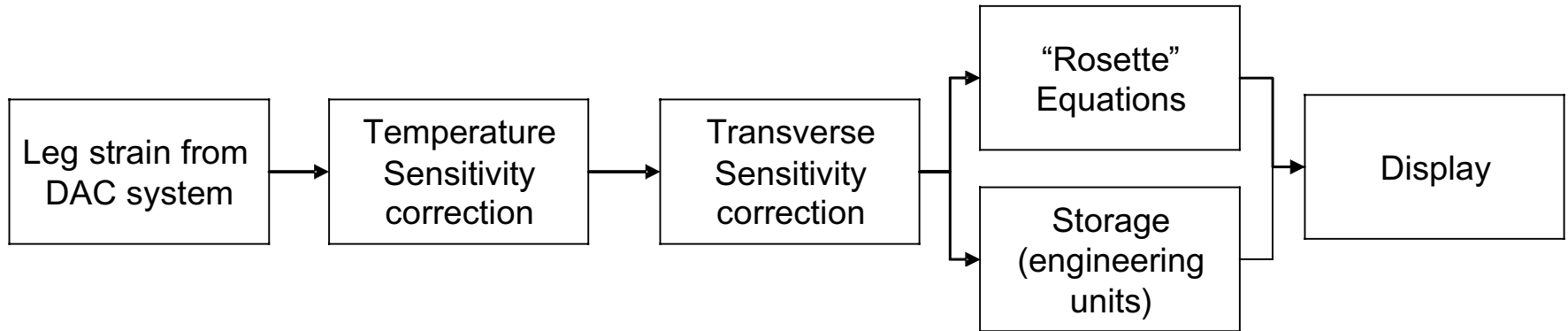
	Name	Reading	Shunt Verification Info							N
			Verify	Verify %	Store	Stored Value	Shunt Reading	Diff. %	Verify Result	
D1	Strain Gage 00001	-303.62 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D2	Strain Gage 00002	-263.86 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D3	Strain Gage 00003	-289.21 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D4	Strain Gage 00004	-317.94 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D5	Strain Gage 00005	-262.60 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D6	Strain Gage 00006	-255.44 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Failed	
D7	Strain Gage 00007	-227.13 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D8	Strain Gage 00008	-254.13 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D9	Strain Gage 00009	-228.25 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input checked="" type="checkbox"/> Passed	
D10	Strain Gage 00010	-140.22 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input type="checkbox"/> ?	
D11	Strain Gage 00011	-149.15 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input type="checkbox"/> ?	
D12	Strain Gage 00012	-501.56 μ Str...	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	1200.00 μ Str...	0.00 μ Strain	0.00...	<input type="checkbox"/> ?	
D13	Strain Gage 00013	-0.01 μ Strain	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	0.00 μ Strain	0.00 μ Strain	0.00...	<input type="checkbox"/> ?	
D14	Strain Gage 00014	-0.01 μ Strain	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	0.00 μ Strain	0.00 μ Strain	0.00...	<input type="checkbox"/> ?	
D15	Strain Gage 00015	0.01 μ Strain	<input type="checkbox"/>	5.00 %	<input type="checkbox"/>	0.00 μ Strain	0.00 μ Strain	0.00...	<input type="checkbox"/> ?	



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Software Scheme

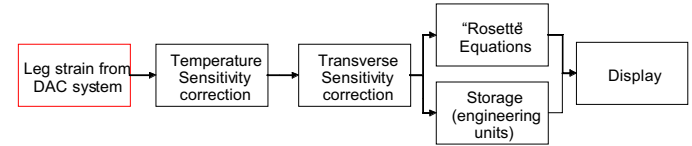




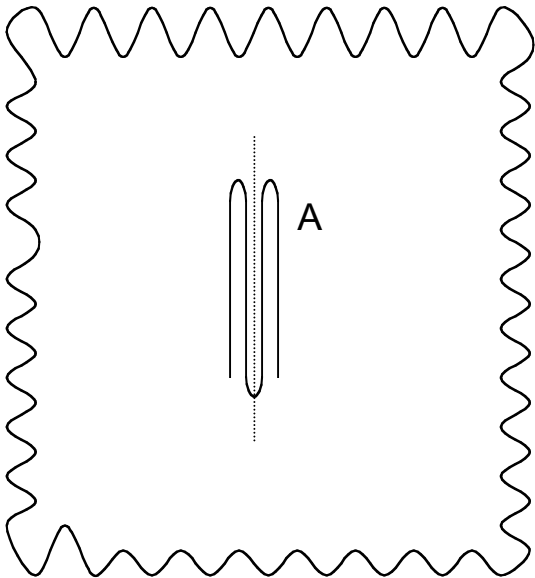
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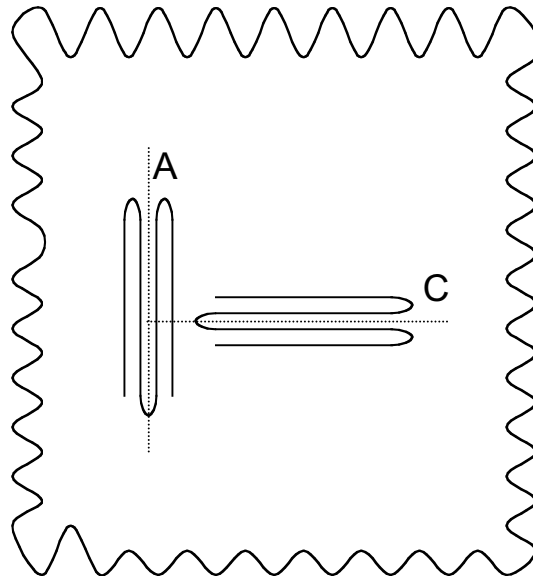
Supported Gage Types



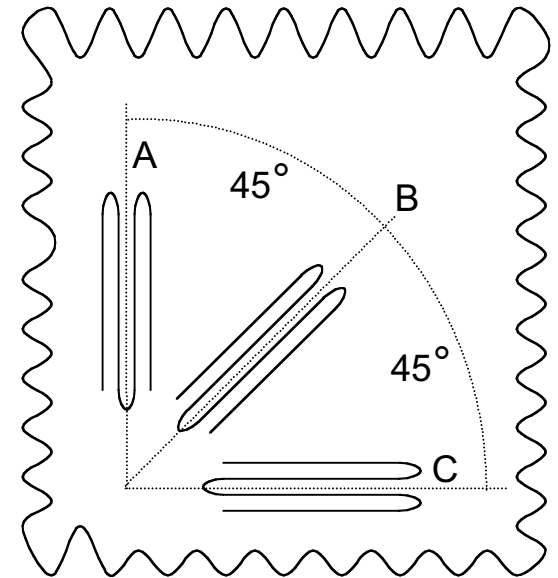
Axial



"Tee"

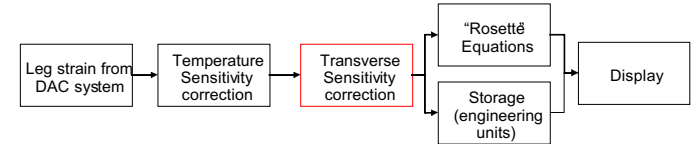


Rectangular

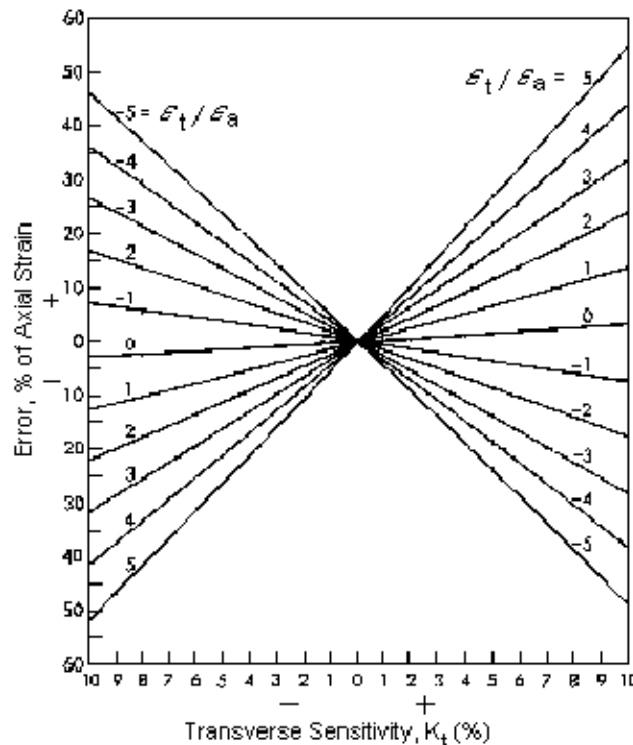
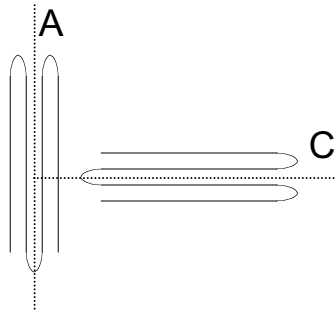




Transverse Sensitivity

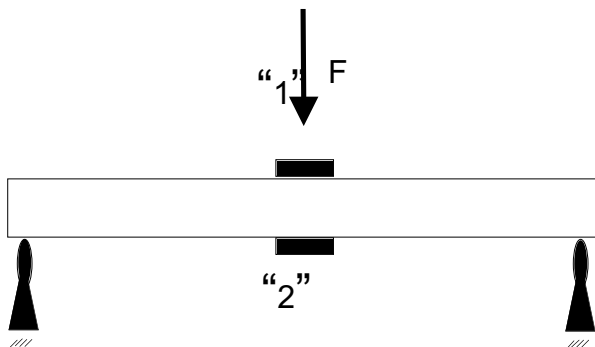
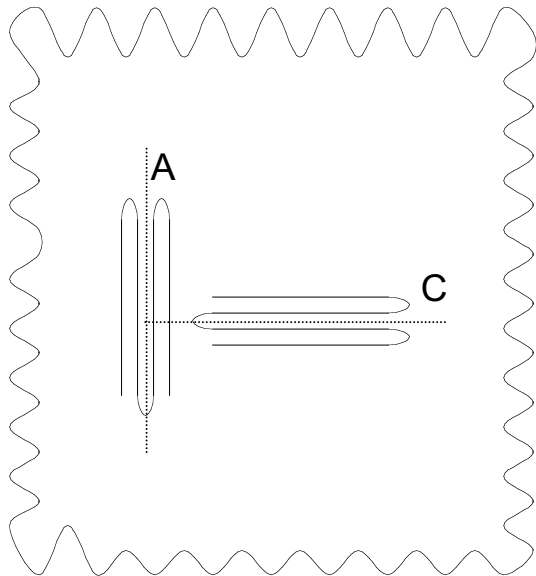
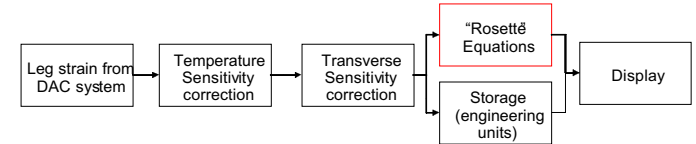


$$\epsilon_A^{TSC} = \frac{1 + k_t}{1 - k_t^2} \epsilon_A^{ind} = k_t \epsilon_C^{ind}$$





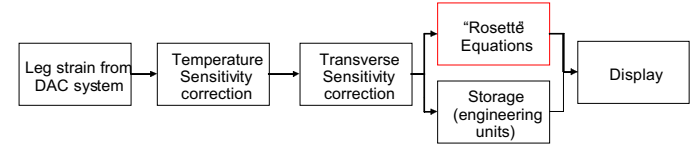
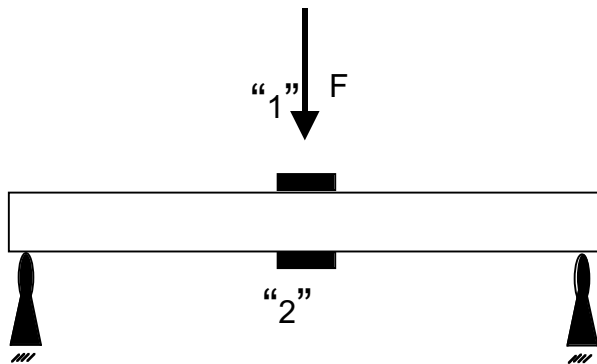
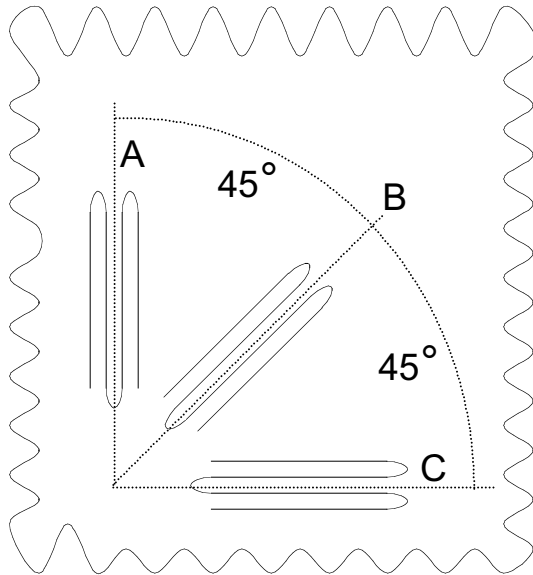
“Tee” Rosette



Measured	SA1	Strain A1
Measured	SA2	Strain A2
Measured	SC1	Strain C1
Measured	SC2	Strain C2
	1 GB1	Shear Strain 1
	2 GB2	Shear Strain 2
	3 FA1	Stress A1
	4 FA2	Stress A2
	5 FC1	Stress C1
	6 FC2	Stress C2
	7 TB1	Shear Stress 1
	8 TB2	Shear Stress 2
	9 SAavg	Average Strain A
	10 SCavg	Average Strain C
	11 GBavg	Average Shear Strain
	12 FAavg	Average Stress A
	13 FCavg	Average Stress C
	14 TBavg	Average Shear Stress
	15 SAbnd	Bending Strain A
	16 SCbnd	Bending Strain C
	17 GBbnd	Bending Shear Strain
	18 FAbnd	Bending Stress A
	19 FCbnd	Bending Stress C
	20 TBbnd	Bending Shear Stress



Rectangular Rosette



1
·
Measured
·
6

1
·
Calculated
·
50

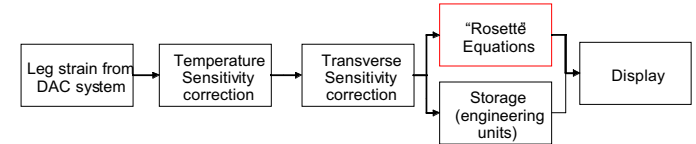
Measured	SA1	Strain A1
Measured	SA2	Strain A2
Measured	SB1	Strain B1
Measured	SB2	Strain B2
Measured	SC1	Strain C1
Measured	SC2	Strain C2
1	GAC1	Shear Strain along A1 & C1
2	GAC2	Shear Strain along A2 & C2
3	GMAX1	Max Shear Strain 1
4	GMAX2	Max Shear Strain 2
5	SMAX1	Max In-Plane Principal Strain 1
6	SMAX2	Max In-Plane Principal Strain 2
7	SMIN1	Min In-Plane Principal Strain 1
8	SMIN2	Min In-Plane Principal Strain 2
9	FA1	Stress A1
10	FA2	Stress A2
11	FC1	Stress C1
12	FC2	Stress C2
13	TAC1	Shear Stress along A1 or C1
14	TAC2	Shear Stress along A2 or C2
15	FMAX1	Max In-Plane Principal Stress 1
16	FMAX2	Max In-Plane Principal Stress 2
17	FMIN1	Min In-Plane Principal Stress 1
18	FMIN2	Min In-Plane Principal Stress 2
19	TMAX1	Max Shear Stress 1
20	TMAX2	Max Shear Stress 2
21	ANG1	Angle 1
22	ANG2	Angle 2
23	SAavg	Average Strain A
24	SBavg	Average Strain B
25	SCavg	Average Strain C
26	GACavg	Average Shear Strain along A & C
27	GMAXavg	Average Max Shear Strain
28	SMAXavg	Average Max In-Plane Principal Strain
29	SMINavg	Average Min In-Plane Principal Strain
30	FAavg	Average Stress A
31	FCavg	Average Stress C
32	TACavg	Average Shear Stress along A or C
33	FMAXavg	Average Max In-Plane Principal Stress
34	FMINavg	Average Min In-Plane Principal Stress
35	TMAXavg	Average Max Shear Stress
36	ANGavg	Average Angle
37	SAbnd	Bending Strain A
38	SBbnd	Bending Strain B
39	SCbnd	Bending Strain C
40	GACbnd	Bending Shear Strain along A & C
41	GMAXbnd	Bending Max Shear Strain
42	SMAXbnd	Bending Max In-Plane Principal Strain
43	SMINbnd	Bending Min In-Plane Principal Strain
44	FAbnd	Bending Stress A
45	FCbnd	Bending Stress C
46	TACbnd	Bending Shear Stress along A & C
47	FMAXbnd	Bending Max In-Plane Principal Stress
48	FMINbnd	Bending Min In-Plane Principal Stress
49	TMAXbnd	Bending Max Shear Stress
50	AGNbnd	Bending Angle



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Setup



Properties - Tee Rosette

General | Tee Rosette | Transverse

Axial and Rosettes\Tee Rosette 00001

Material: M 2324-T39 Aluminum

Leg A: Tee Rosette 00001A

Leg C: Tee Rosette 00001C

View Table

Back-to-Back Relationship: <none>

This sensor is in the front.

OK Cancel Apply

Properties - Rectangular Rosette

General | Rectangular Rosette | Transverse

Axial and Rosette gages\Rectangular Rosette 00009

Material: M 2024-T4 Aluminum

Leg A: Rectangular Rosette 00009A

Leg B: Rectangular Rosette 00009B

Leg C: Rectangular Rosette 00009C

View Table

Back-to-Back Relationship: Rectangular Rosette 00008

This sensor is in the front.

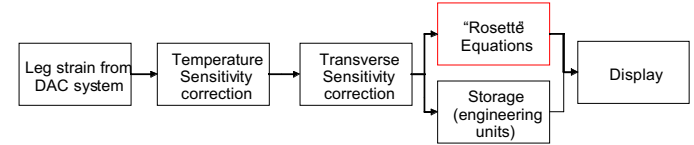
OK Cancel Apply



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Materials Database



Properties - Metal

MTS General **K** Constants

2324-T39 Aluminum

	Name	Value	Unit	Notes
1	K Compression Modulus ...	10.30 N/m ²	N/m ²	
2	K Compression Yield	10.50 N/m ²	N/m ²	
3	K Poisson's Ratio	4.00		
4	K Shear Modulus	0.33 N/m ²	N/m ²	
5	K Tension Modulus	63.00 N/m ²	N/m ²	
6	K Tension Yield	65.00 N/m ²	N/m ²	

Type

Add Remove Properties

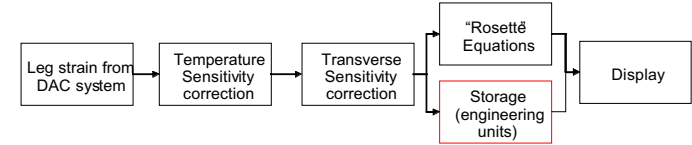
OK Cancel Apply



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Storage



- Only leg strains stored in binary format for efficiency

```

RosetteTest1-A_export Inp1 1.txt - Notepad
File Edit Format View Help
[Test Name: RosetteTest1-A
Data Set Name: VTI Scan Index Recorder (8/1/2005 1:22:27 PM)
Scan Type(s): All Scan Types
Signal ID:
Input 1
Test Chan Key D1 D2 D3 D4 D5 D6
Test Chan Name Left Front A Left Front B Left Front C
Left Rear A Left Rear B Left Rear C Right Rear A Right Rear B
Test Chan No 1 2 3 4 5 6
Chan Type
Units
Scan Index Date Time
1 01-Aug-2005 13:20:17.397 -129.396102905273 12.37074661254
11.8975763320923 9.29820156097412 12.6382541656494 11.759
114.157814025879 12.3592147827148 12.8607025146484 10.824
2 01-Aug-2005 13:20:17.497 -129.430313110352 12.36446857452
11.9639778137207 9.33093643188477 12.5158700942993 11.787
114.147026062012 12.3974370956421 12.900691986084 10.85173988342
3 01-Aug-2005 13:20:17.597 -129.507690429688 12.32666683197
11.9072484970093 9.30294513702393 12.5724124908447 11.739
114.110389709473 12.3410797119141 13.0160074234009 10.862
4 01-Aug-2005 13:20:17.697 -129.499969482422 12.31350803375
11.9315214157104 9.29866695404053 12.5116386413574 11.764
114.169151306152 12.195912361145 12.8388481140137 10.79528999328
5 01-Aug-2005 13:20:17.797 -129.470123291016 12.32499313354
11.9109687805176 9.29308700561523 12.5316333770752 11.819
114.163948059082 12.3152265548706 12.9305429458618 10.767
6 01-Aug-2005 13:20:17.897 -129.539520263672 12.33736133575
9.29197120666504 12.4898309707642 11.8289442062378 6.2247
12.2252054214478 12.8693046569824 10.7777824401855
7 01-Aug-2005 13:20:17.997 -129.42529296875 12.41101455688
11.946494102478 9.31875419616699 12.4744396209717 11.82066726684
  
```

- Export leg strain + derived values in XML, ASCII

	SA	SB	SC	SMAX	SMIN	GAC	TAC	ANG
Rectangular Rosette 00027	-4.52	-96.91	28.94	122.60	-98.18	-218.23	28.94	-85.64
Rectangular Rosette 00028	22.22	62.56	28.81	62.71	-11.68	74.09	28.81	87.46
Rectangular Rosette 00029	-34.71	-0.36	29.50	29.58	-34.79	4.49	29.50	47.00
Rectangular Rosette 00030	60.97	26.32	-2.10	61.12	-2.26	-6.22	-2.10	-42.18

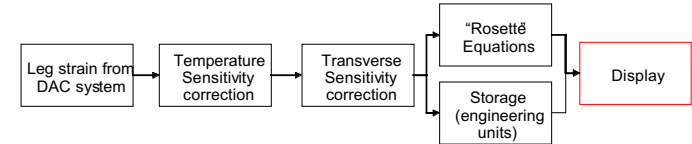
2005/07/28 10:09:01.434 - VTI SM #940 Rate: 1.0 Hz



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Display



Select Signals

Monitor 1 (MON1)

- Rectangular Rosette 00003
 - Rectangular Rosette 00003, Angle
 - Rectangular Rosette 00003, Max Shear Strain
 - Rectangular Rosette 00003, Max Shear Stress
 - Rectangular Rosette 00003, Max Strain
 - Rectangular Rosette 00003, Max Stress
 - Rectangular Rosette 00003, Min Strain
 - Rectangular Rosette 00003, Min Stress
 - Rectangular Rosette 00003, Monitor 1
 - Rectangular Rosette 00003, Shear Strain
 - Rectangular Rosette 00003, Shear Stress
 - Rectangular Rosette 00003, Strain A
 - Rectangular Rosette 00003, Strain B
 - Rectangular Rosette 00003, Strain C
 - Rectangular Rosette 00003, Stress A
 - Rectangular Rosette 00003, Stress C

X: Time

OK Cancel

List View 2 -> Test Station 1: RosetteTest3 (Continuous)

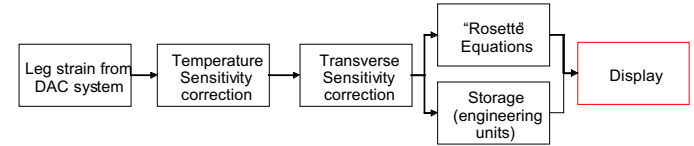
	Value
Rectangular Rosette 00003, Angle	-78 deg
Rectangular Rosette 00003, Max Shear Strain	512 (m/m)
Rectangular Rosette 00003, Max Shear Stress	0 kN/mm ²
Rectangular Rosette 00003, Max Strain	398 (m/m)
Rectangular Rosette 00003, Max Stress	0 kN/mm ²
Rectangular Rosette 00003, Min Strain	-115 (m/m)
Rectangular Rosette 00003, Min Stress	0 kN/mm ²
Rectangular Rosette 00003, Monitor 1	33.855 N/m ²
Rectangular Rosette 00003, Shear Strain	-465 (m/m)
Rectangular Rosette 00003, Shear Stress	249 kN/mm ²
Rectangular Rosette 00003, Strain A	34 (m/m)
Rectangular Rosette 00003, Strain B	-91 (m/m)
Rectangular Rosette 00003, Strain C	249 (m/m)
Rectangular Rosette 00003, Stress A	0 kN/mm ²
Rectangular Rosette 00003, Stress C	0 kN/mm ²



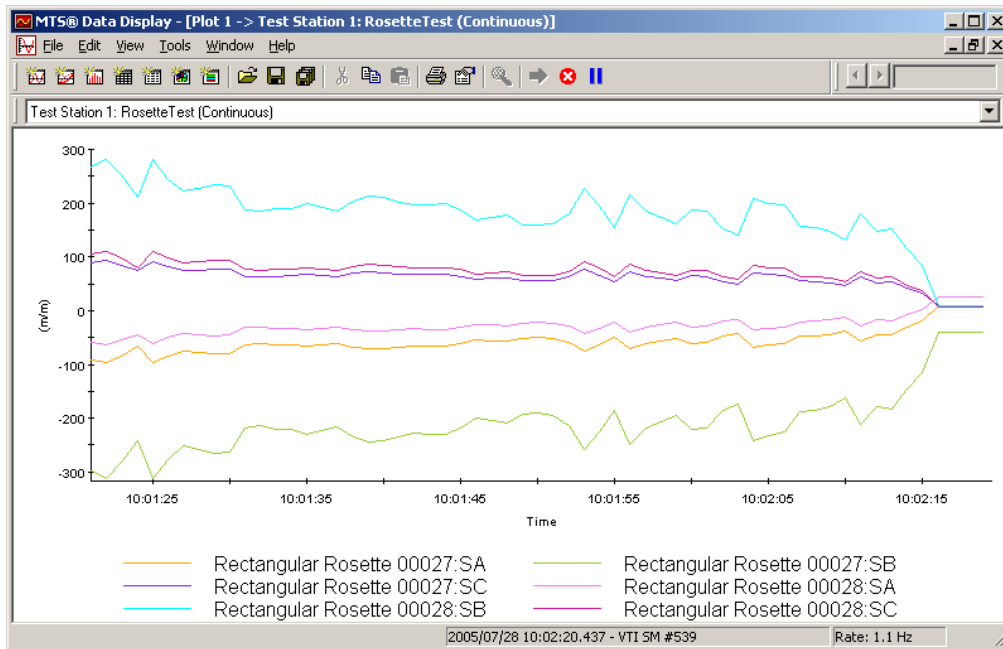
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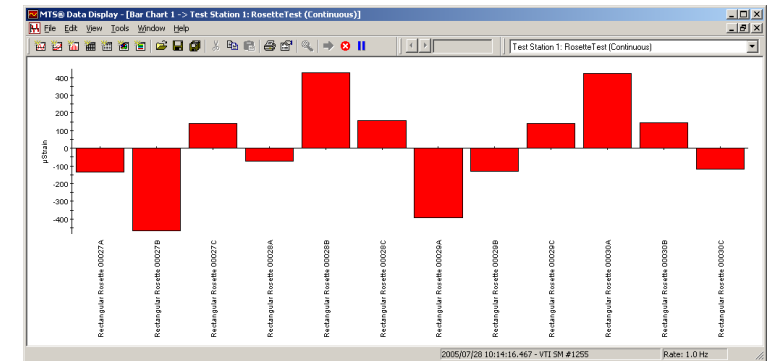
Display: In Lab or Remotely



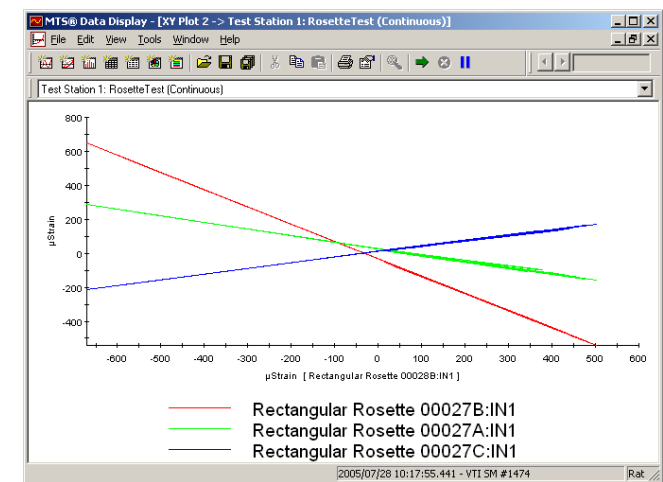
Time Trace



Bar Chart



X-Y Plot





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Questions Please ?

**See us at Booth 414
(near Auditorium 1)
for a Demo**