Modern high precision, high speed measurement of segments and moulds

Presented by
Nod Clarke-Hackston
International Sales Manager VMT

Mould & Segment Measurement

VMT GmbH
Gesellschaft für Vermessungstechnik

14.2m Diameter Tunnel Boring Machine – Elbe Tunnel - Germany

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S-300 machine used in the construction of M30 Highway in Madrid

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M30 Tunnel showing segmental lining

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Geometrical Verification of main body of S 300 machine

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Laser tracker and workstation position for outer measurement

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Retro-reflective Prism positioning via scaffolding

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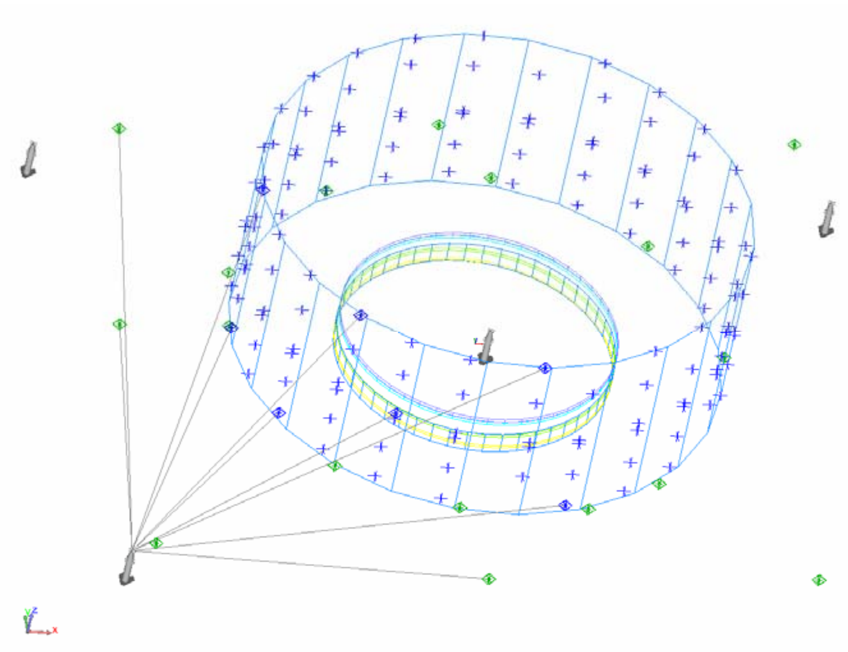
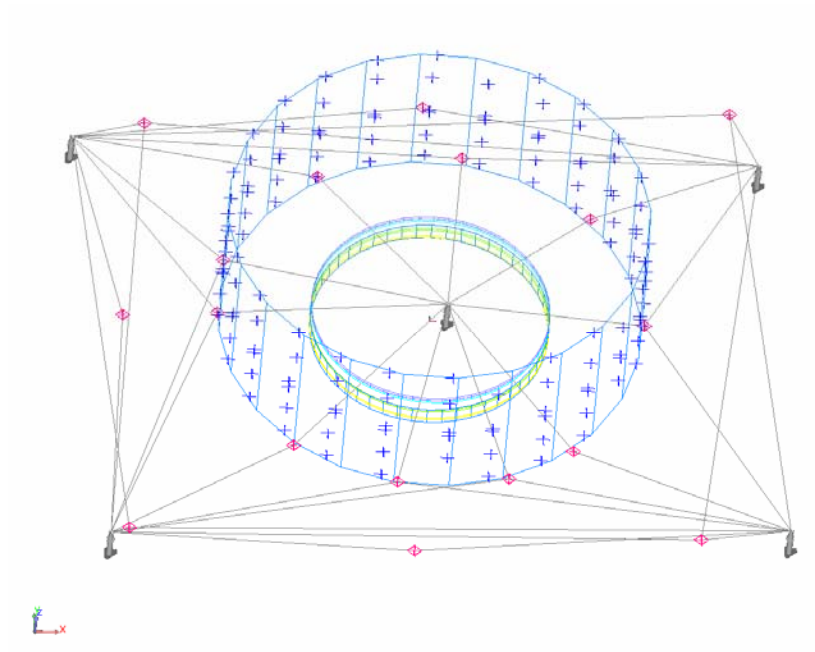
3D view showing measurement area



Range of operation from one standpoint



Typical fixed point set-up

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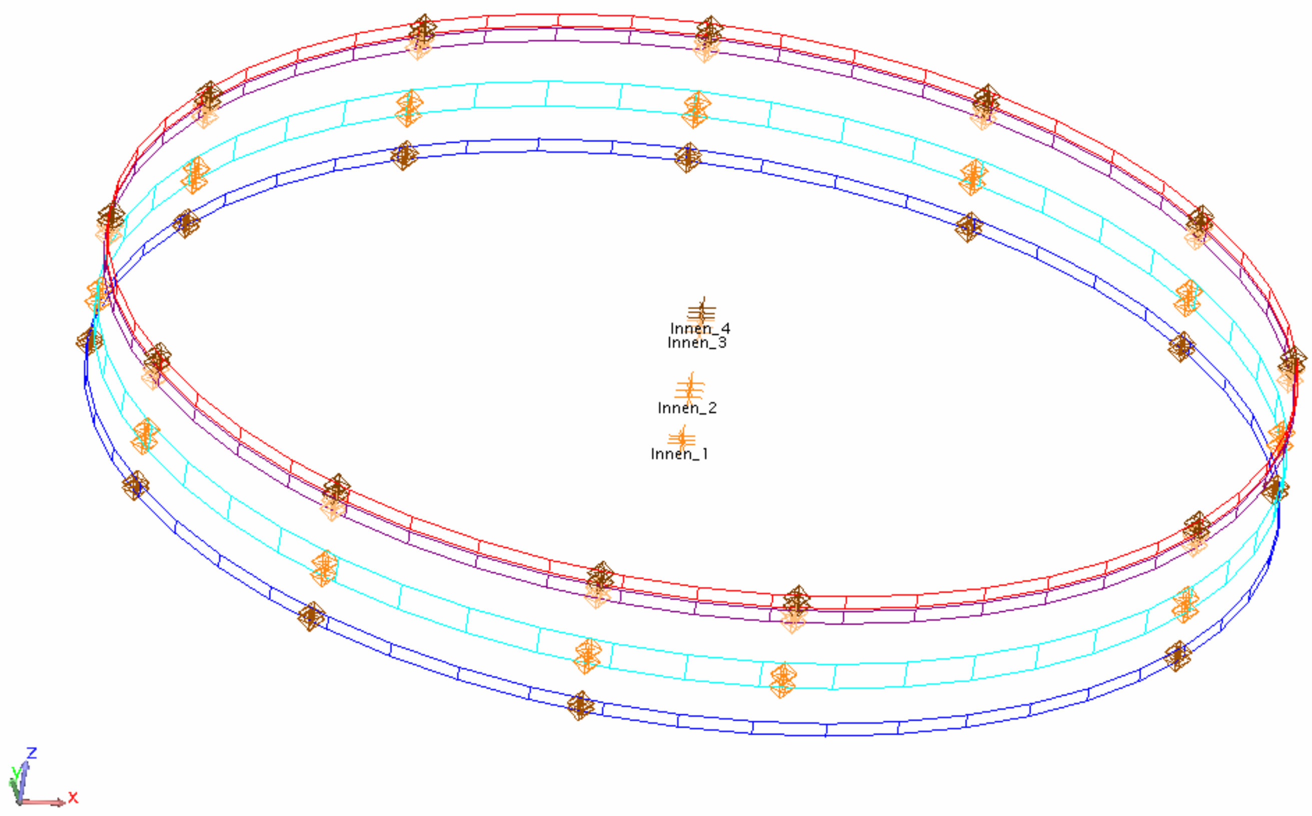
Inside reference for main gear mounting



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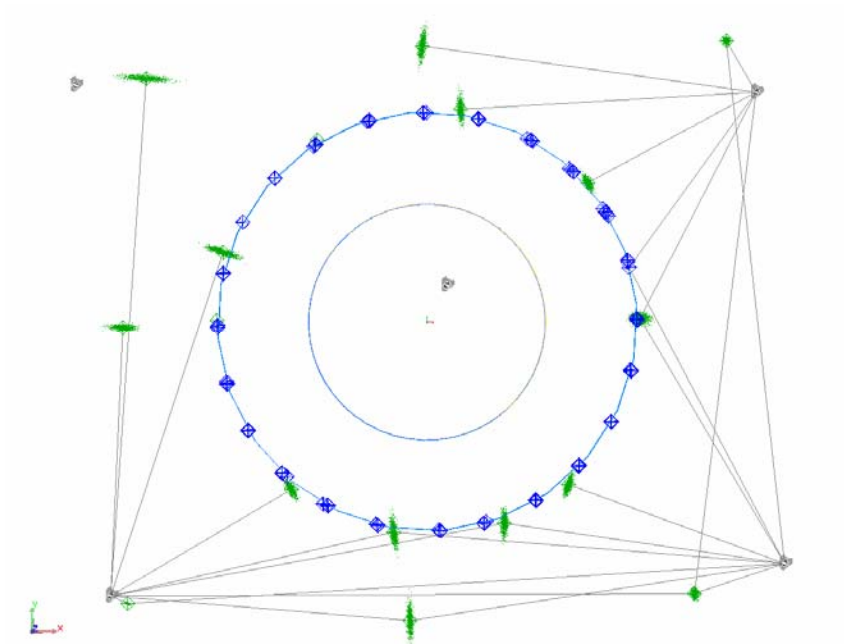
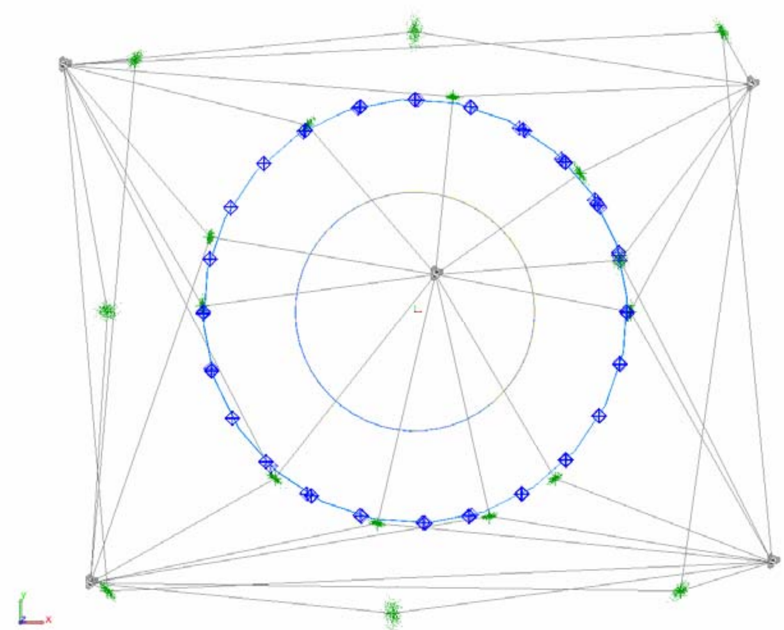
Plan of measurement operating area





Point cloud distribution without Bundling
Scale exaggerated by 1000

Point cloud distribution with Bundling
Scale exaggerated by 1000

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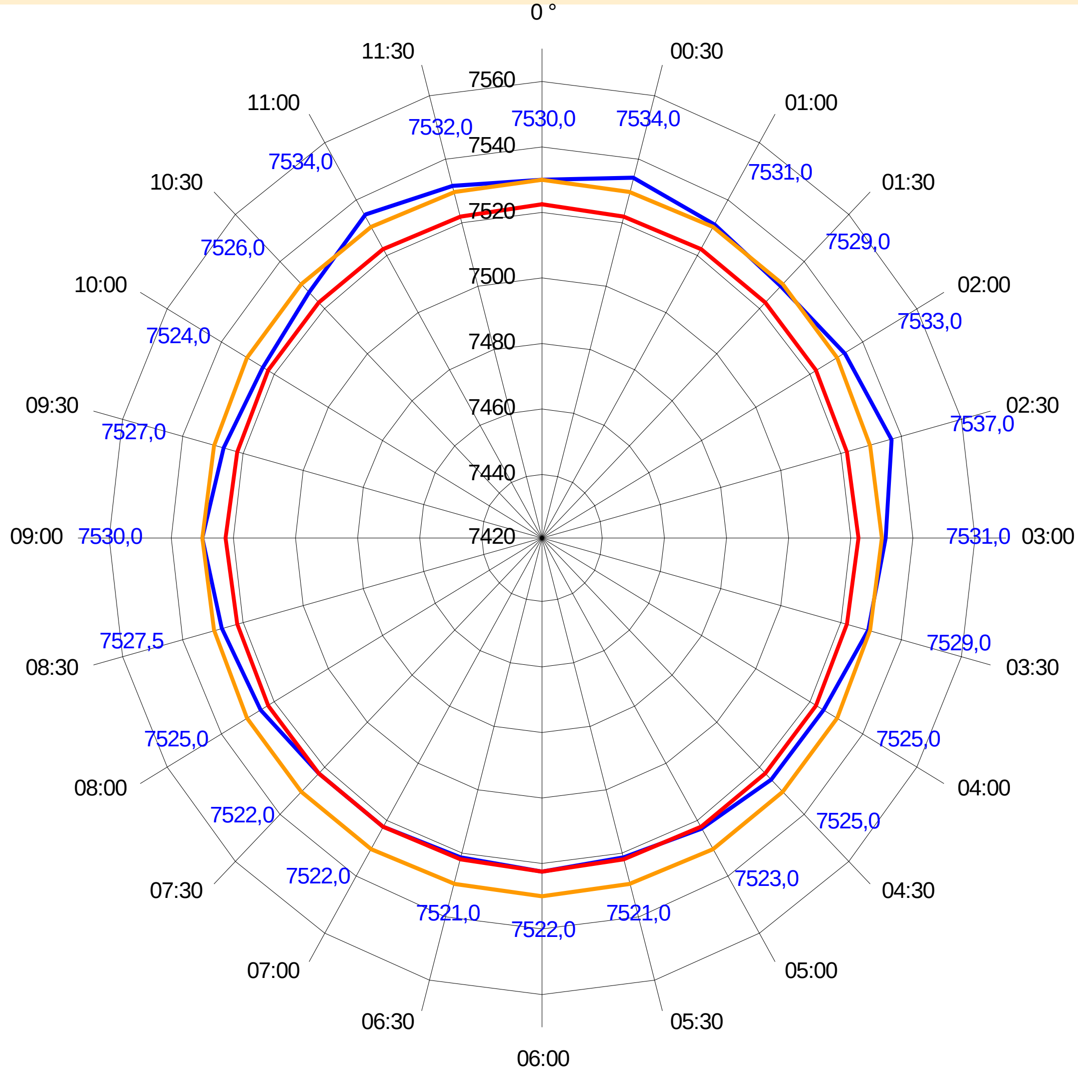
Presentation of results in Customers preferred style

Level 6



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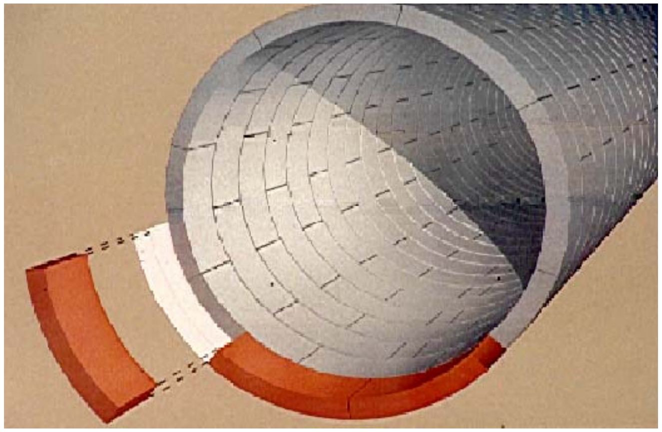
Geometrical Verification as part of Quality Management



- Requirements for segmental liners:
  - Full plane surface contact in radial and circumferential joints due to the high loads being transferred among them
  - Correct linear dimensions to avoid stepping and lipping
  - Correct angles between contact surfaces to minimize birds mouthing or uneven point loads
- Documentary evidence that only certified segments have been used in the tunnel construction

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Sample ring build

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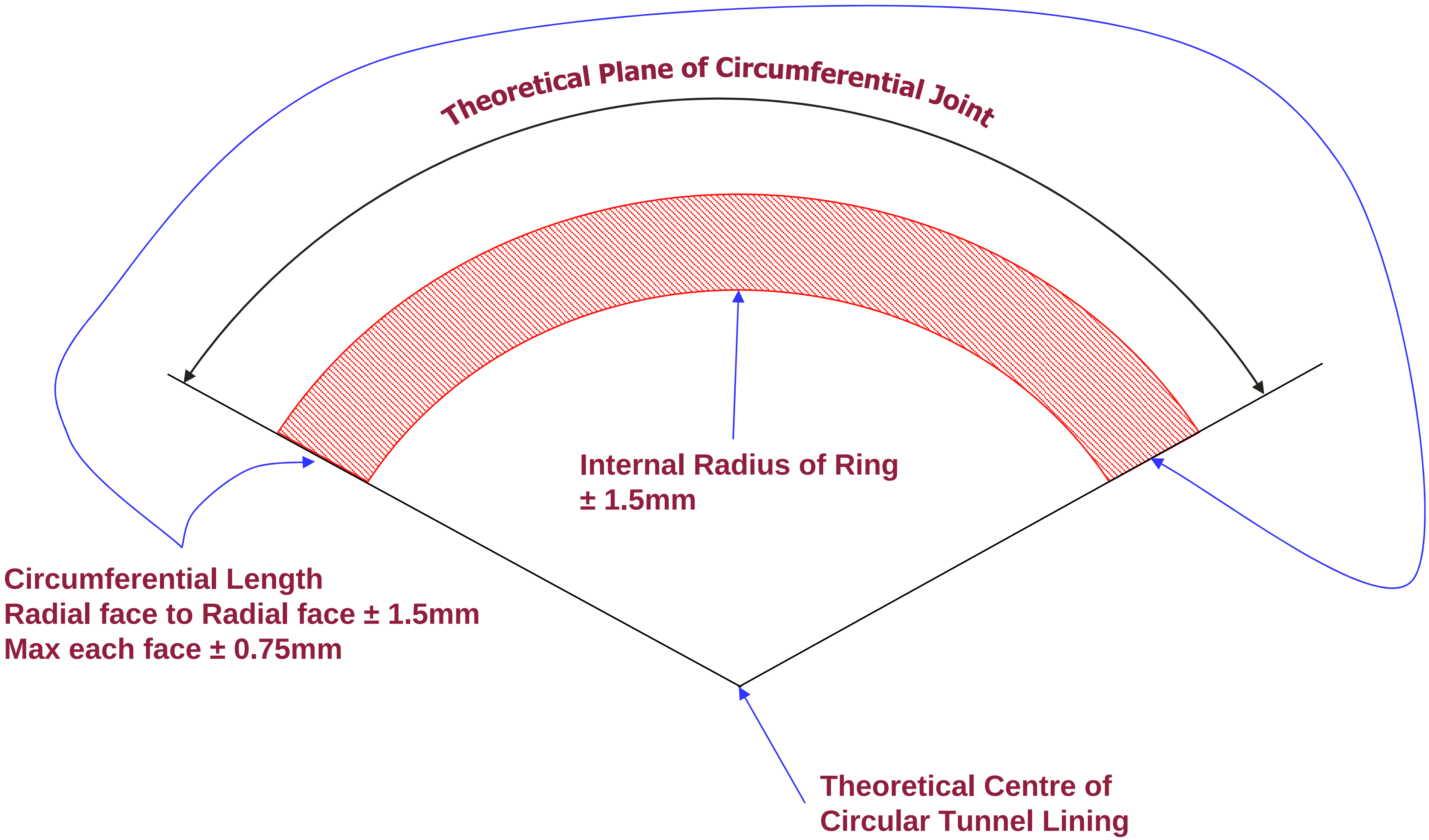
Segment Tolerance



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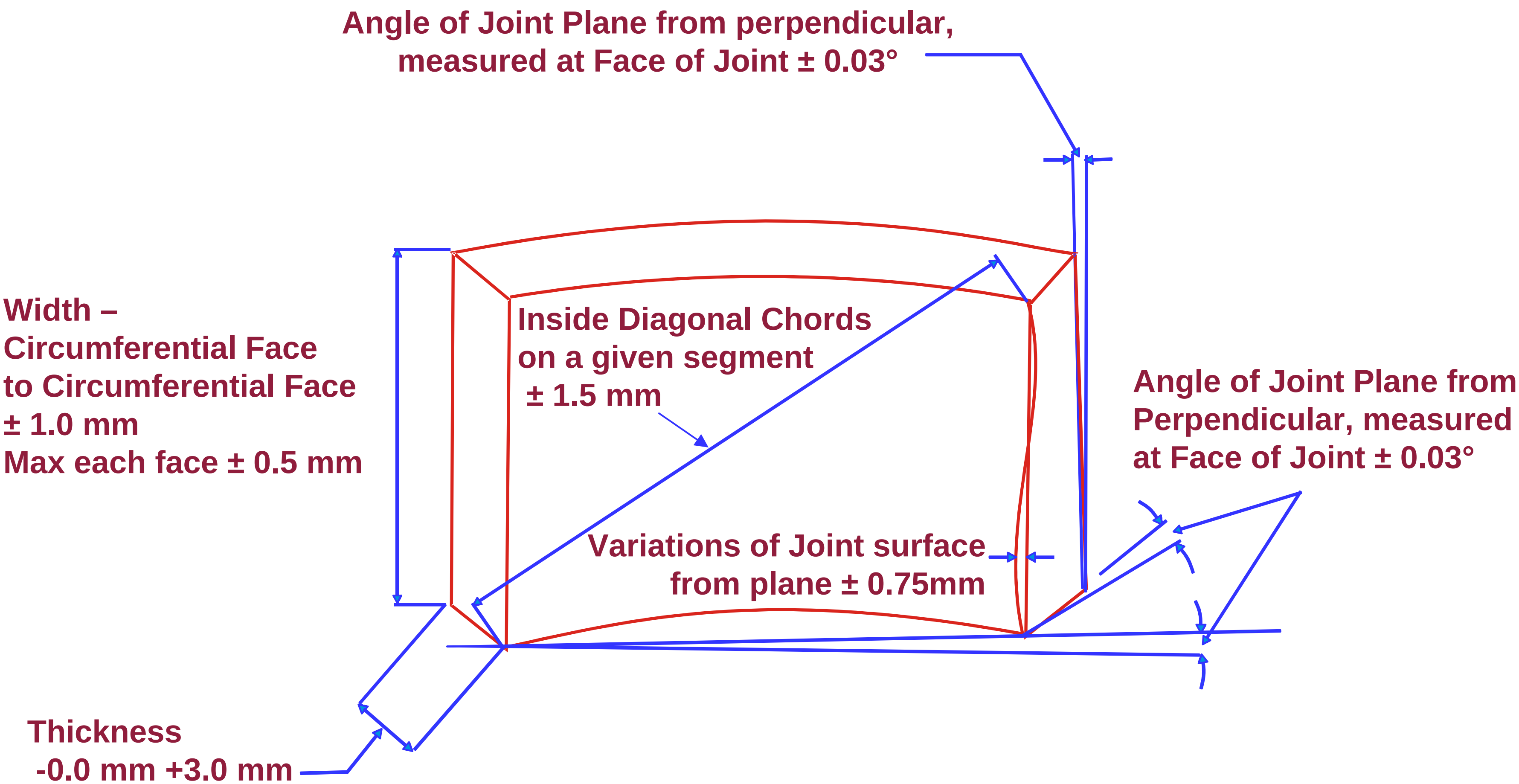
Segmental Dimensional Tolerance



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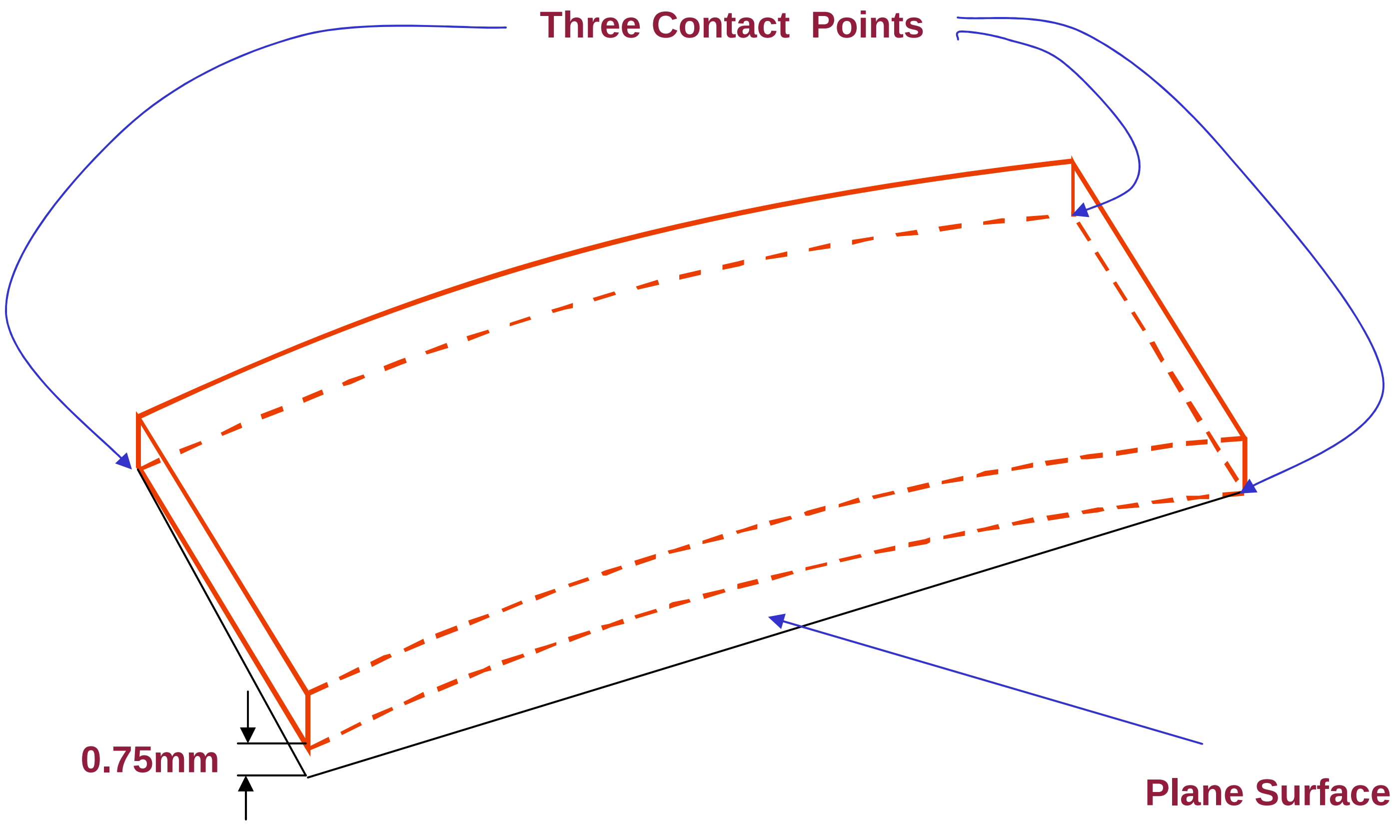
Warping Tolerance



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Typical Segmental Dimensional Tolerance

1	Circumferential Length	+ 3mm,	- 0mm.	
2	Thickness	+ 3mm,	-1mm.	
3	Width	+1mm,	-1mm.	
4	Internal Diameter of completed ring	+0.15%,	-0mm.	of theoretical diameter
5	Bolt Hole sizes	+1mm,	-0mm.	
6	Bolt holes and dowels: position	+1mm,	-1mm.	
7	E & M Fixing holes	(TBA)	(TBA)	
8	Gasket Grooves: depth	+0.5mm	-0.5mm	
9	Gasket Grooves: width	+0.5mm	-0.5mm	
10	Longitudinal Joints			
	In plane containing axis of the tunnel (longitudinal)	0.3mm	from theoretical plane with rate of deviation not exceeding 0.6mm/m	
	In a Radial plane	0.1mm	from theoretical plane with rate of deviation not exceeding 0.6mm/m	
11	Circumferential faces	0.5mm	from theoretical plane with rate of deviation not exceeding 1mm/m	
12	Smoothness of other faces			
	Back	+1.5mm	-1.5mm	Smooth float
	Front	+1mm	-1mm	Formed

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Optimum time for measurement of segments

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All segment measurement at the same phase

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Methods for precise mould and segment control

- Steel Templates
- Measurement arms
- Theodolite Measurement Systems
- Photogrammetry
- Laser Interferometer System

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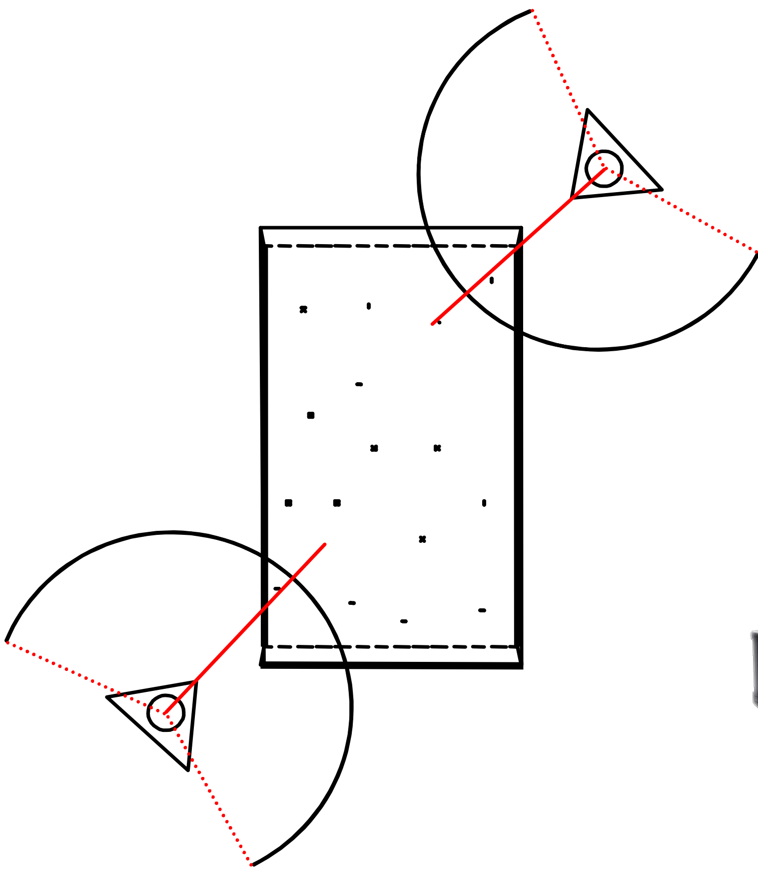
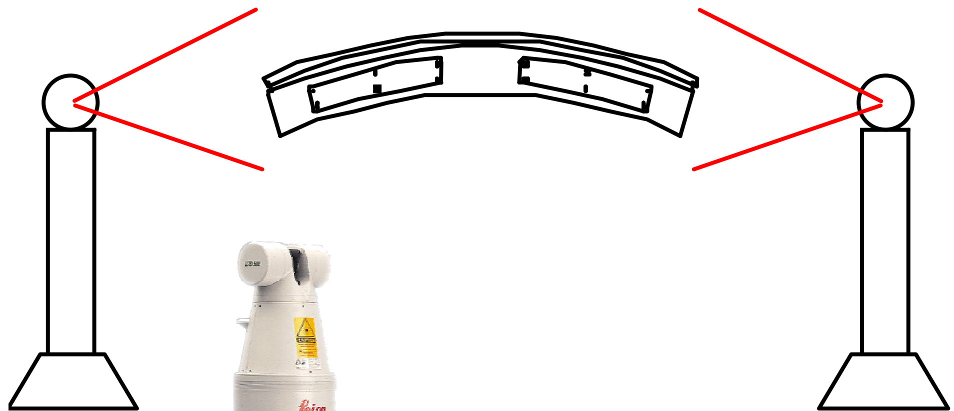
Laser Tracker System





Accurate digitization of surfaces by direct polar co-ordinate measurement

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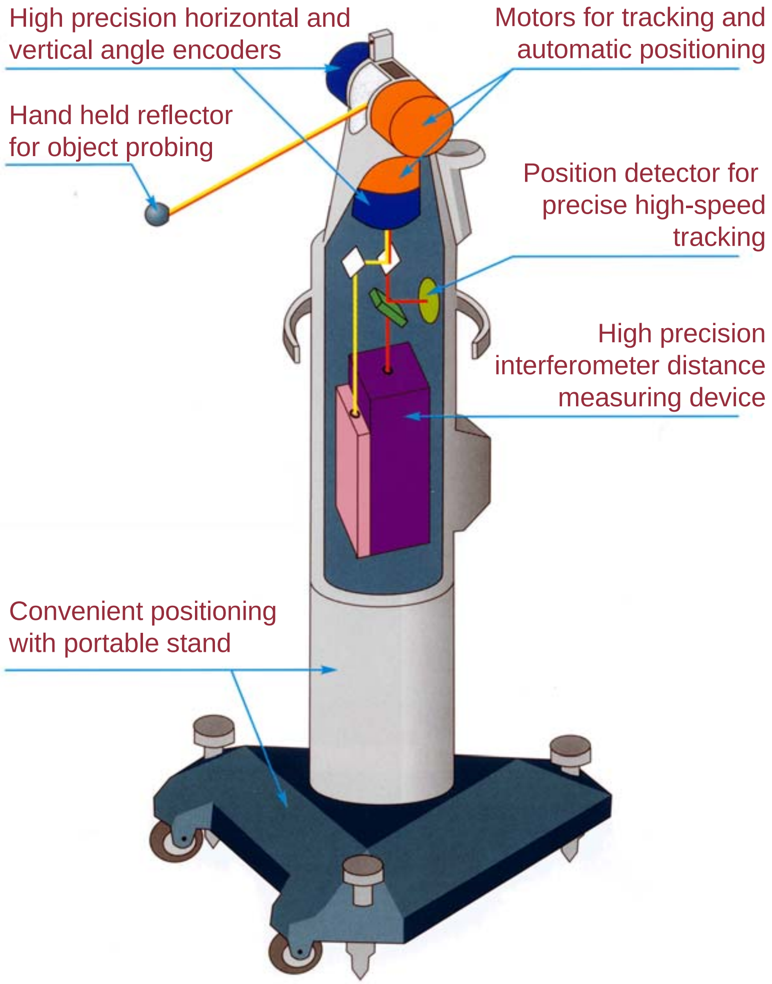
Laser Tracker Instrument



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Large Segment Measurement in Malaysia

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Central Positioning for measuring Key Segment Moulds

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Speed of prism across surface

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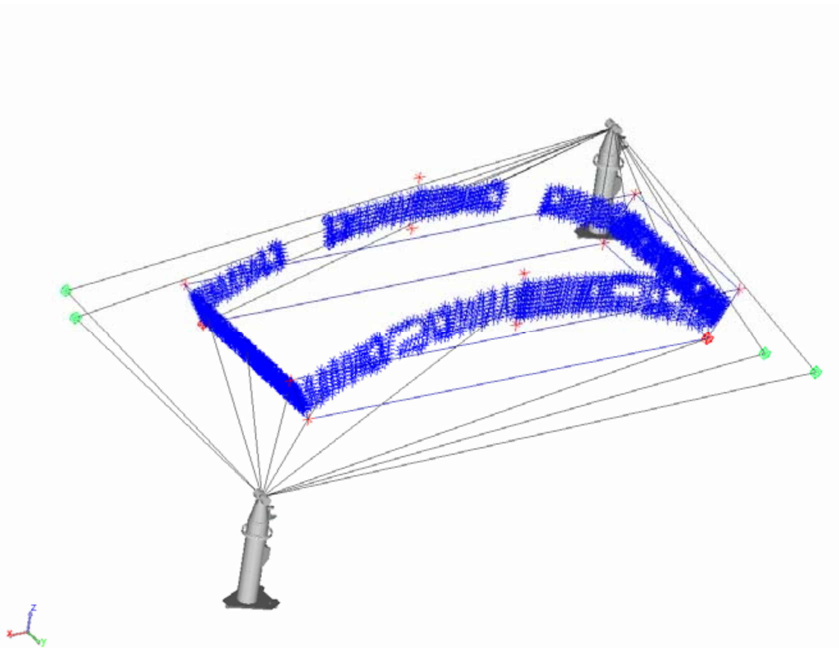
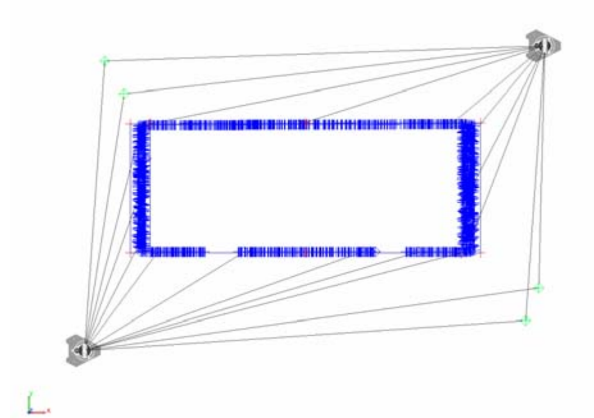
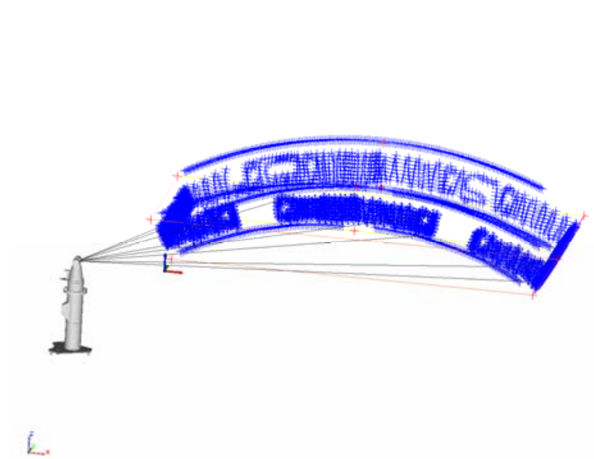
View of measurement area







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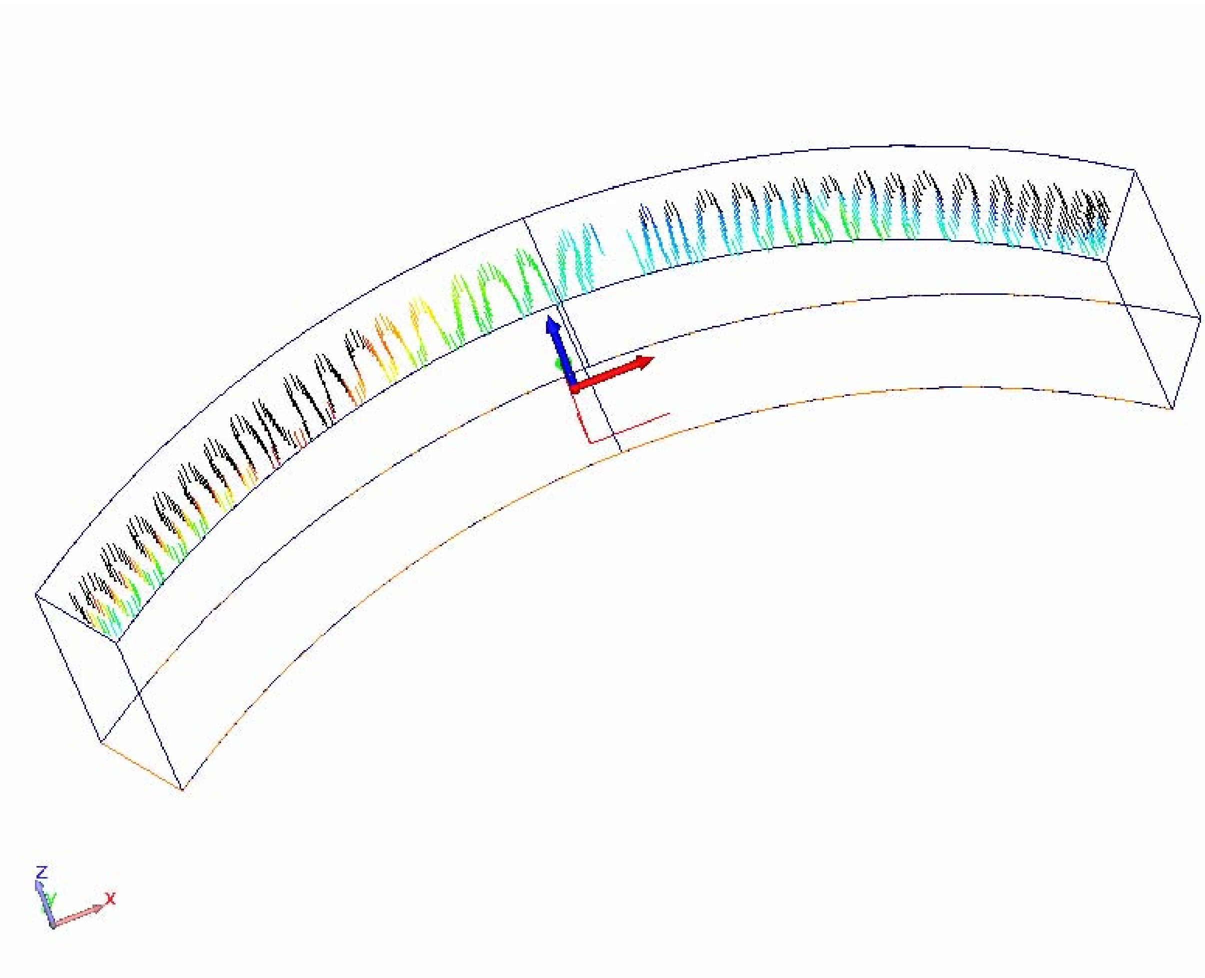
Measured Points Trace



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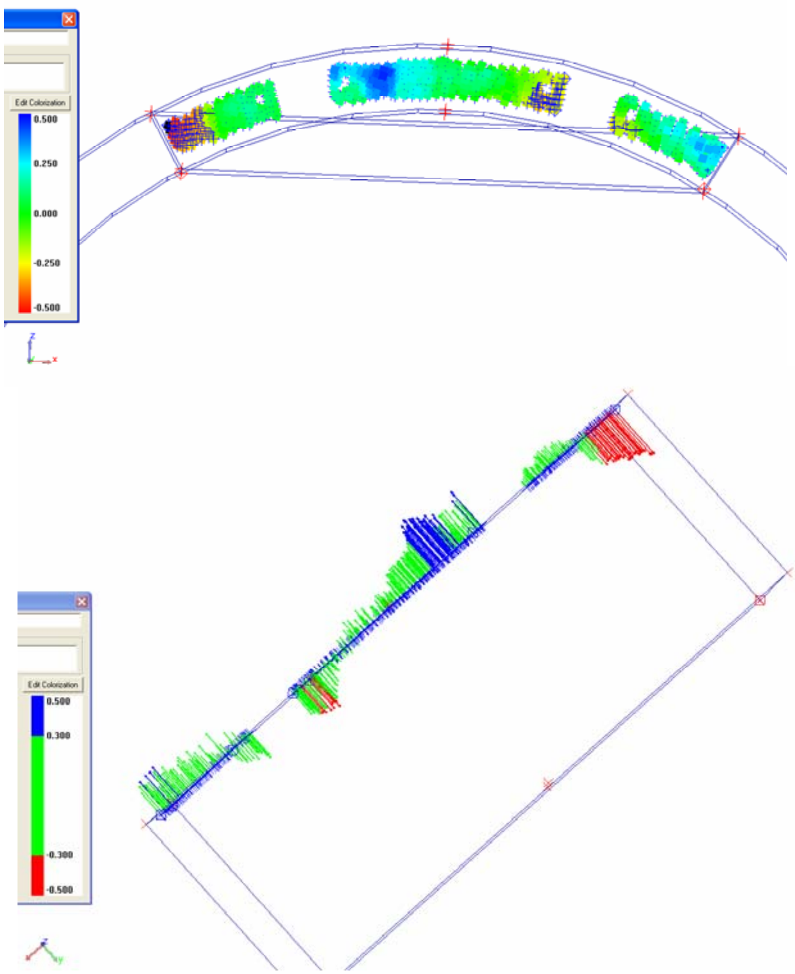
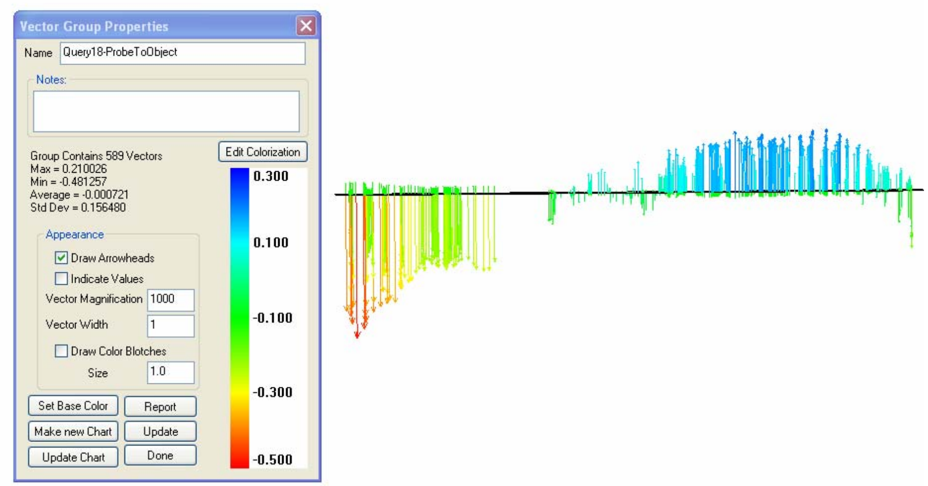
Spatial Analyzer 3D Graphical Software platform





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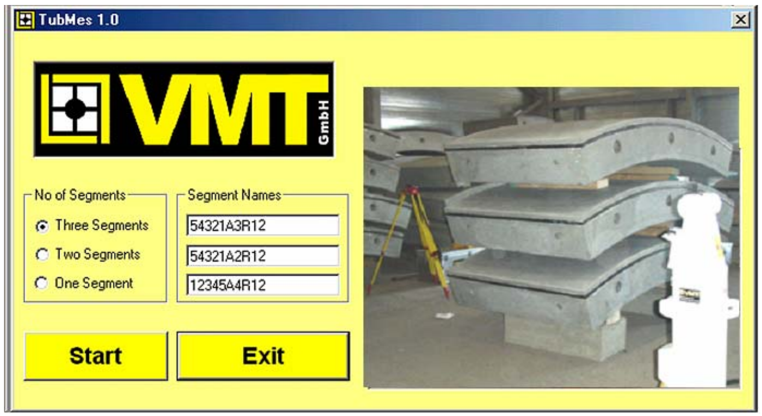
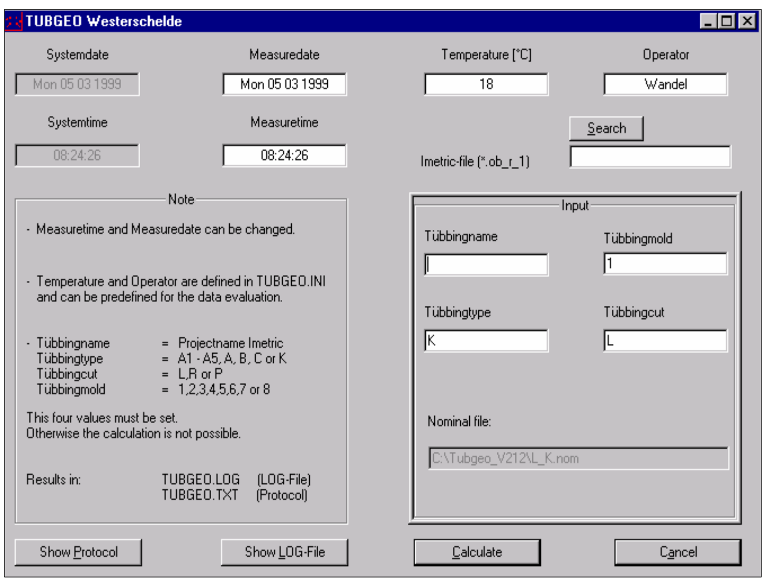
VMT's TubGeo© Evaluation Software





- TubGeo© software processes 3D co-ordinates for the geometrical properties of moulds and segments
- Interactive guidance of the user during the entire measurement process
- Visual Basic Scripts for the controlling of regular measurements with individual programming for repetitive tasks.
- User defined formatting of final report together with an extensive log-file of intermediate results

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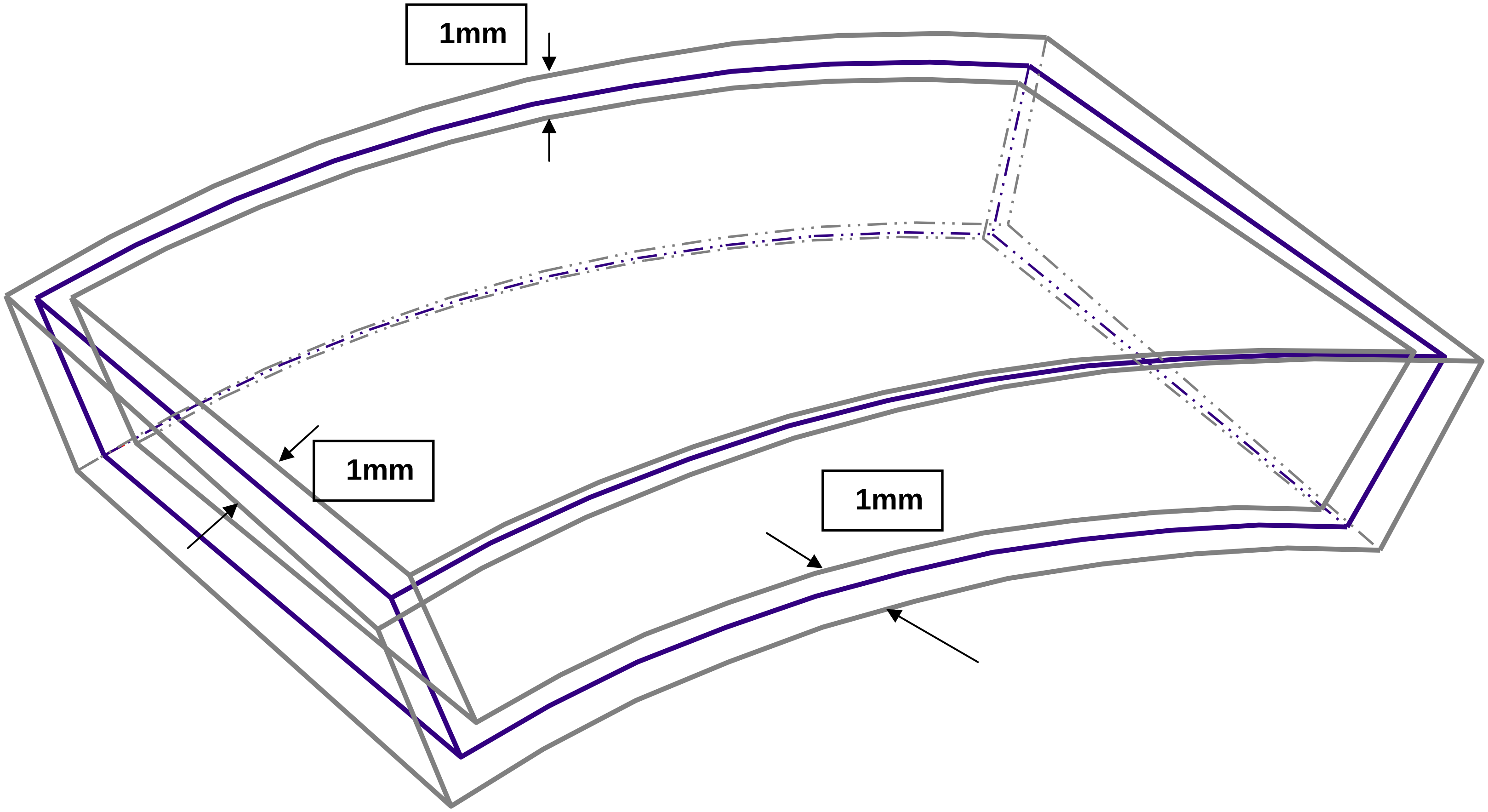
Best Fit - Volume



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Graphical and Tabular Records

Record

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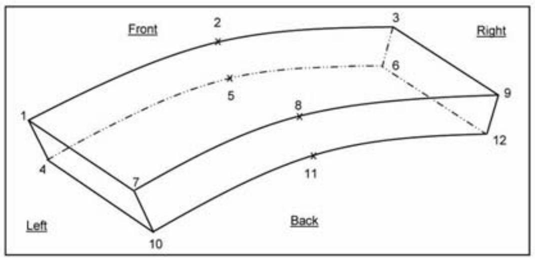
Project: P039-01

TUBGEO S.M.A.R.T. KUALA LUMPUR, 02.12.2003

Customer:	Kuala-Lumpur	**Place of work:**	W&F
MeasureDate:	12.01.2003	**Mould-No.:**	88888A1L1
MeasureTime:	14:18:25	**Segment-Type:**	A1
Temperature:	+10.0°C	**Ring-Type:**	L
Operator:	Wandel	**Calculated:**	15-12-2003



All unities are [mm]	Distance	Measured	Designed	Difference	Tolerance
Width	1-7	1646.1	1646.1	0.0	±0,00
	4-10	1650.3	1650.3	0.0	±0,00
	Mean (1-7 & 4-10)	1648.2	1648.2	0.0	±0,00
	2-8	1654.3	1654.3	0.0	±0,00
	5-11	1657.8	1657.8	0.0	±0,00
	3-9	1669.4	1669.4	0.0	±0,00
	6-12	1671.8	1671.8	0.0	±0,00
	Mean (3-9 & 6-12)	1670.6	1670.6	0.0	±0,00
	Mean value	1657.7	1657.7	0.0	±0,00
Thickness	1-4	500.0	500.0	0.0	±0,00
	7-10	500.0	500.0	0.0	±0,00
	3-6	500.0	500.0	0.0	±0,00
	9-12	500.0	500.0	0.0	±0,00
	Mean value	500.0	500.0	0.0	±0,00
Arc length	1-2-3	5038.3	5038.3	0.0	±0,00
	4-5-6	4645.6	4645.6	0.0	±0,00
	7-8-9	5038.3	5038.3	0.0	±0,00
	10-11-12	4645.6	4645.6	0.0	±0,00
	Mean value	4842.0	4842.0	0.0	±0,00
Torsion		0.0	0.0	0.0	±0,00
Inside radius		5915.0	5915.0	0.0	±99,90
Outside radius		6415.0	6415.0	0.0	±99,90
Packer			0.0		
Plane bestfit Longitudinal joints	Left	0.0	0.0	0.0	±0,00
	Right	0.0	0.0	0.0	±0,00
Plane bestfit Circumferential joints	Front	0.0	0.0	0.0	±0,00
	Back	0.0	0.0	0.0	±0,00
Parallelism	Inside radius	0.0	0.0	0.0	±0,00
	Outside radius	0.0	0.0	0.0	±0,00

Record

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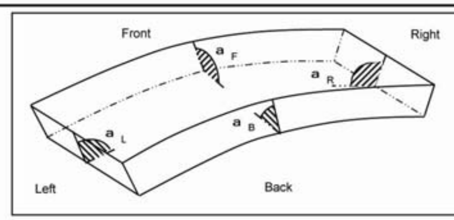
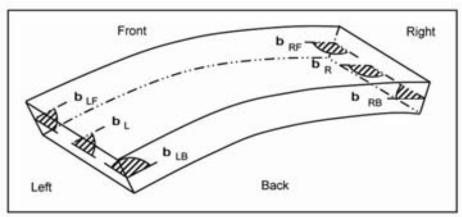


	Angle	Measured	Designed	Difference	Tolerance
Division angle	[°]	45.00	45.00	0.00	±0,000
Border angles (über: +500,00mm)	a_L [°]	90.00	90.00	0.00	±0,000
	[mm]			0.0	±0,00
	a_R [°]	90.00	90.00	0.00	±0,000
	[mm]			0.0	±0,00
	a_F [°]	89.80	89.80	0.00	n.a.
	[mm]			0.0	n.a.
	a_B [°]	89.80	89.80	0.00	n.a.
	[mm]			0.0	n.a.



	Angle	Measured	Designed	Difference	Tolerance
Longitudinal joints (über: +1657,72mm)	b_{LF} [°]	90.05	90.05	0.00	±0,000
	b_{LB} [°]	90.05	90.05	0.00	±0,000
	Mean b_L [°]	90.00	90.00	0.00	±0,000
	[mm]			0.0	±0,00
	b_{RF} [°]	89.80	89.80	0.00	±0,000
	b_{RB} [°]	89.80	89.80	0.00	±0,000
	Mean b_R [°]	90.00	90.00	0.00	±0,000
	[mm]			0.0	±0,00

1. Bestfit and Parallelism of Contact-surfaces

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segment	longitudinal		circumferrential		parallelism	
	left	right	front	back	inside	outside
A_R6	0.3	-0.3	0.4	-0.5	-1.9	-3.0
A_R7	0.4	-0.4	-0.6	-0.4	-0.8	1.6
A_L8	-0.3	-0.3	0.3	0.7	0.8	2.1
A_L9	0.4	-0.3	0.5	0.5	-1.7	1.0
A_L10	-0.4	0.3	-0.4	-0.6	-0.7	1.3
B_R6	-0.2	-0.3	0.3	-0.5	-2.0	1.7
B_R7	-0.4	0.4	-0.4	0.5	1.0	1.4
B_L8	-0.3	0.2	0.4	-0.5	-1.6	1.4
B_L9	-0.3	0.4	-0.3	-0.3	-0.7	0.9
B_L10	-0.3	-0.3	-0.4	-0.4	-0.9	1.2
C_R6	0.5	-0.4	-0.4	-0.6	0.6	1.6
C_R7	0.5	-0.3	-0.4	-0.5	0.9	1.6
C_L8	-0.5	0.3	-0.4	-0.4	-1.7	2.0
C_L9	-0.4	0.4	-0.3	0.7	0.4	-1.1
C_L10	-0.6	0.7	0.5	-0.6	0.5	-1.3
D_R6	-0.4	-0.2	-0.3	0.4	0.6	1.9
D_R7	-0.6	0.5	-0.3	-0.4	-0.8	1.7
D_L8	0.4	-0.4	-0.4	-0.7	0.7	1.6
D_L9-1	-0.6	-0.4	-0.4	0.4	0.6	1.5
D_L9-2	-0.6	-0.3	-0.5	0.4	0.7	1.4
D_L10	-0.8	-0.5	-0.3	-0.6	-1.6	1.1
E_R6	0.5	-0.3	-0.4	0.6	0.7	-1.5
E_R7	-0.4	0.3	0.3	0.3	0.7	1.5
E_L8	-0.5	-0.2	-0.2	-0.3	-0.6	1.4
E_L9	-0.7	-0.4	0.2	0.4	0.8	-1.5
E_L10	-0.6	0.5	0.3	-0.7	0.6	1.3
F_R6	-0.3	-0.3	-0.3	0.4	0.5	-1.3
F_R7	-0.6	-0.5	-0.4	-0.6	0.6	1.5
F_L8	-0.4	-0.9	-0.4	0.6	0.3	2.1
F_L9	0.5	0.4	-0.2	0.7	0.6	1.4
F_L10	-0.6	-0.4	-0.4	-0.5	0.9	1.1
G_R6	-0.2	-0.3	-0.2	0.6	0.7	2.7
G_R7	-0.4	-0.5	-0.2	0.4	0.6	1.2
G_L8	-0.5	0.3	0.3	-0.4	0.3	-1.3
G_L9	-0.3	0.4	0.5	-0.4	0.4	1.4
G_L10	-0.7	-0.7	0.2	0.6	0.8	1.1
H_R6	-0.3	0.3	-0.3	-0.4	-1.0	1.1
H_R7	-0.4	0.4	-0.4	0.6	0.4	1.2
H_L8	-0.3	0.3	0.3	-0.4	-0.4	1.1
H_L9	0.7	-0.2	0.2	-0.3	-0.7	1.3
H_L10	-0.6	0.4	-0.3	-0.2	0.6	-1.3
K_R6	-0.5	-0.5	-0.2	-0.2	0.2	1.1
K_R7	0.5	0.4	0.2	-0.2	0.4	1.3
K_L8	-0.7	-0.4	-0.2	-0.2	0.3	0.8
K_L9	0.5	-0.7	0.2	0.4	0.4	-1.3
K_L10	0.4	-0.4	0.1	-0.1	0.3	0.9
mean value	**0.44**	**0.41**	**0.33**	**0.48**	**0.88**	**1.25**
Tolerance	+/-0,7	+/-0,7	+/-1,0	+/-1,0	+/-2,0	+/-3,0

Mould & Segment Measurement

Test Certificate

Date:	27.09.2001	Segment No.	0013A5R10		
Time:	10:41:28	Segment Type:	A5		
Temperature:	+25.0°C	Taper:	R		
Criteria:	**Measurement**	**Design Value**	**DIFFerence**	**TOLerance**	**Release**
Smoothness of contact surfaces					
Radial Joint					
Left:	-0.23mm	+0.00mm	**-0.23mm**	±0.30mm	YES
Right:	+0.13mm	+0.00mm	**+0.13mm**	±0.30mm	YES
Front:	-0.34mm	+0.00mm	**-0.34mm**	±0.50mm	YES
Back:	-0.44mm	+0.00mm	**-0.44mm**	±0.50mm	YES
Inner radius (Single segment)					
Inside:	-0.60mm	+0.00mm	**-0.60mm**	±2.00mm	YES
Linear Dimensions					
Segment Width					
Left / Outside:	+2021.87mm	+2021.94mm	-0.07mm	±0.60mm	YES
Left / Inside:	+2020.29mm	+2020.14mm	+0.15mm	±0.60mm	YES
Middle / Outside:	+2021.59mm	+2021.94mm	-0.35mm	±0.60mm	YES
Middle / Inside:	+2020.03mm	+2020.14mm	-0.11mm	±0.60mm	YES
Right / Outside:	+2017.53mm	+2017.59mm	-0.06mm	±0.60mm	YES
Right / Inside:	+2016.30mm	+2016.15mm	+0.15mm	±0.60mm	YES
Mean:	+2019.90mm	+2020.00mm	**-0.10mm**	±0.60mm	YES
Segment Arc length					
Front / Outside:	+4936.35mm	+4936.79mm	-0.44mm	±2.00mm	YES
Front / Inside:	+4533.70mm	+4532.87mm	+0.83mm	±2.00mm	YES
Back / Outside:	+4936.46mm	+4936.78mm	-0.32mm	±2.00mm	YES
Back / Inside:	+4533.81mm	+4532.87mm	+0.94mm	±2.00mm	YES
Mean:	+4735.08mm	+4734.83mm	**+0.25mm**	±2.00mm	YES
Angular deviation					
Segment:displacement angle	+51.431[°]	+51.429[°]	**+0.002[°]**	±0.020[°]	YES
Radial Conicality (over: +450.0mm)					
Left (Inner):	+89.922[°]	+90.000[°]	-0.078[°]	±0.100[°]	YES
			-0.61mm	±0.79mm	YES
Right (Inner):	+89.914[°]	+90.000[°]	-0.086[°]	±0.100[°]	YES
Longitudinal Conicality (over: +2019.90mm)					
Front / Left:	+89.989[°]	+90.000[°]	-0.011[°]	±0.030[°]	YES
Left / Back:	+90.063[°]	+90.052[°]	+0.011[°]	±0.030[°]	YES
Left (Front):	+89.963[°]	+89.974[°]	-0.011[°]	±0.030[°]	YES
			-0.38mm	±1.05mm	YES
Right / Front:	+90.014[°]	+90.000[°]	+0.014[°]	±0.030[°]	YES
Back / Right:	+90.132[°]	+90.146[°]	-0.014[°]	±0.030[°]	YES
Right (Front):	+89.941[°]	+89.927[°]	+0.014[°]	±0.030[°]	YES
			+0.49mm	±1.05mm	YES

Mould & Segment Measurement

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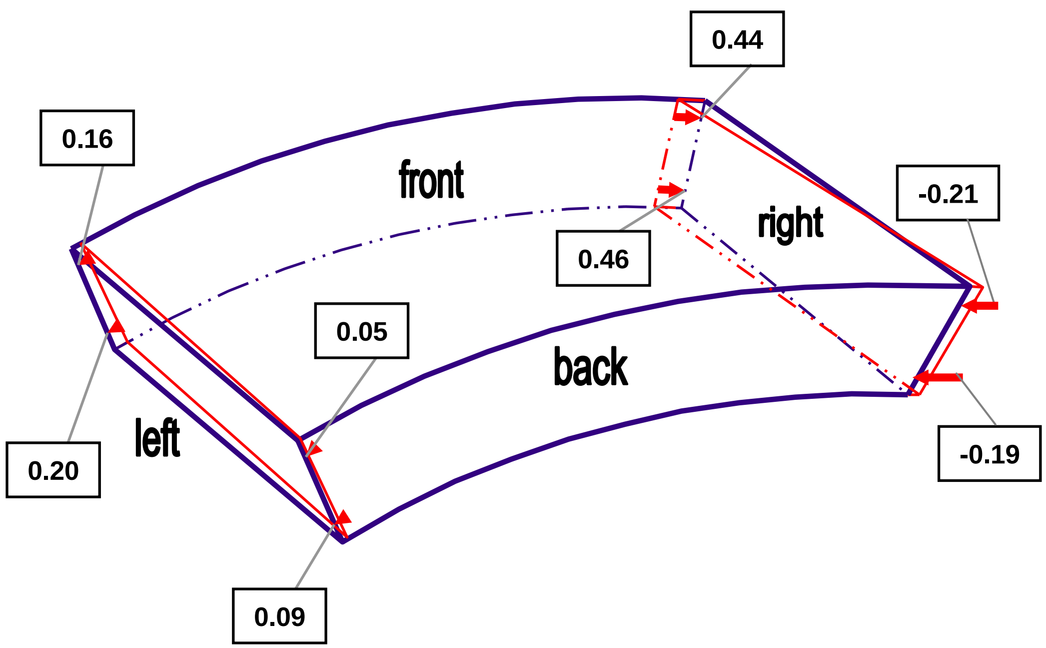
Correction Scheme



- Illustrates any significant modifications proposed with respect to their feasibility
- Based on test certificate
- After any geometrical modification the mould must be resurveyed for confirmation

Mould & Segment Measurement

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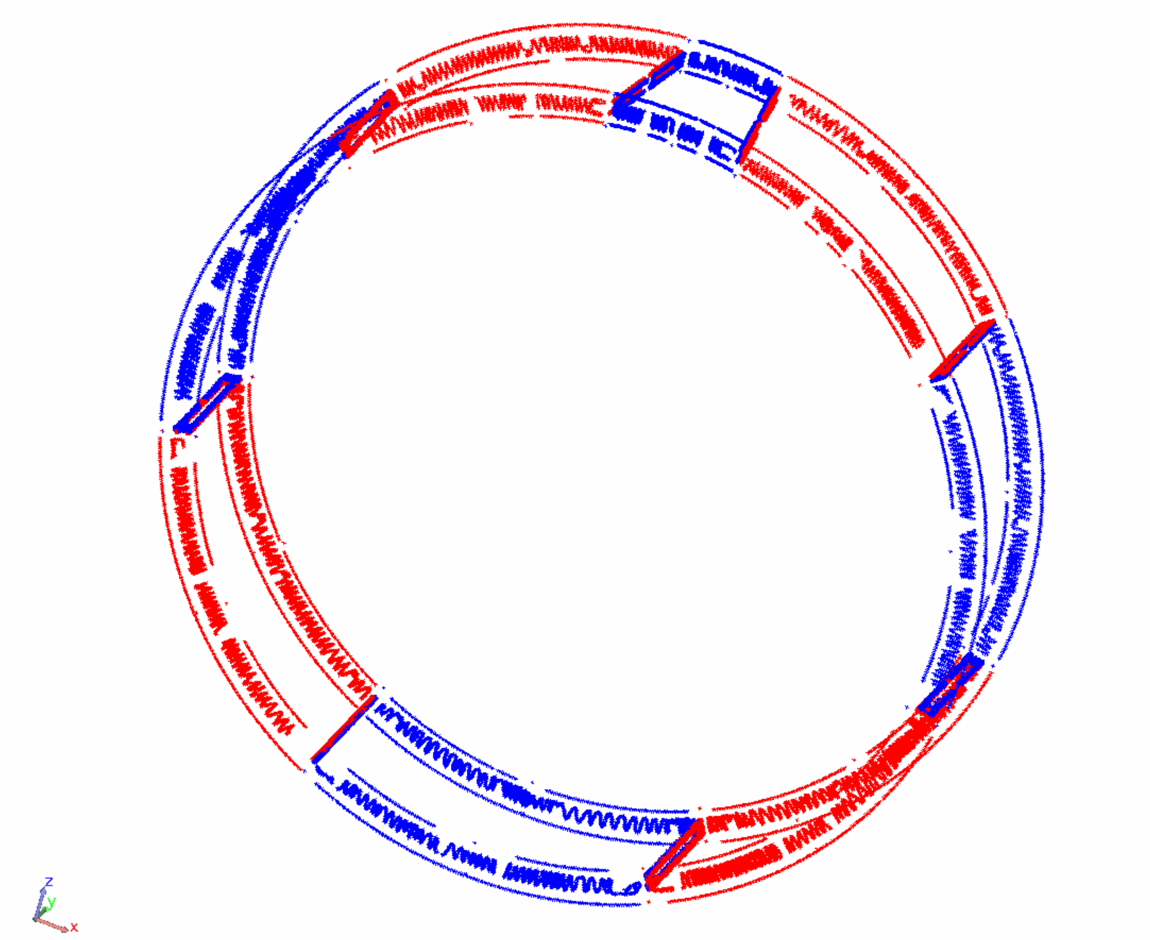
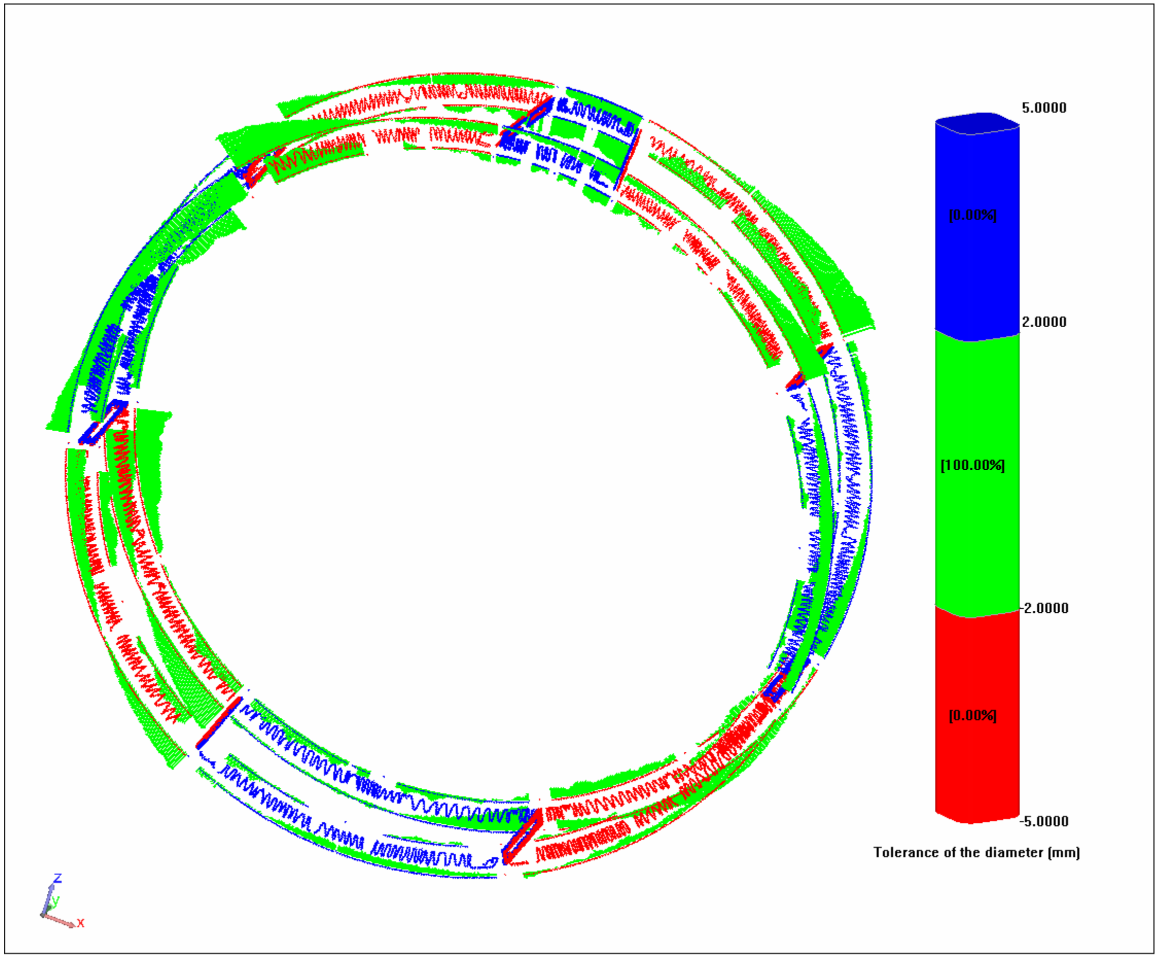
Virtual Ring Build



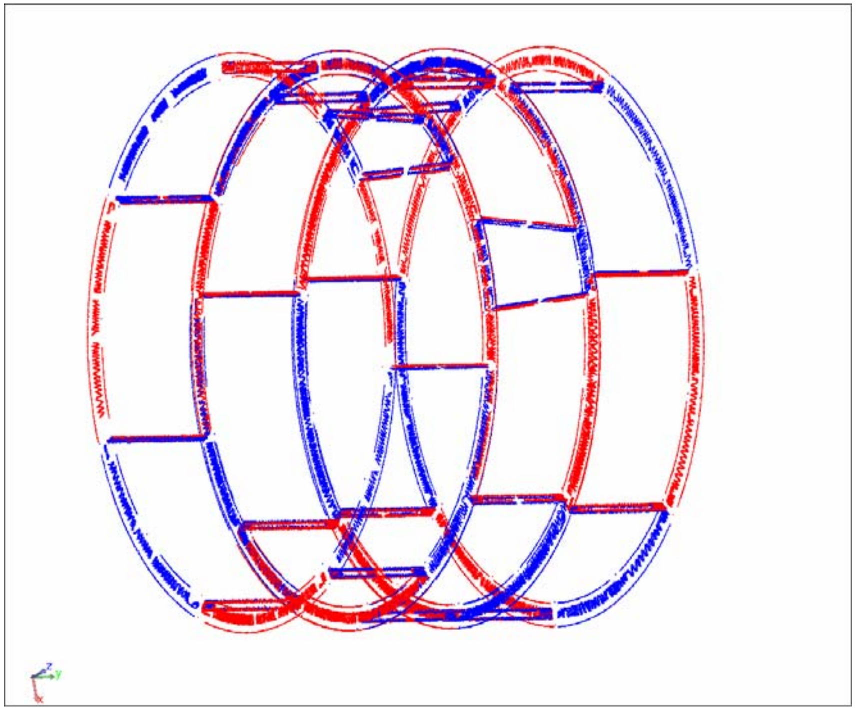
Mould & Segment Measurement

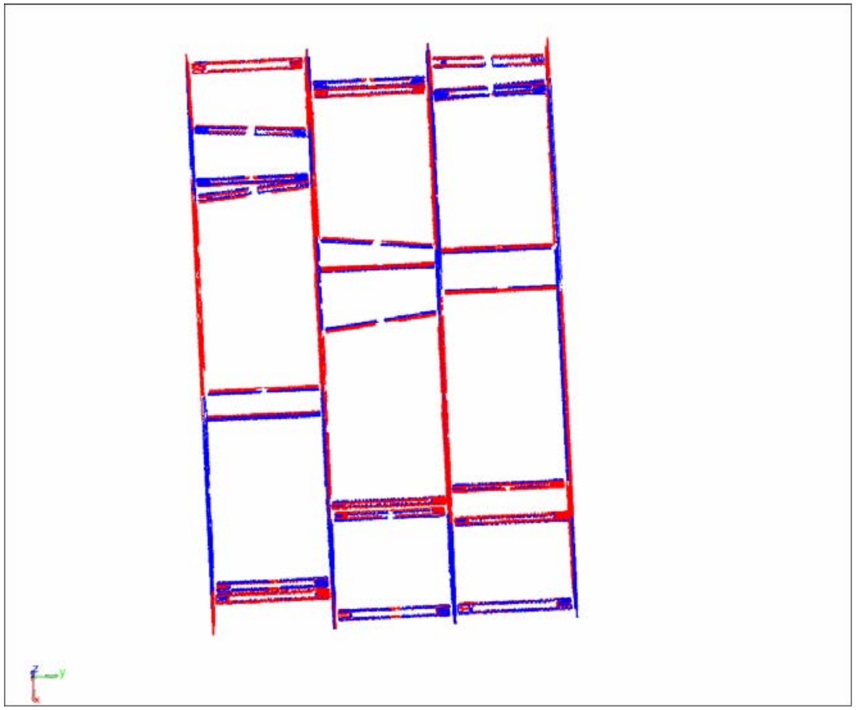
Tolerances on Virtual Ring Build



Mould & Segment Measurement

Virtual Ring Build – Multiple Rings





Mould & Segment Measurement

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Suggested Quality Assurance of Segments

1. Measurement control of all moulds before mass production
2. Measurement control of all segments after first pouring
3. Measurement control of all segments after 10^{th} pouring
4. Measurement control of all segments after 20^{th} pouring
5. Measurement control of all segments after 30^{th} pouring
6. Tolerances on “closed“ (built) ring must NOT be the sum of all individual tolerances.
7. Individual tolerances should be compensated with the mathematical sign
8. Every controlled segment must be proved by a record sheet


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Thank you for your attention !