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The Octoball – an artefact for additive manufacturing precision assessment

by

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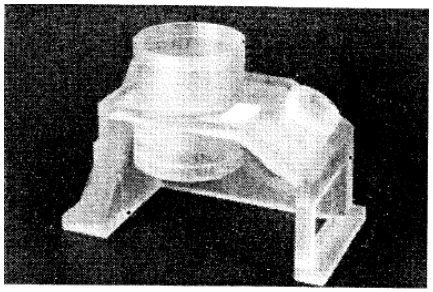
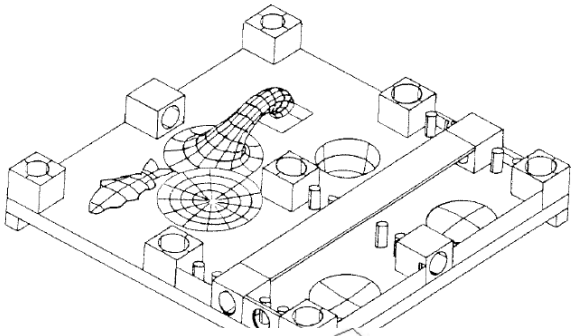
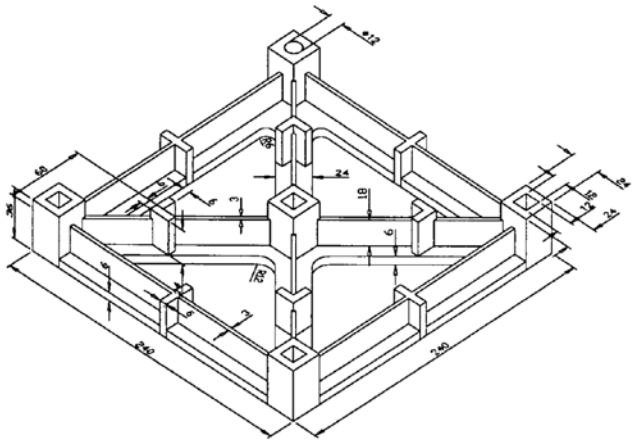
STC P

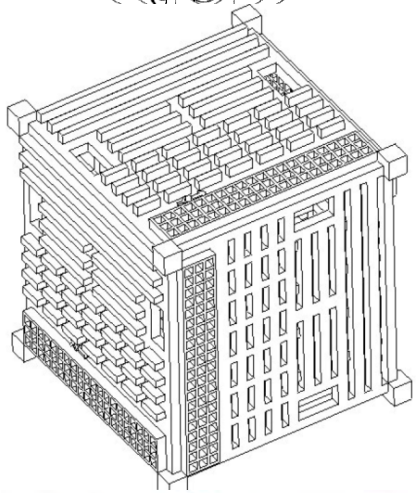
Literature Review

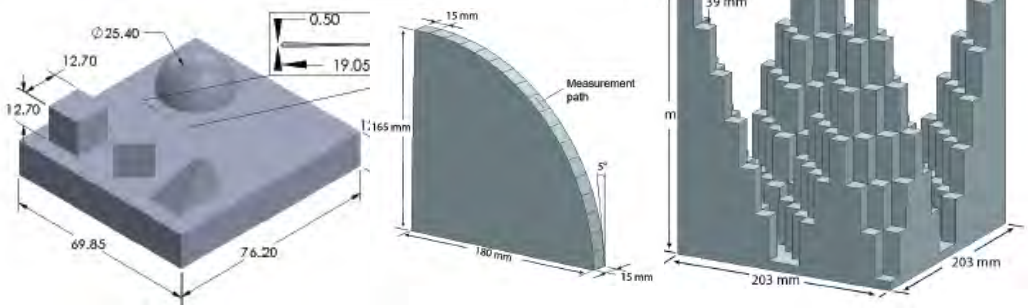
- Keynote: **Kruth**, J. P. (**1991**). "Material Incress Manufacturing by Rapid Prototyping Techniques." **CIRP** Annals - Manufacturing Technology 40(2): 603-614.
- **Childs**, T. H. C. and N. P. **Juster** (**1994**). "Linear and Geometric Accuracies from Layer Manufacturing." **CIRP** Annals - Manufacturing Technology 43(1): 163-166. (FDM: 0.254 mm)
- **Ippolito**, R., L. **Iuliano** and A. **Gatto**, "Benchmarking of Rapid Prototyping Techniques in Terms of Dimensional Accuracy and Surface Finish." CIRP Annals - Manufacturing Technology 44(1): 157-160, **1995**.
- D. **Dimitrov**, W. van **Wijck**, K. **Schreve**, N. **de Beer**, and J. **Meljer**, "An Investigation of the Capability Profile of the Three Dimensional Printing Process wit an Emphasis on the Achievable Accuracy," **CIRP** Annals - Manufacturing Technology, 52(1): 189-192, **2003**.
- **C. Bayley1, L. Bochmann, C. Hurlbut, M. Helu, R. Transchel, and D. Dornfeld**, "Understanding Error Generation in Fused Deposition Modeling," in **2014** Spring Topical Meeting, **ASPE**, Volume 57 , 98-103.











The process : fused deposition modelling (FDM)

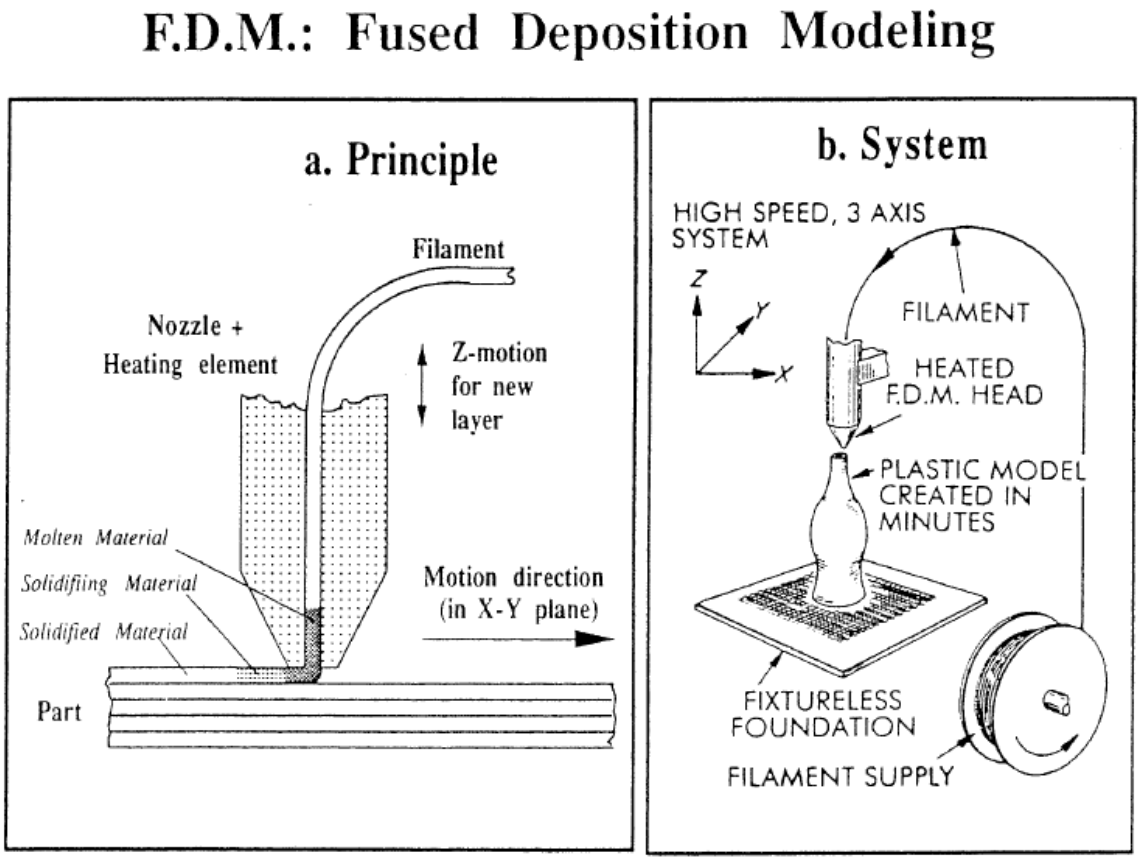
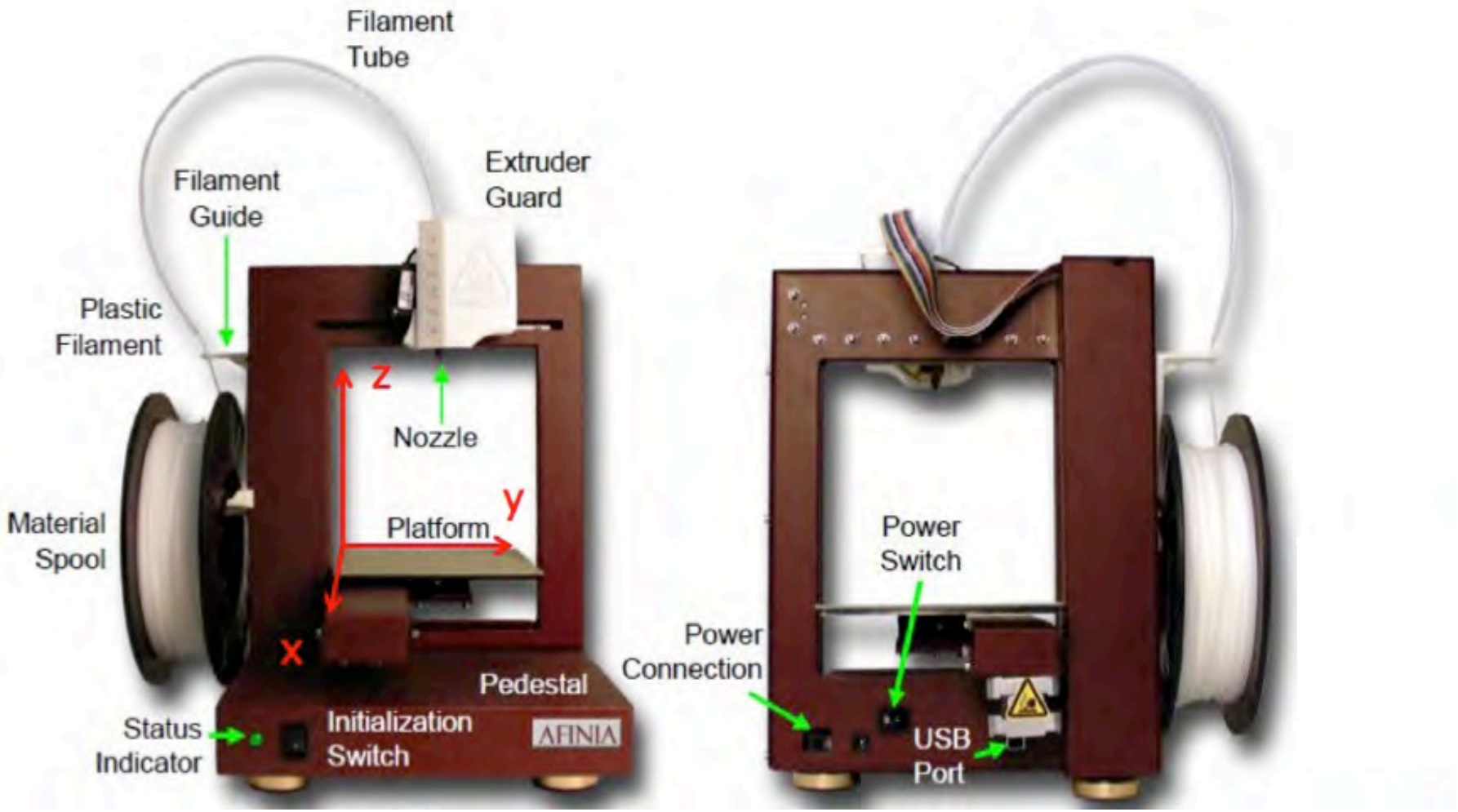


Fig.12. Fused Deposition Modeling.

Keynote: Kruth, J. P. (1991). "Material Incress Manufacturing by Rapid Prototyping Techniques." CIRP Annals - Manufacturing Technology 40(2): 603-614.

The FDM machines

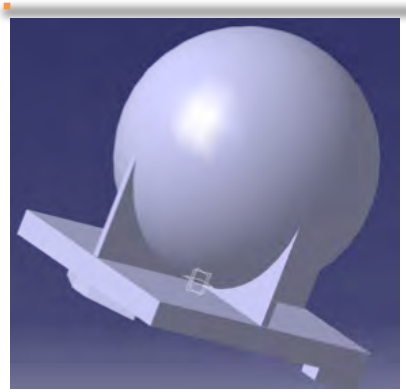
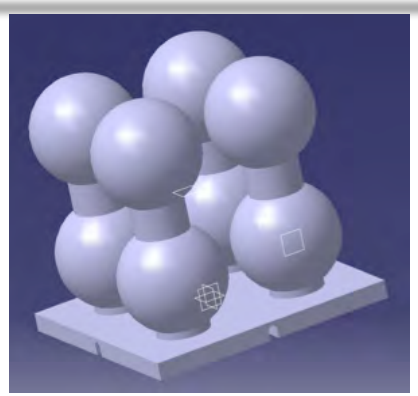
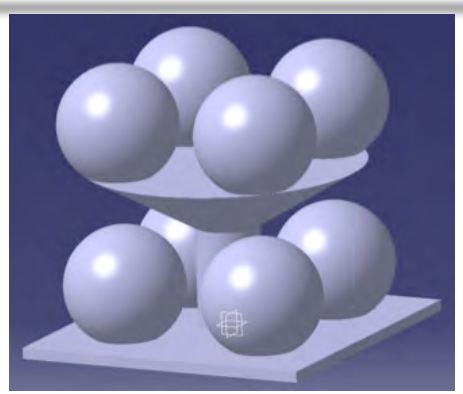
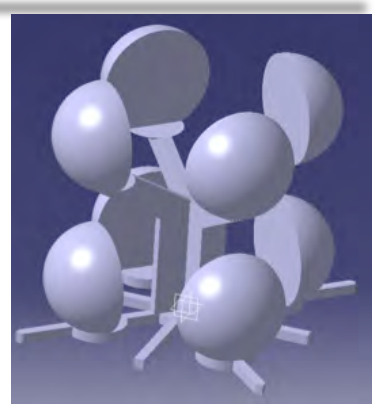
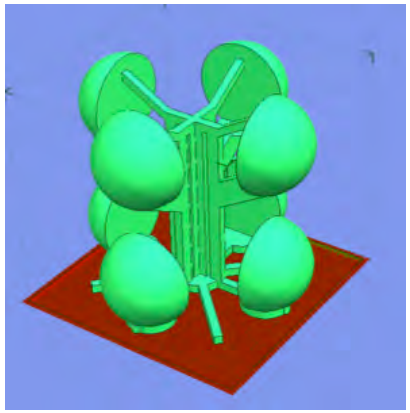
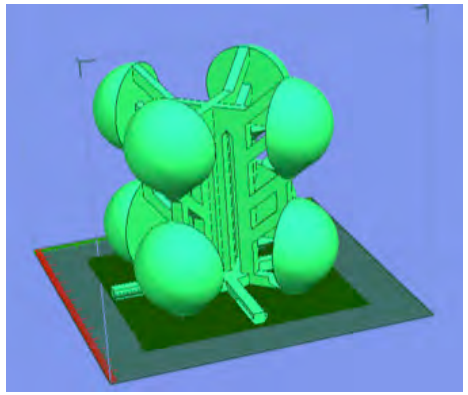
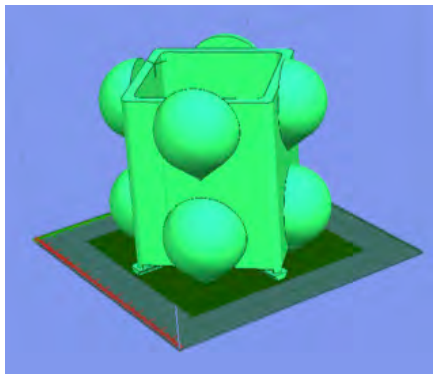
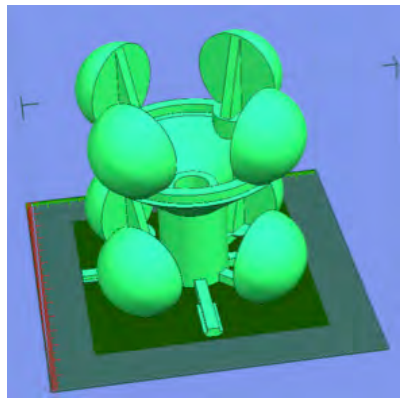
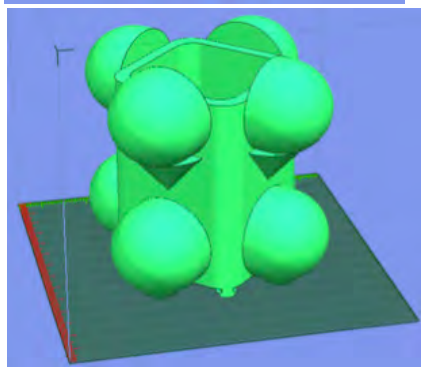
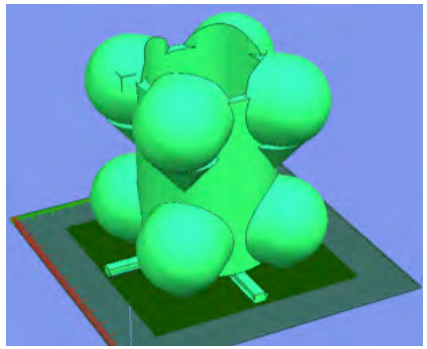
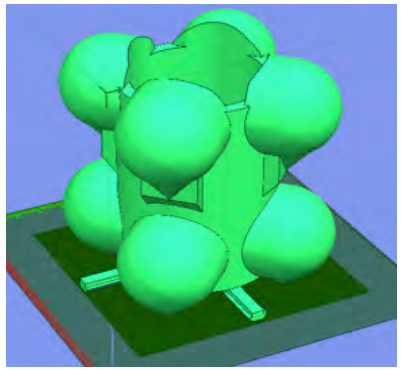


The lab : fused deposition modelling

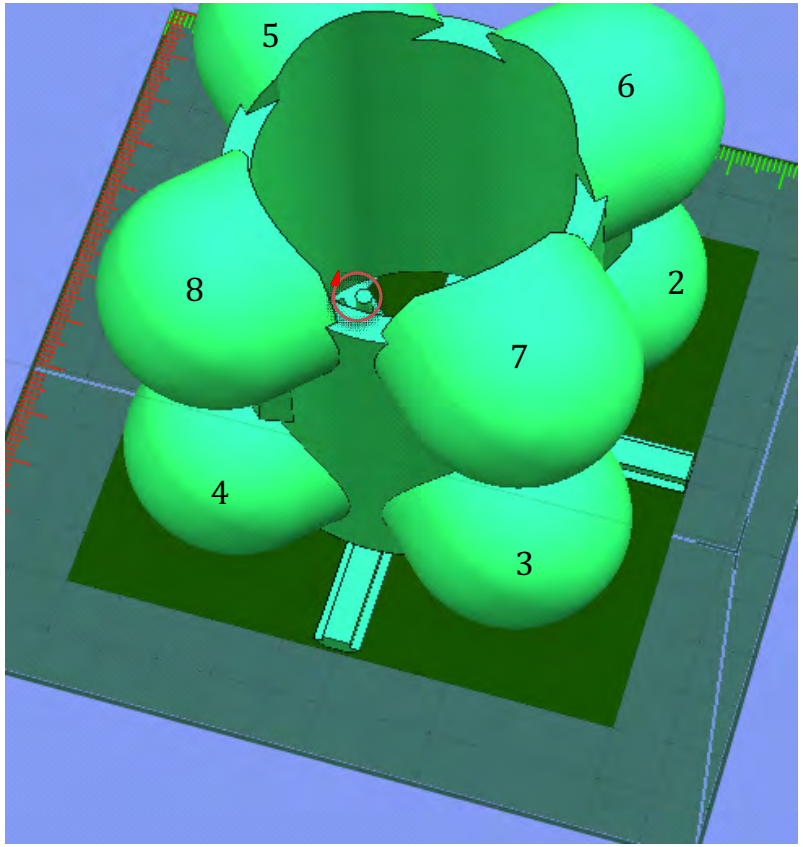
Objective

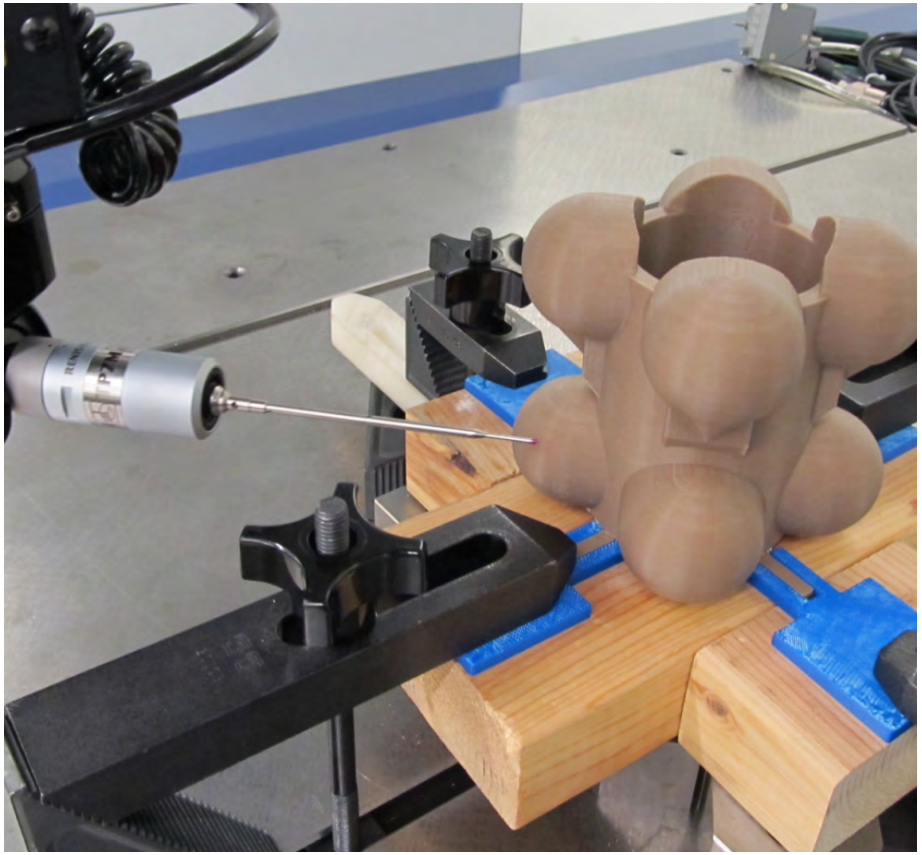
- Simple measurement and analysis
- Quantify the effect of :
  - Feature position and orientation.
- on:
  - Form;
  - Size;
  - Position.

The artefact design evolution

Measurement

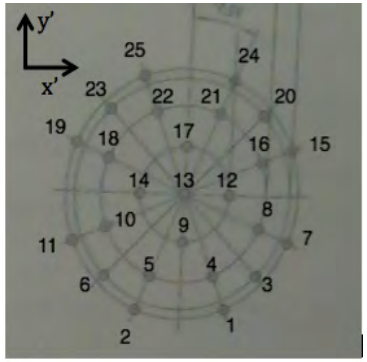




LEGEX+TP7M

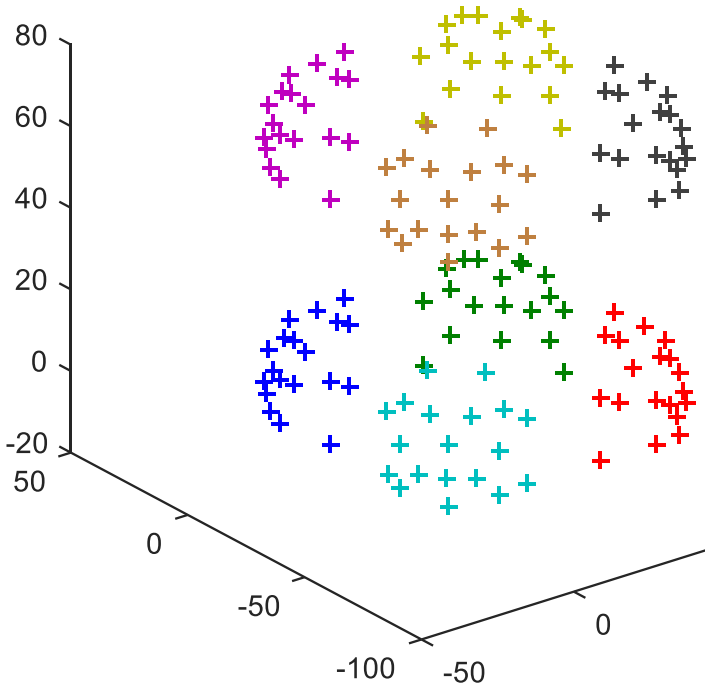
Stylus tip ϕ = 2 mm

Measurement; higher density

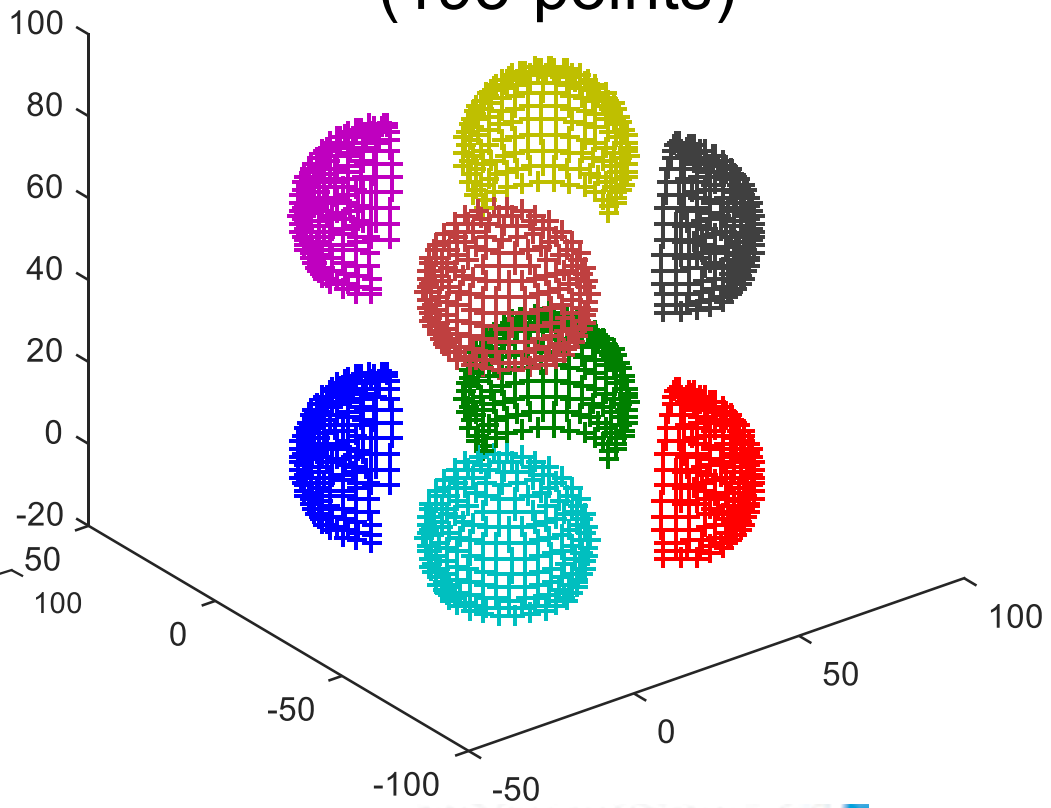


ISO 10360-2

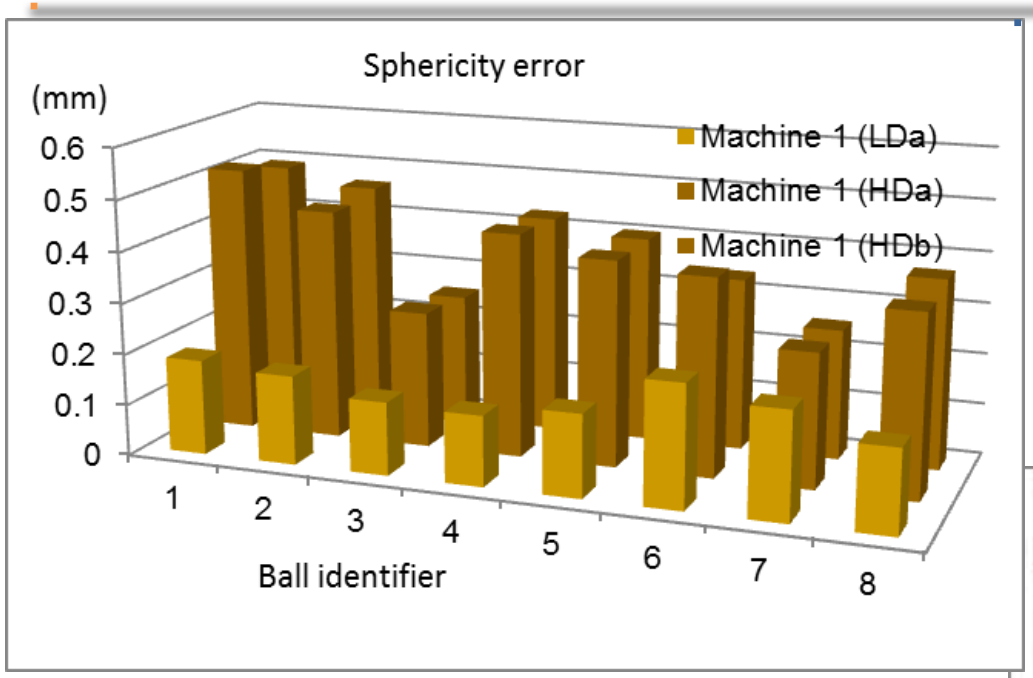
Low density
(19 points)

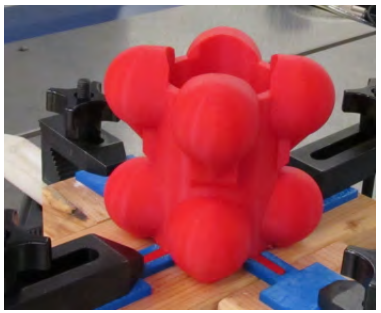


High density
(193 points)

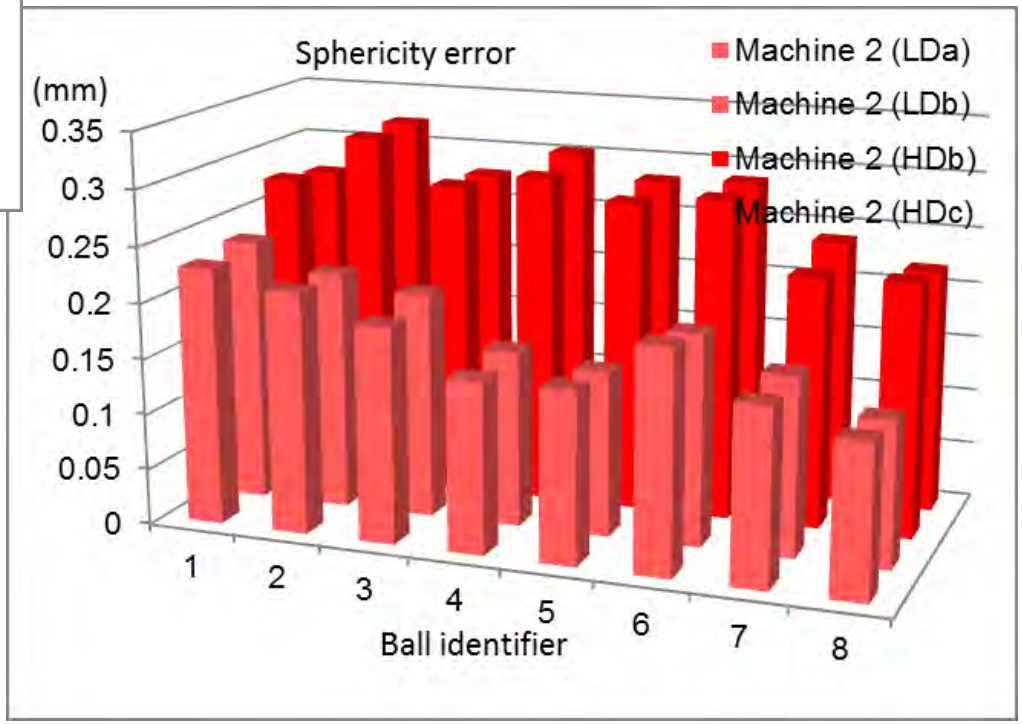


Sphericity of spheres; low and high density

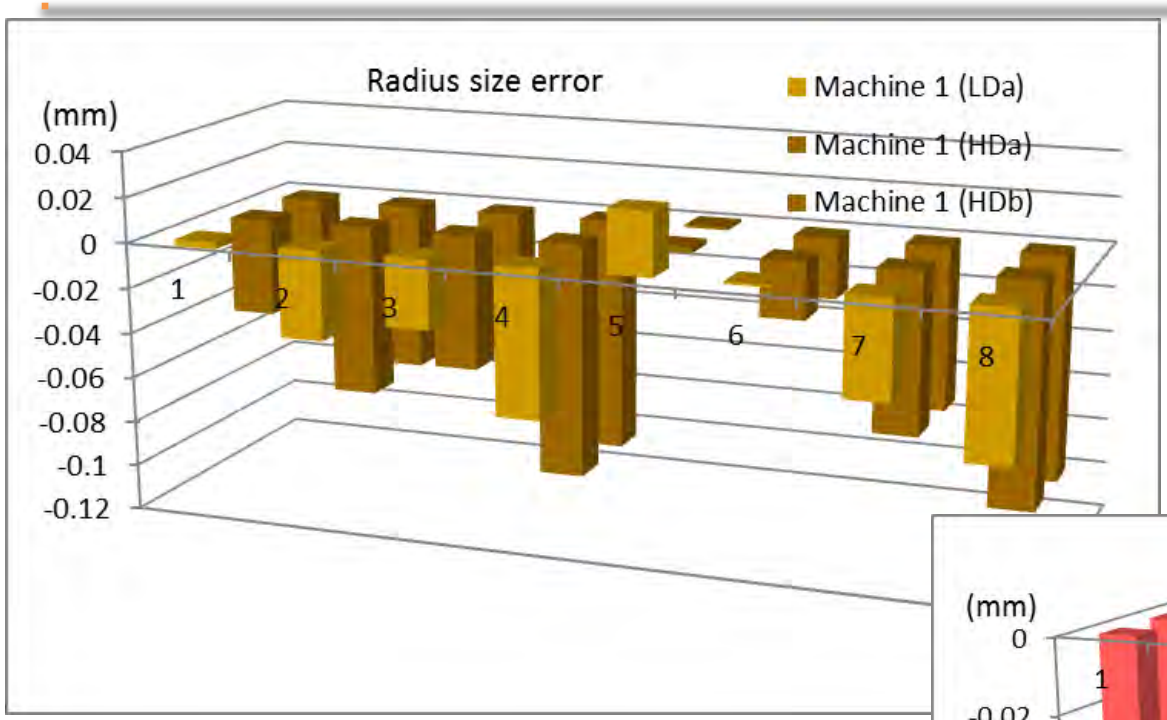


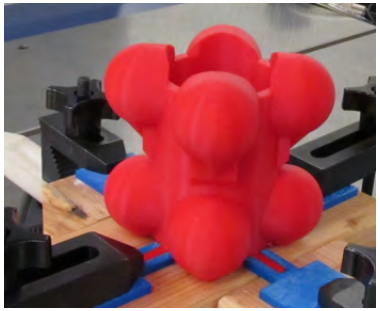


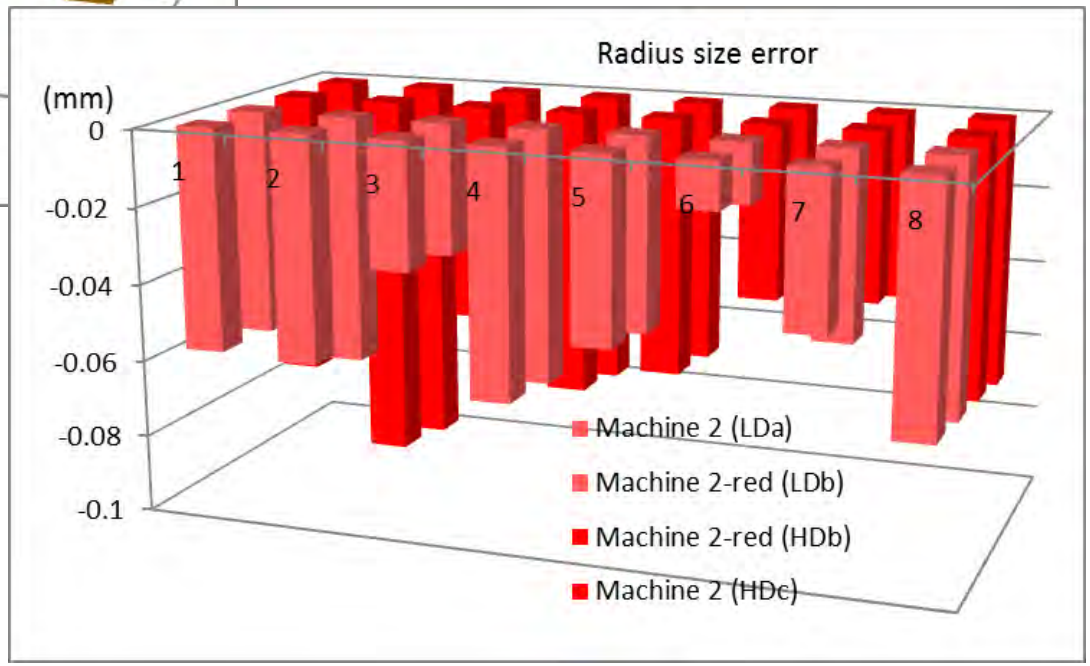
P. Bourdet, A. Clément, Controlling a complex surface with a 3-axis measuring machine, Annals of the CIRP, 25(1), 359-361, 1976.



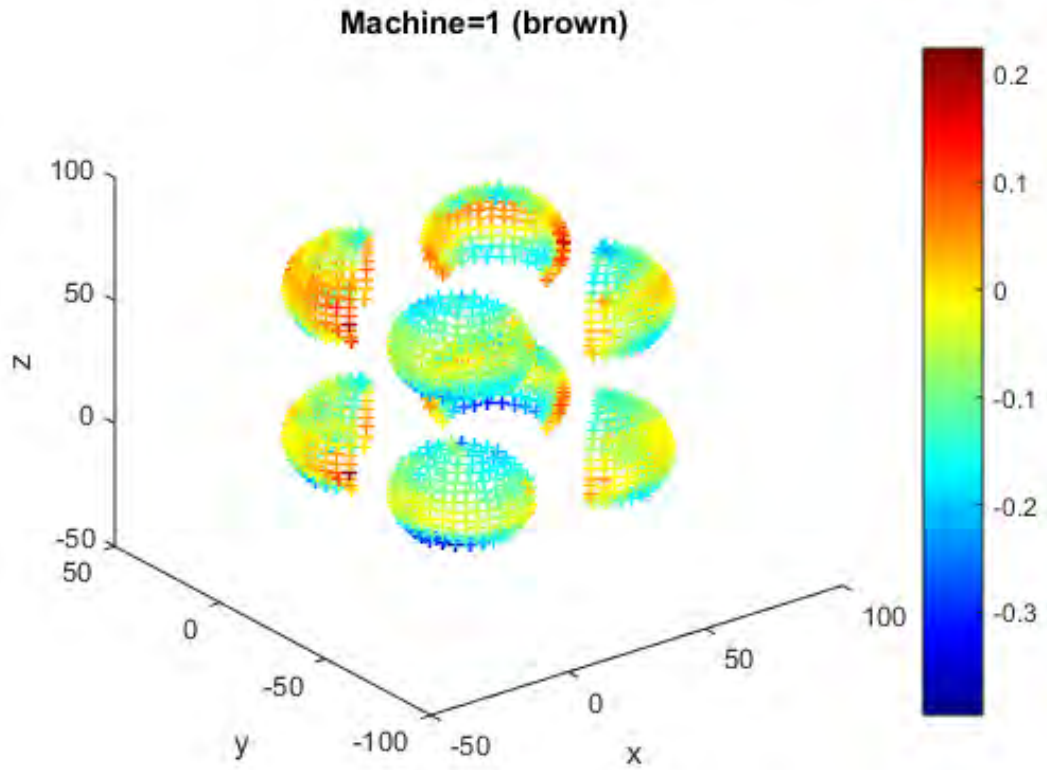
Size of spheres; low and high density

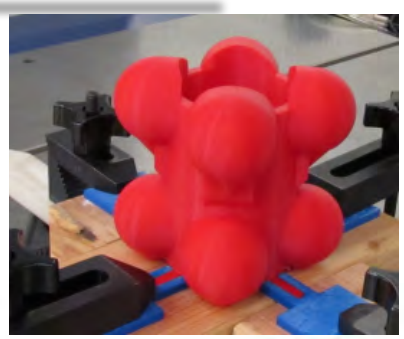


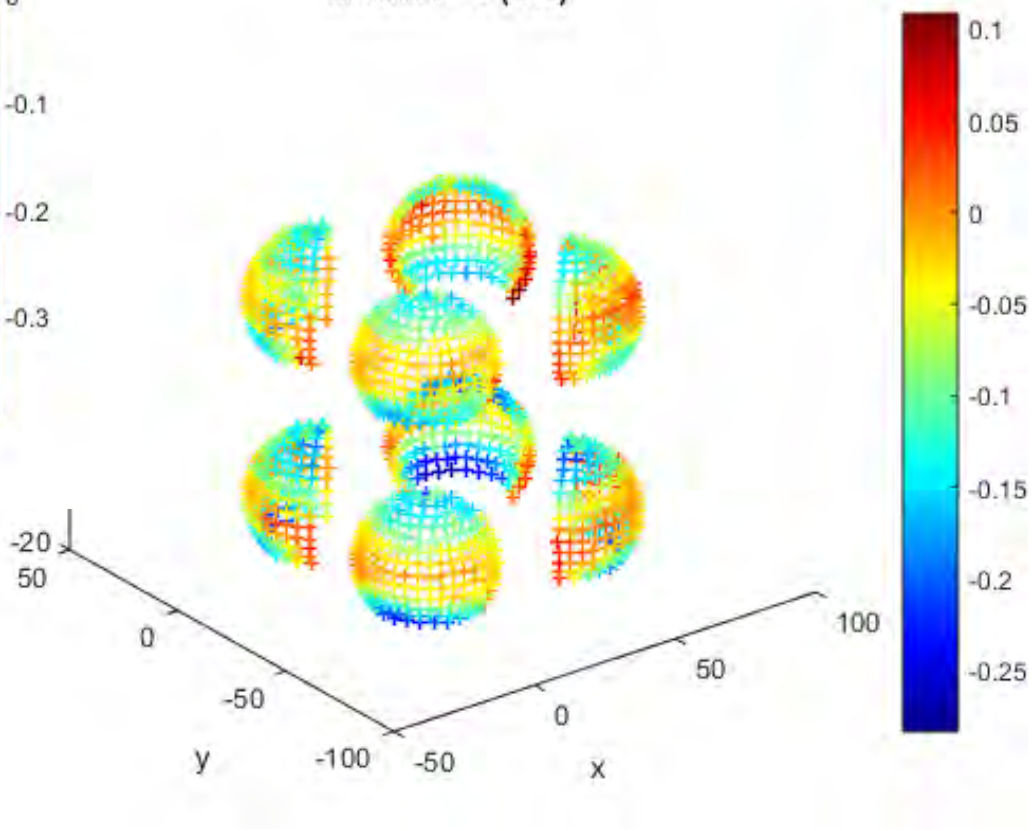




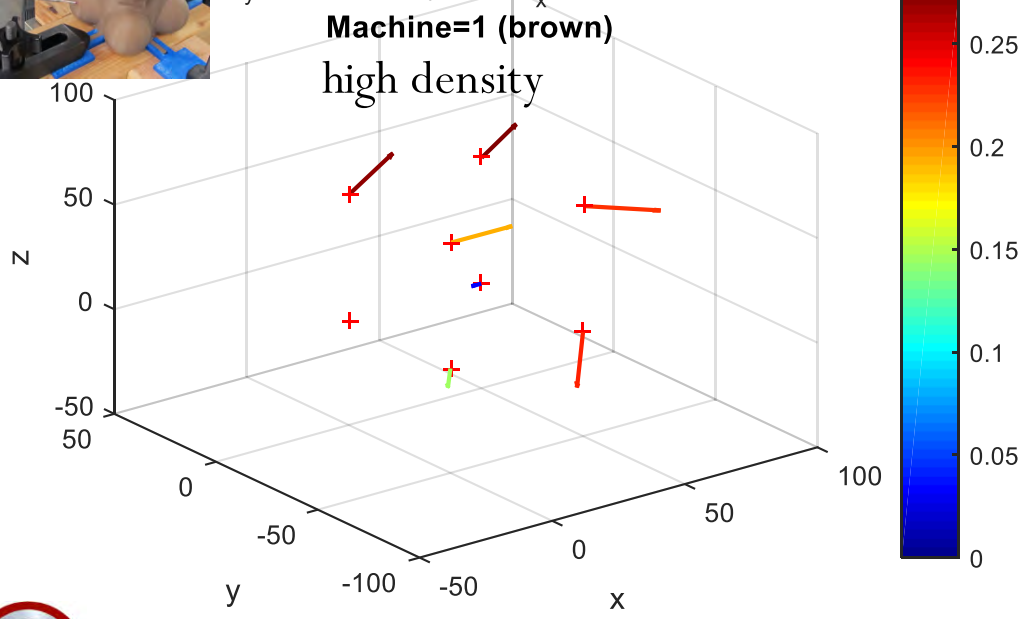
Difference from nominal; shape + size; HD

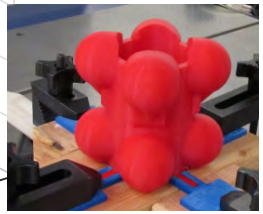


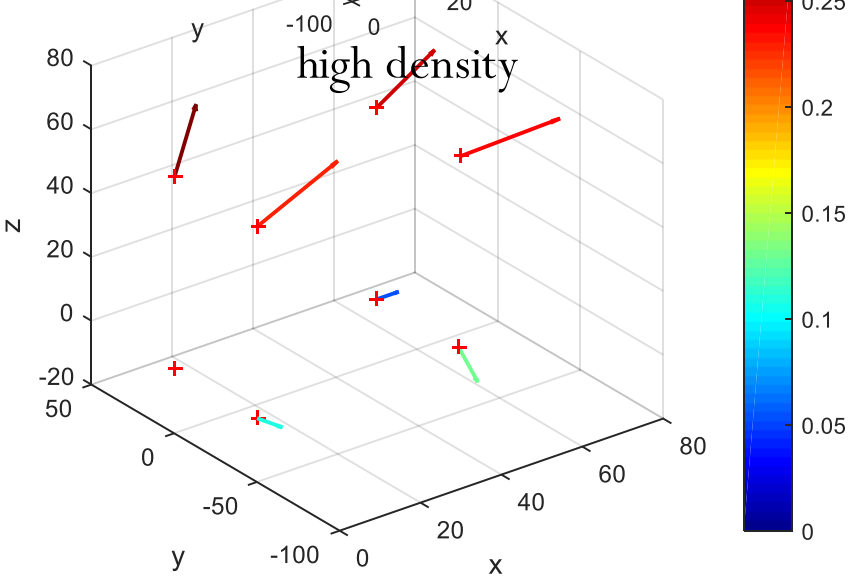




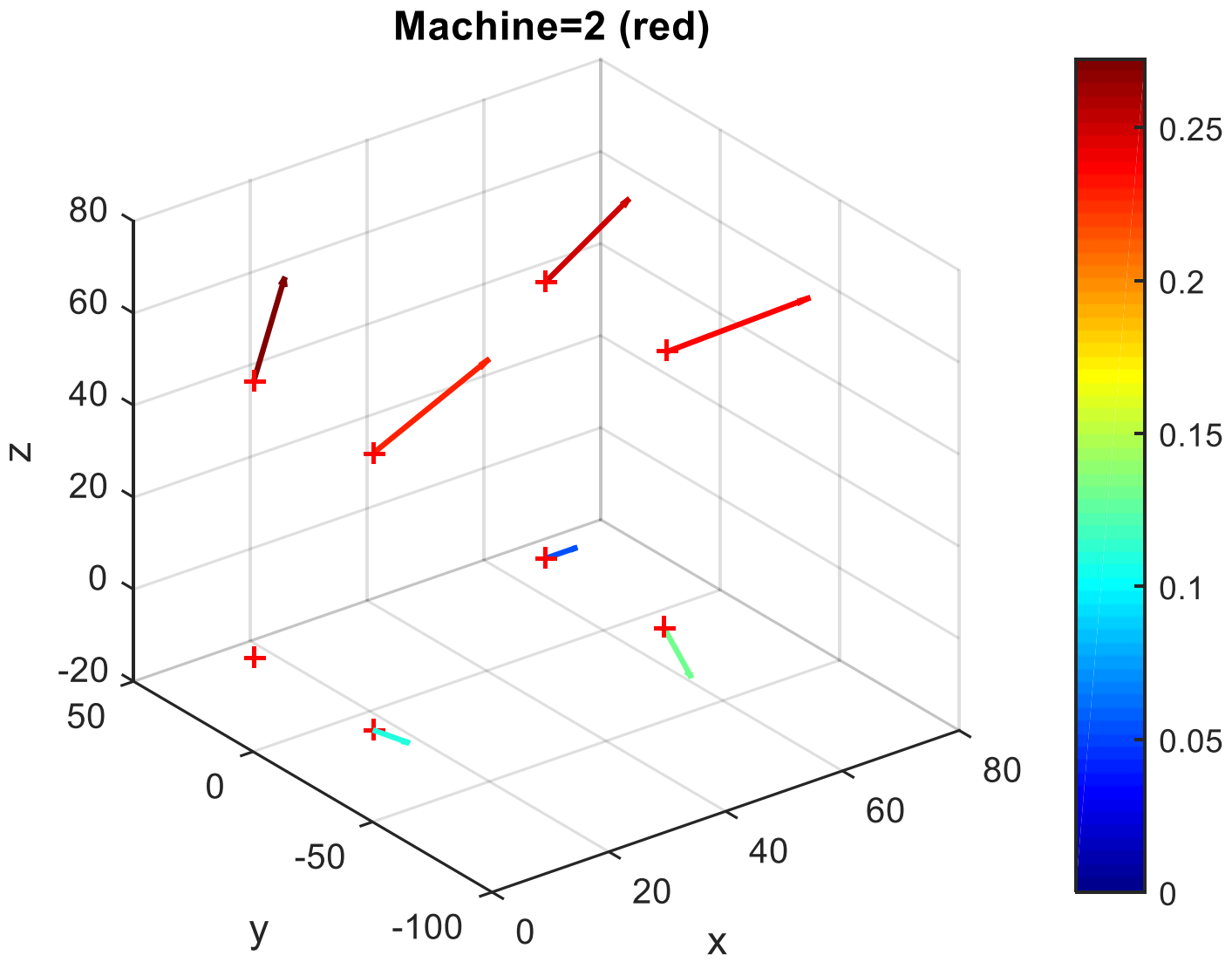
Position of spheres; low and high density



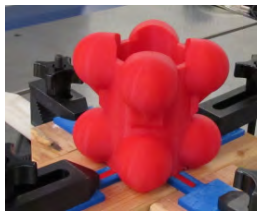




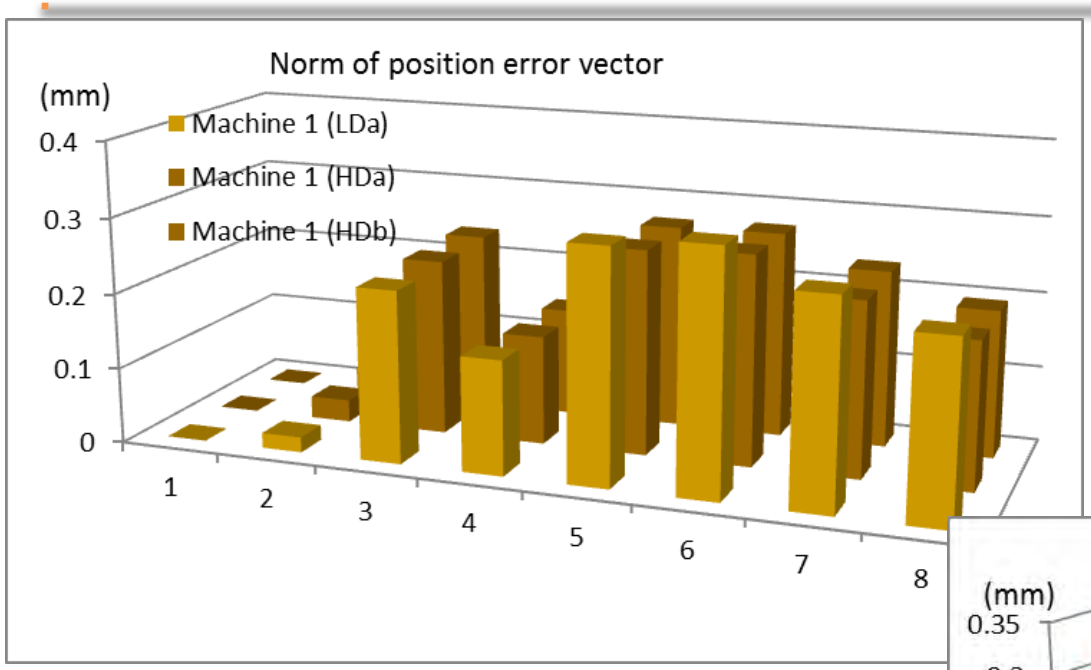
Position of spheres; low and high density

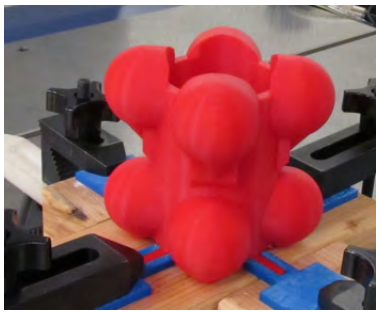


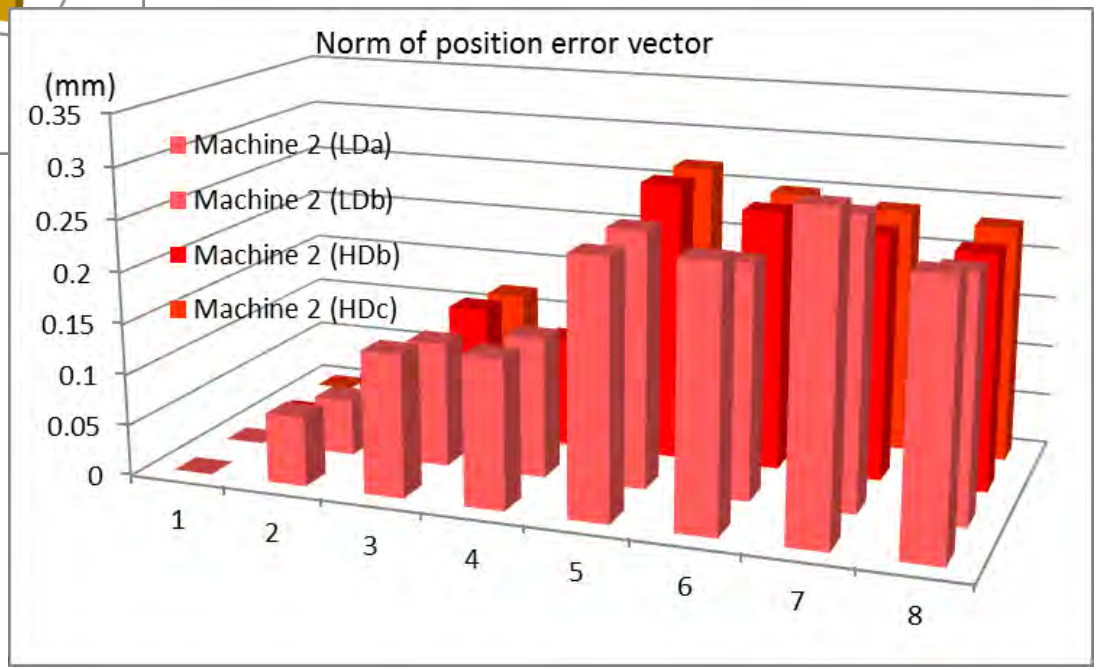
High density



Norm of spheres position error







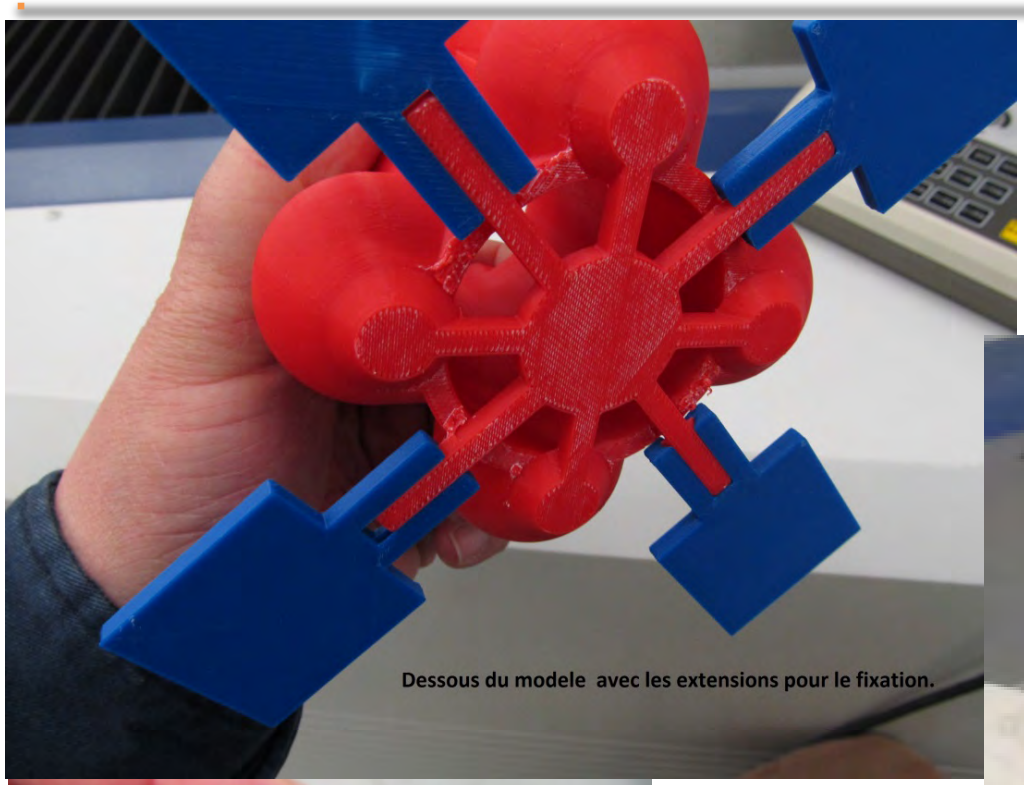
Discussion; future work

- Stylus tip radius?
  - Separating surface finish and form?
- Sampling density?
- Fixturing?
- Choice of datum features (ABC)?
- Optical scanners?
- …

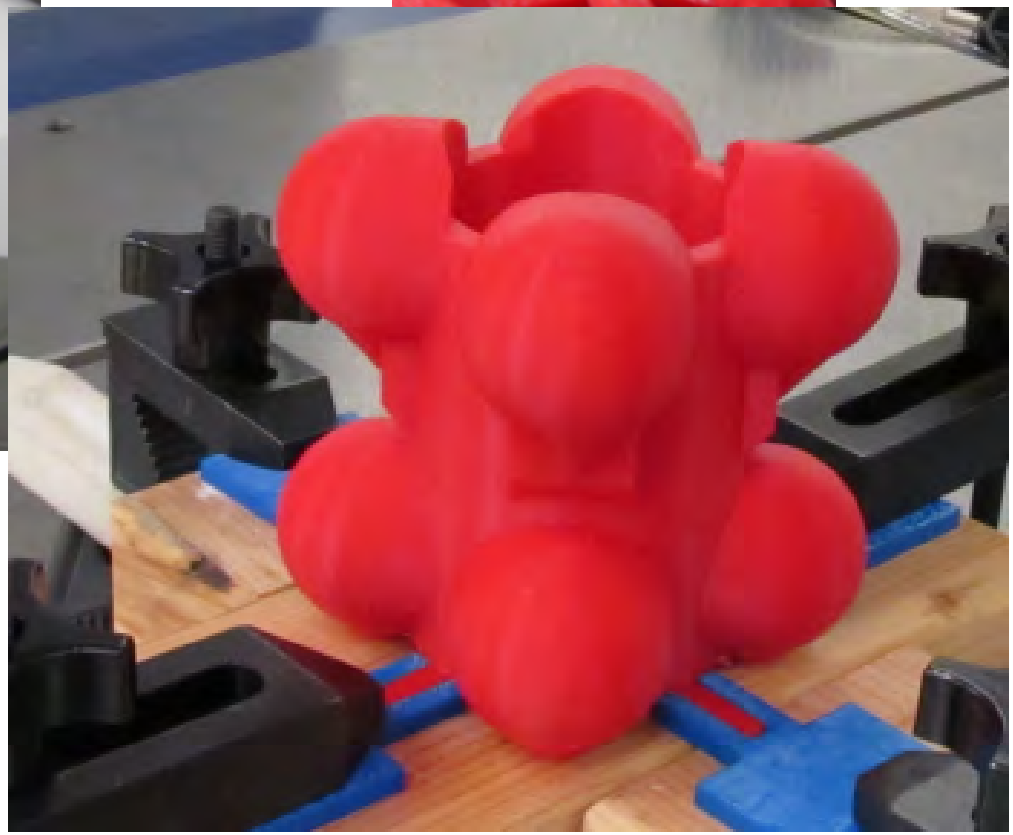
Acknowledgment

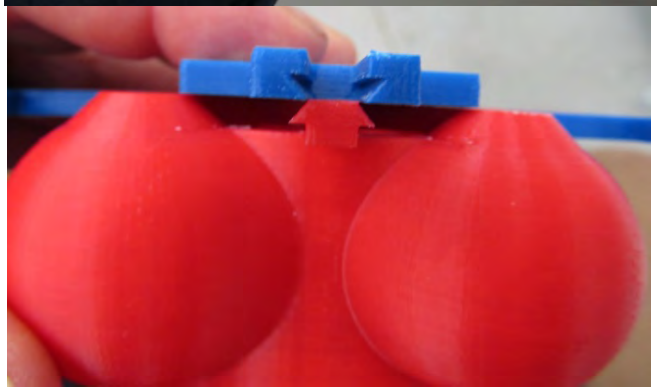
Funded by the Natural Sciences and Engineering Research Council of Canada (NSERC)

The End

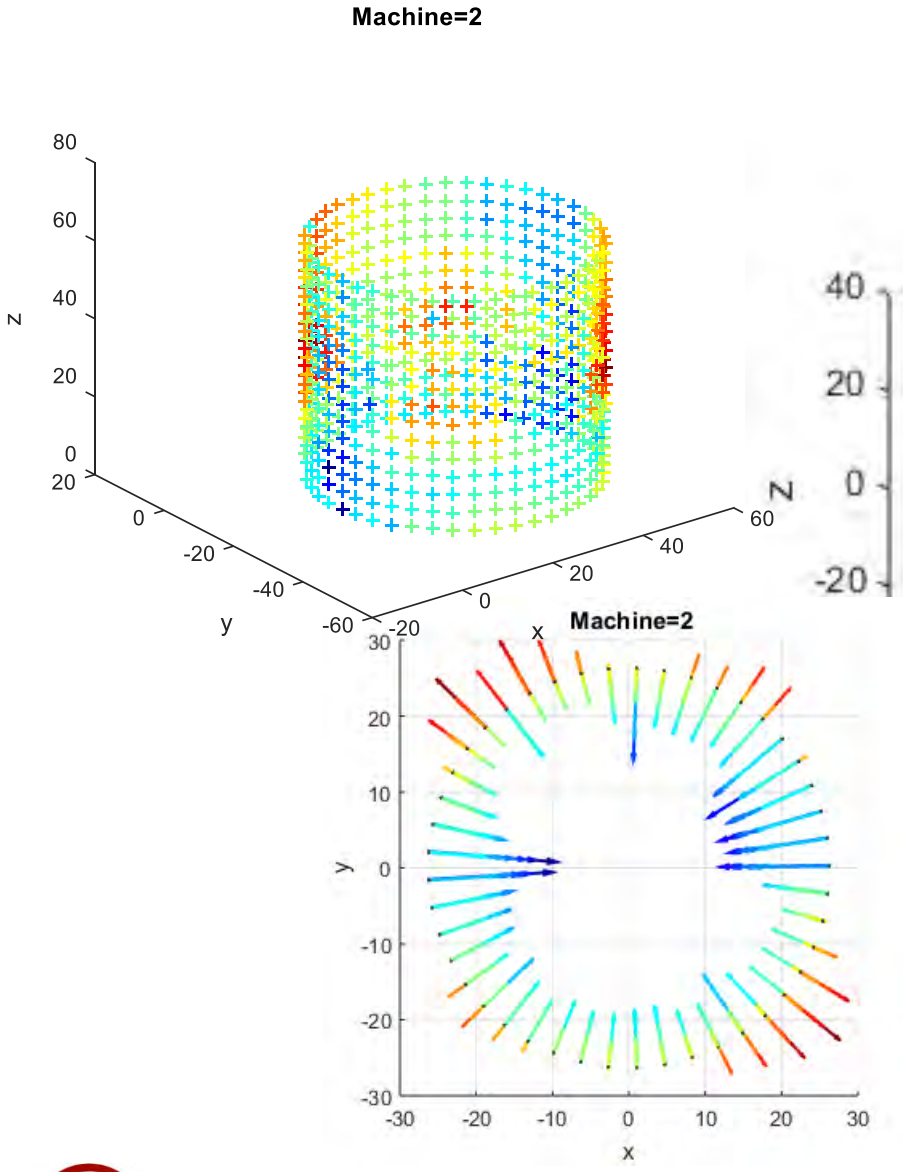

Dessous du modele avec les extensions pour le fixation.

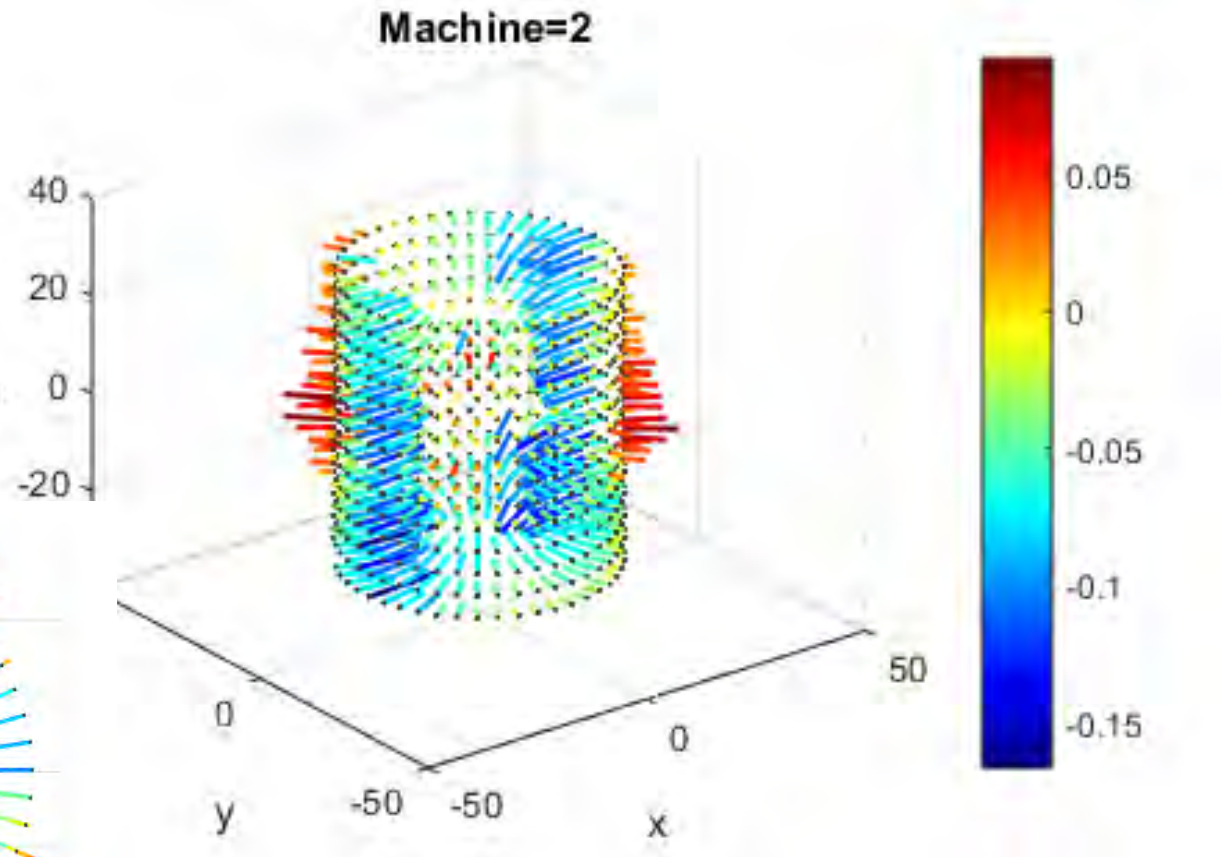

Je constate un jeu entre les deux pieces.





Bore results – red (machine 2) model



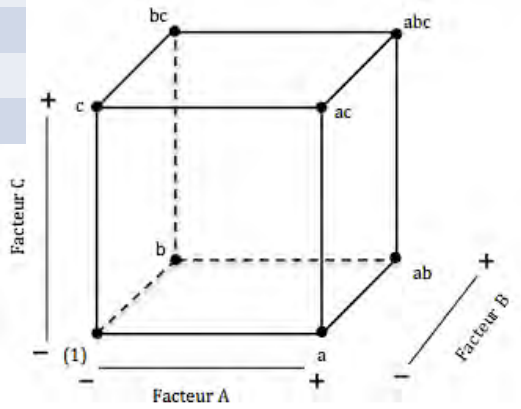


Nominal diameter=52.710
Size error: -0.072
Cylindricity error: 0.259

The procedure

- Two machine models tested;
- Full factorial experiment of effect of xyz sphere position on positional error

	Factor		
Experiment	X	Y	Z
1	−	−	−
2	+	−	−
3	−	+	−
4	+	+	−
5	−	−	+
6	+	−	+
7	−	+	+
8	+	+	+



Contents

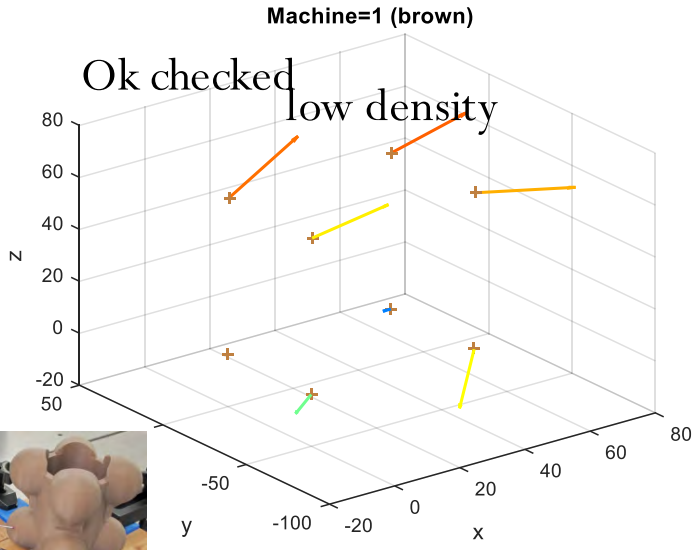
- FDM
- The artefact
- The procedure
- Some results

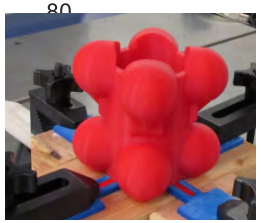
Printing parameters

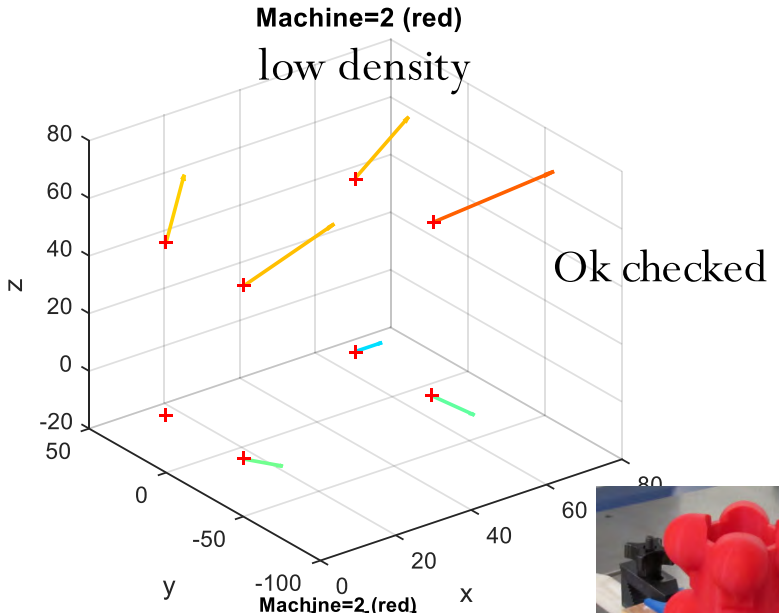
Parameters	Value	Parameters	Value
Layer thickness (wire ϕ=1.75)	0.15 mm	Filling type	
Orientation of internal structures	45 degrees	Thickness of skin	4 wires
Thickness of solid supports	3 wires	Maximum slope of ceilings without support	30°
Spacing of non solid supports	8 lines	Maximum area of holes without support	3 mm^2

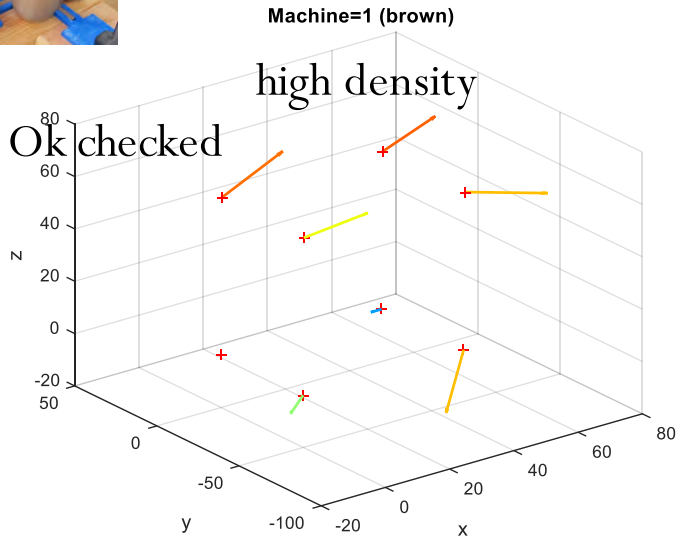
- **ABS** (Acrylonitrile Butadiène Styrène)
- Wire diameter :

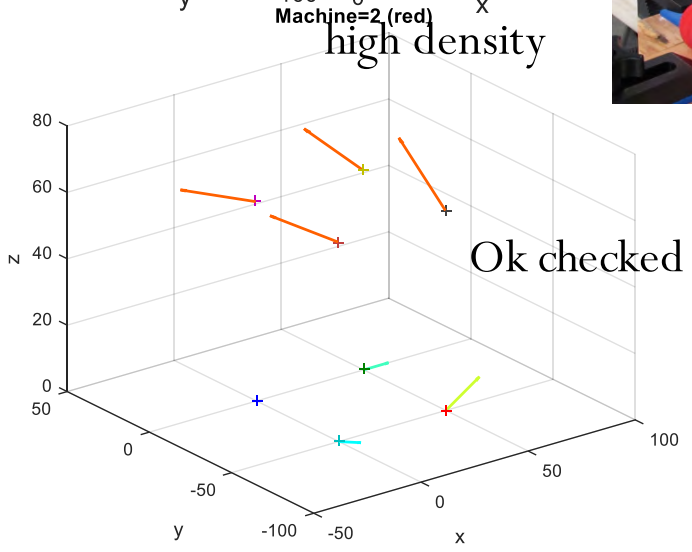
Position of spheres; low and high density



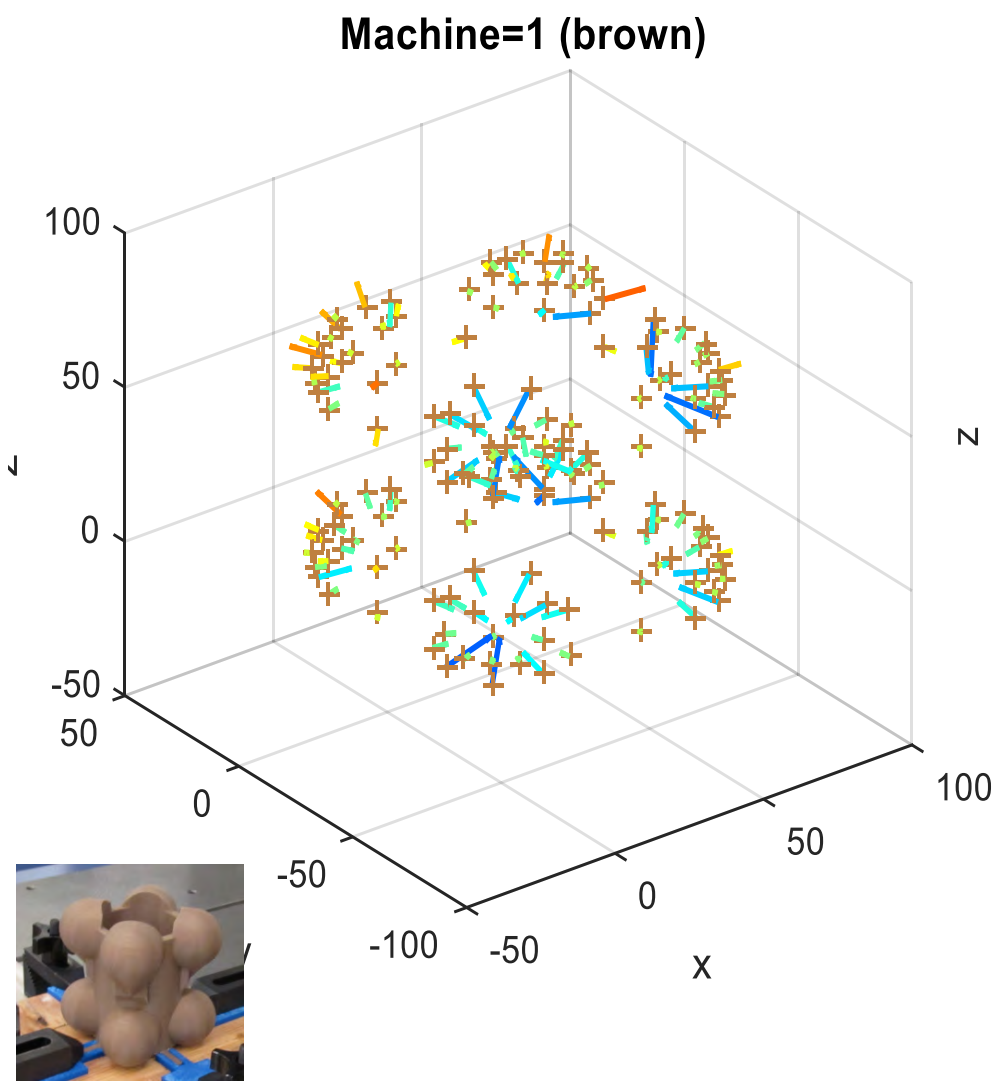


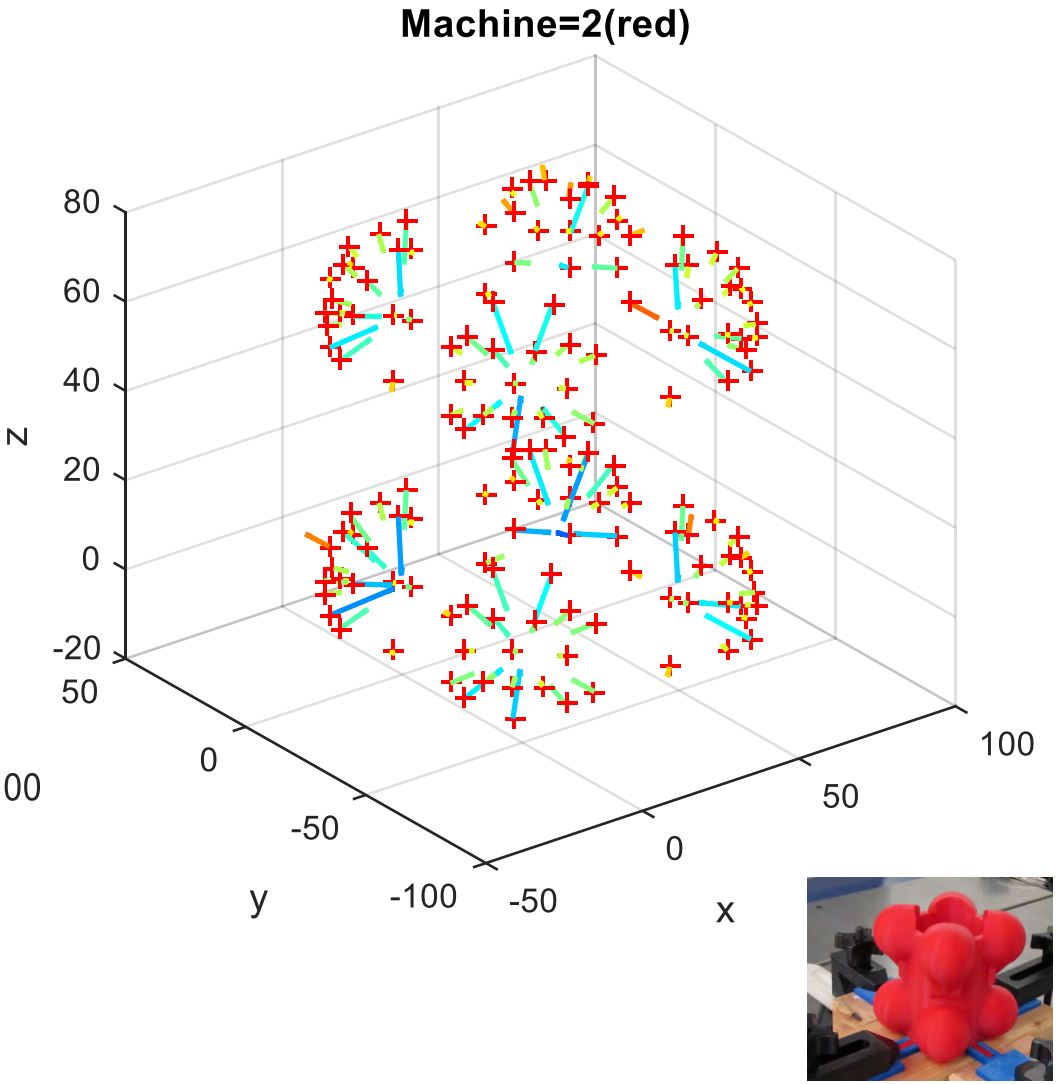






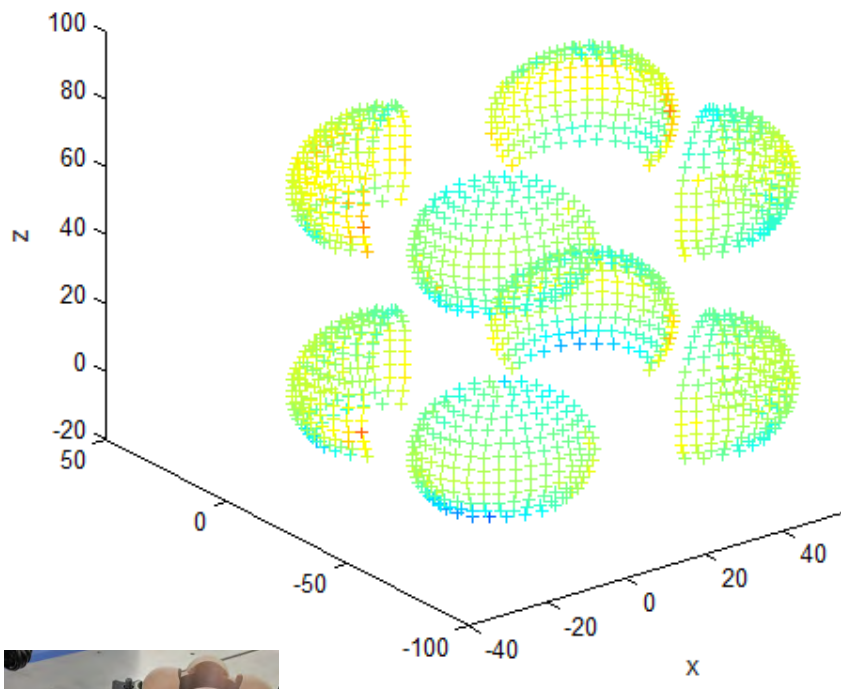
Difference from nominal; shape + size; LD



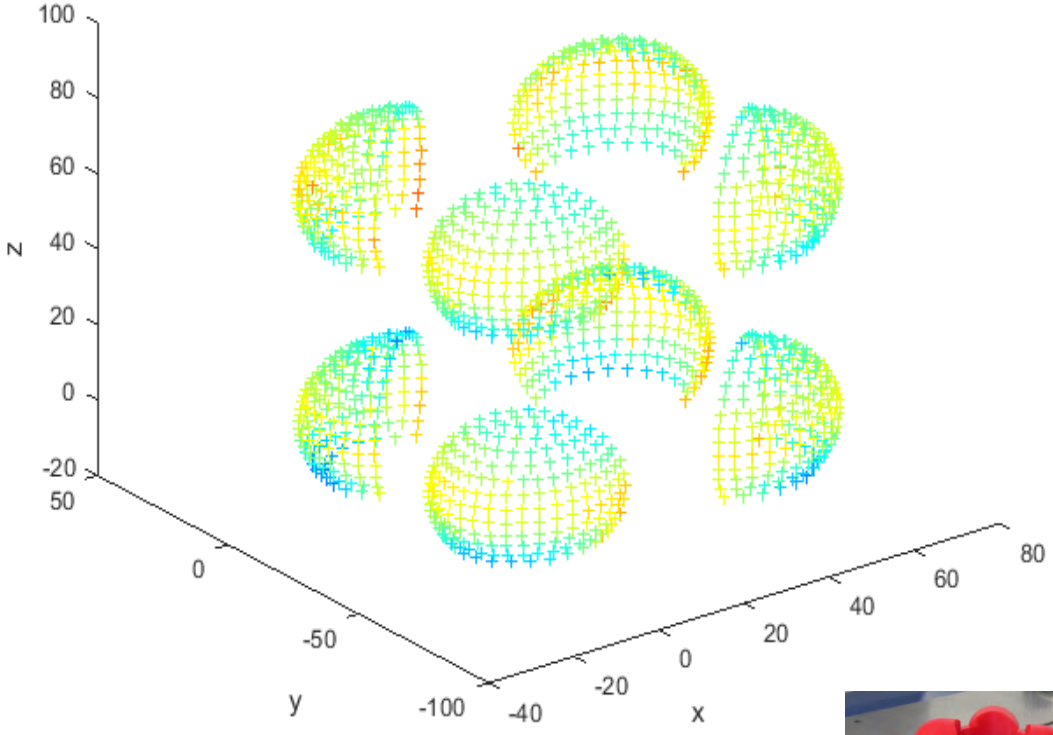


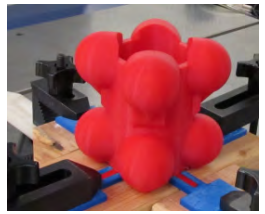
Difference from nominal; shape + size; HD

Machine=1 (brown)



Machine=2 (red)

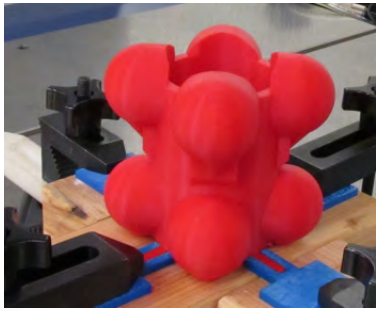


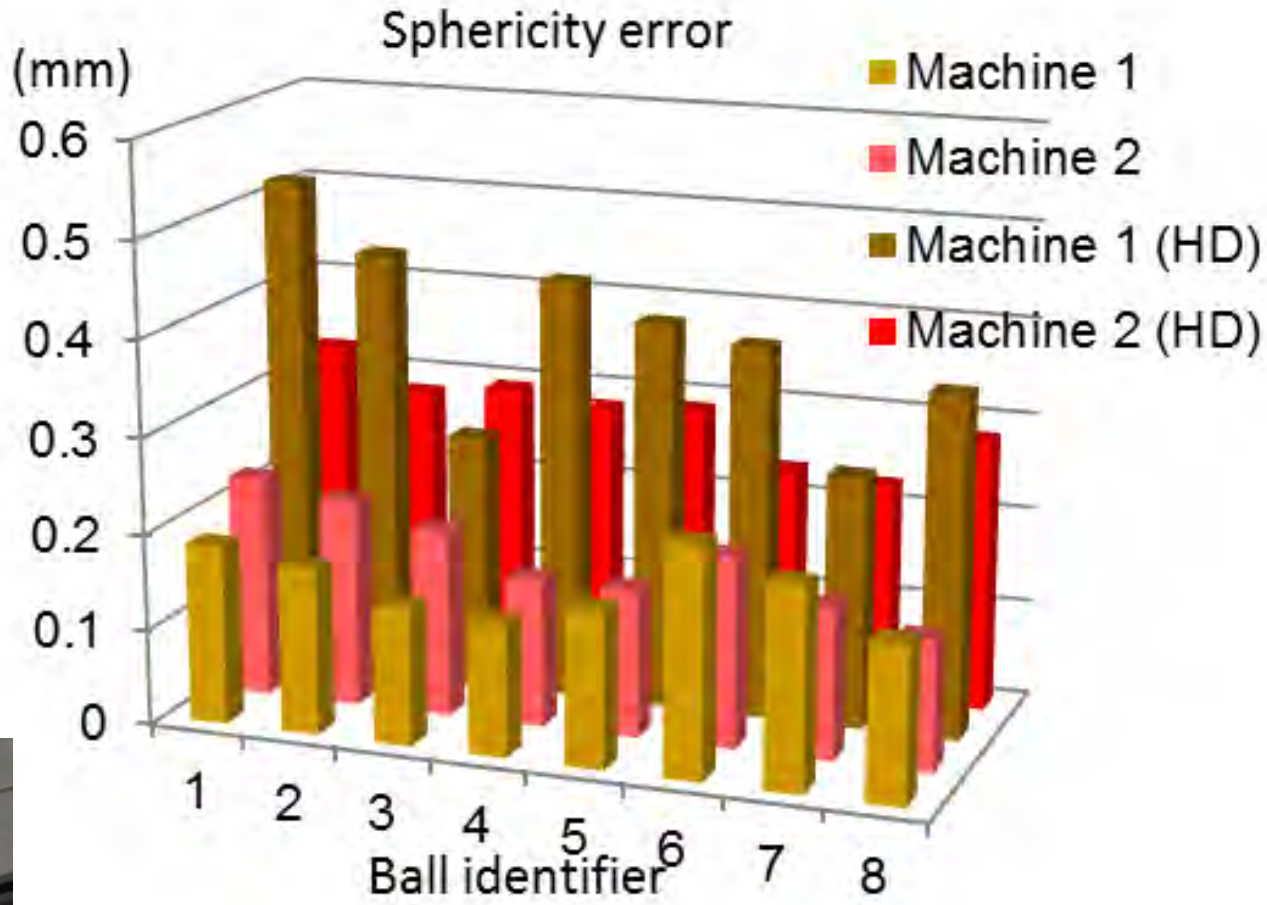


Abstract

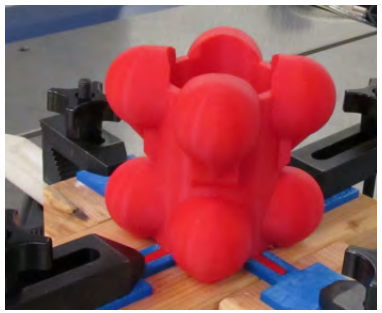
- An artefact made of eight 20 mm radii hemispheres located at the apices of a rectangular parallelipiped and held together by a single cylindrical core is proposed to study the dimensional and geometric performance of a fused deposition modeling (FDM) process. Two replicas are produced on two different machines and measured on a coordinate measuring machines for sphericity, radius and position. The hemisphere allows a gradual change in the vertical angle of the wall which challenges the process. Results differ for the two machines. Form, size and position errors of the order of XX, XX and XX respectively are obtained for machine 1 and XX, XX and XX for machine 2.

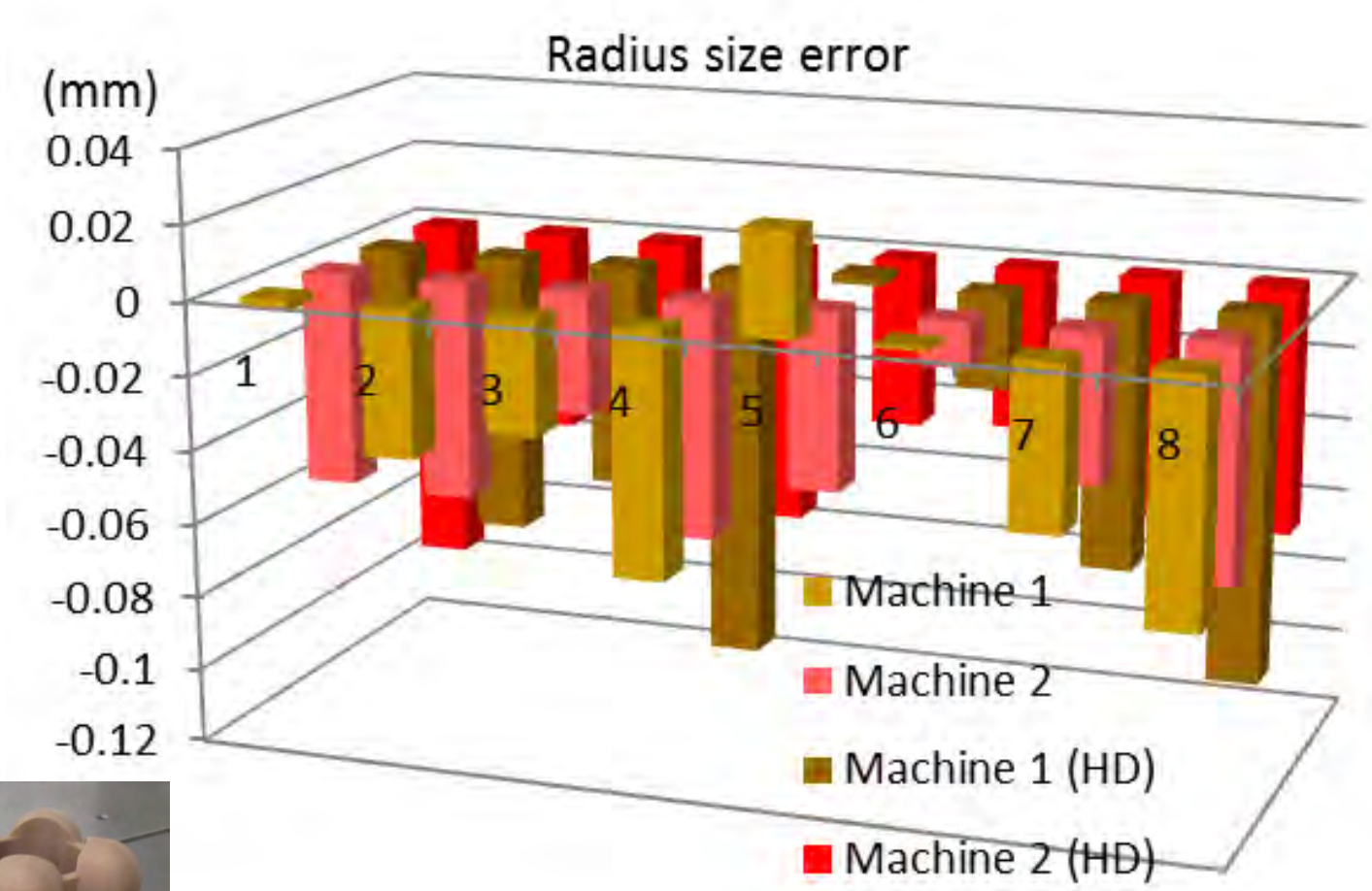
Sphericity of spheres; low and high density



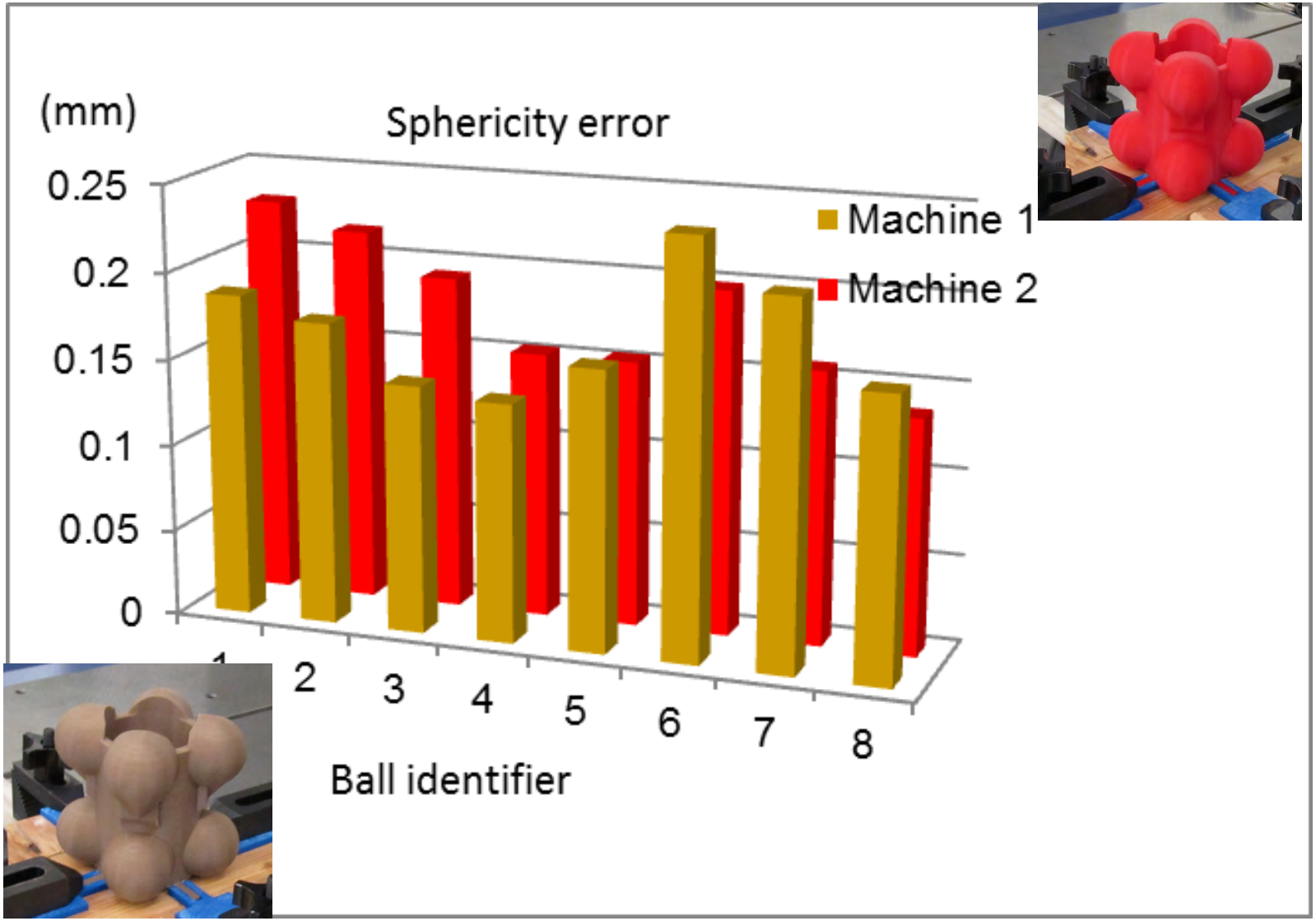


Size of spheres; low and high density

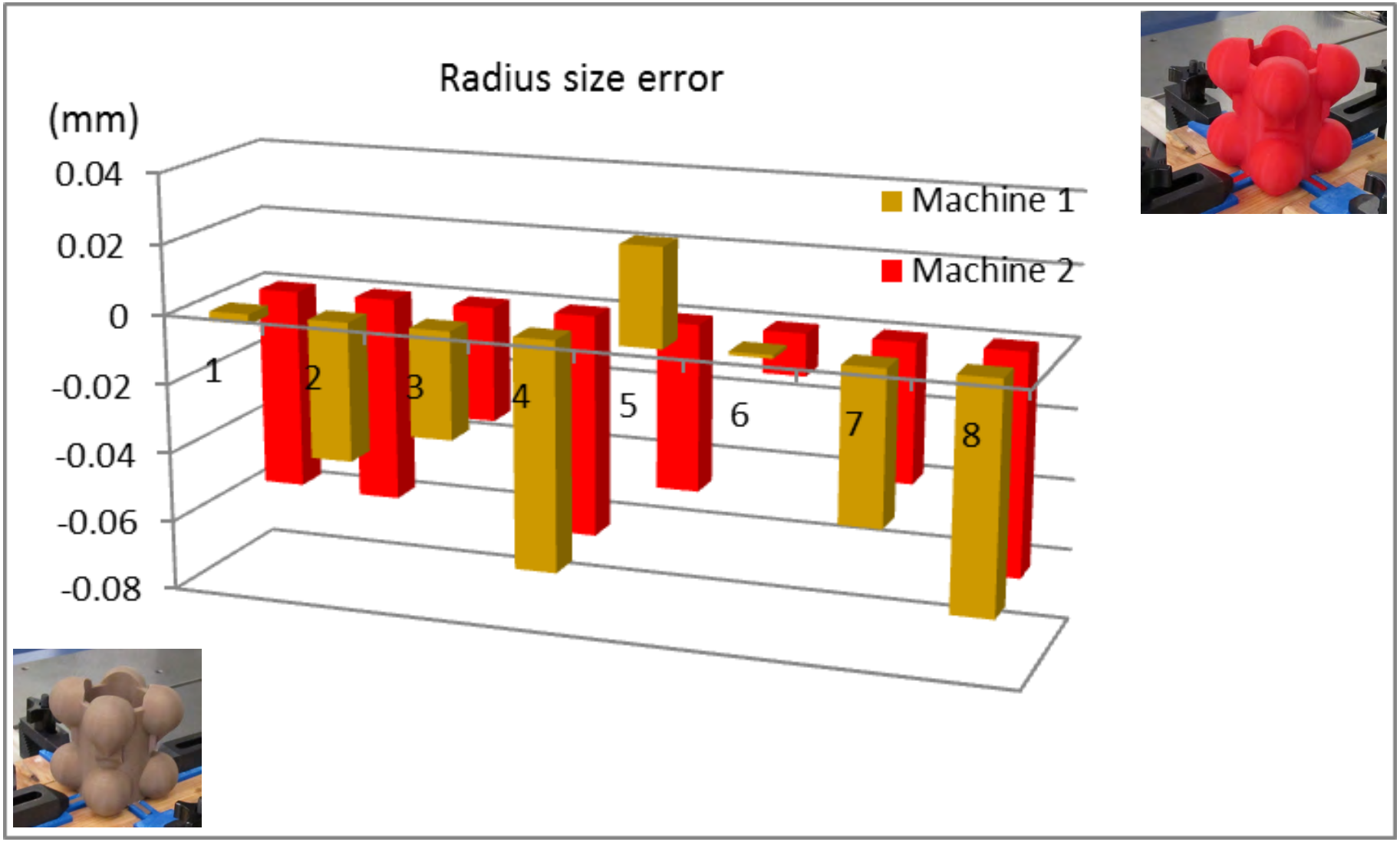




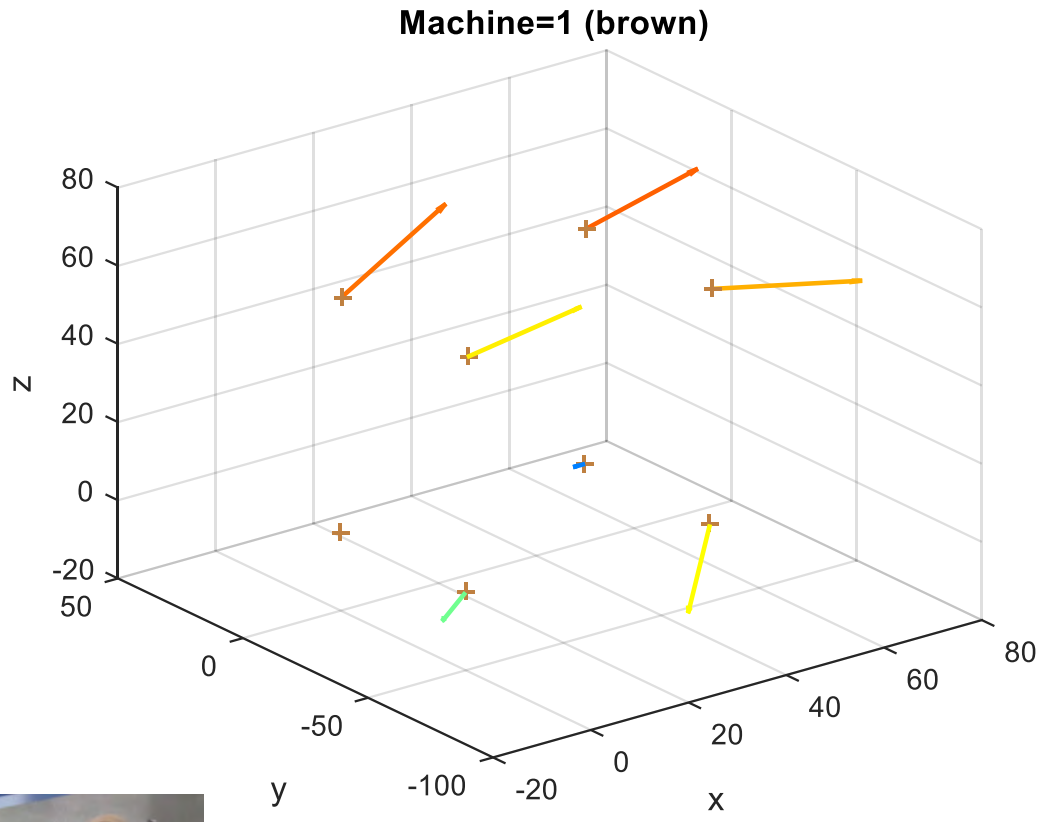
Sphericity of spheres; low density

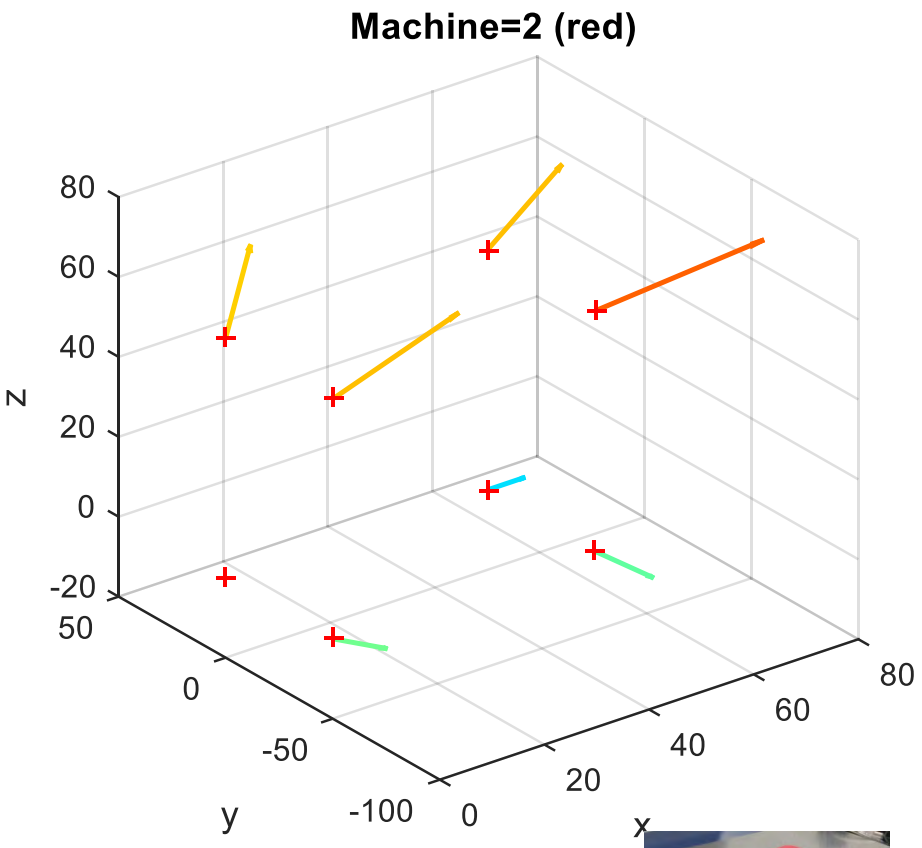


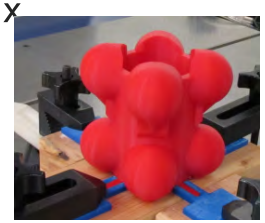
Size of spheres; low density



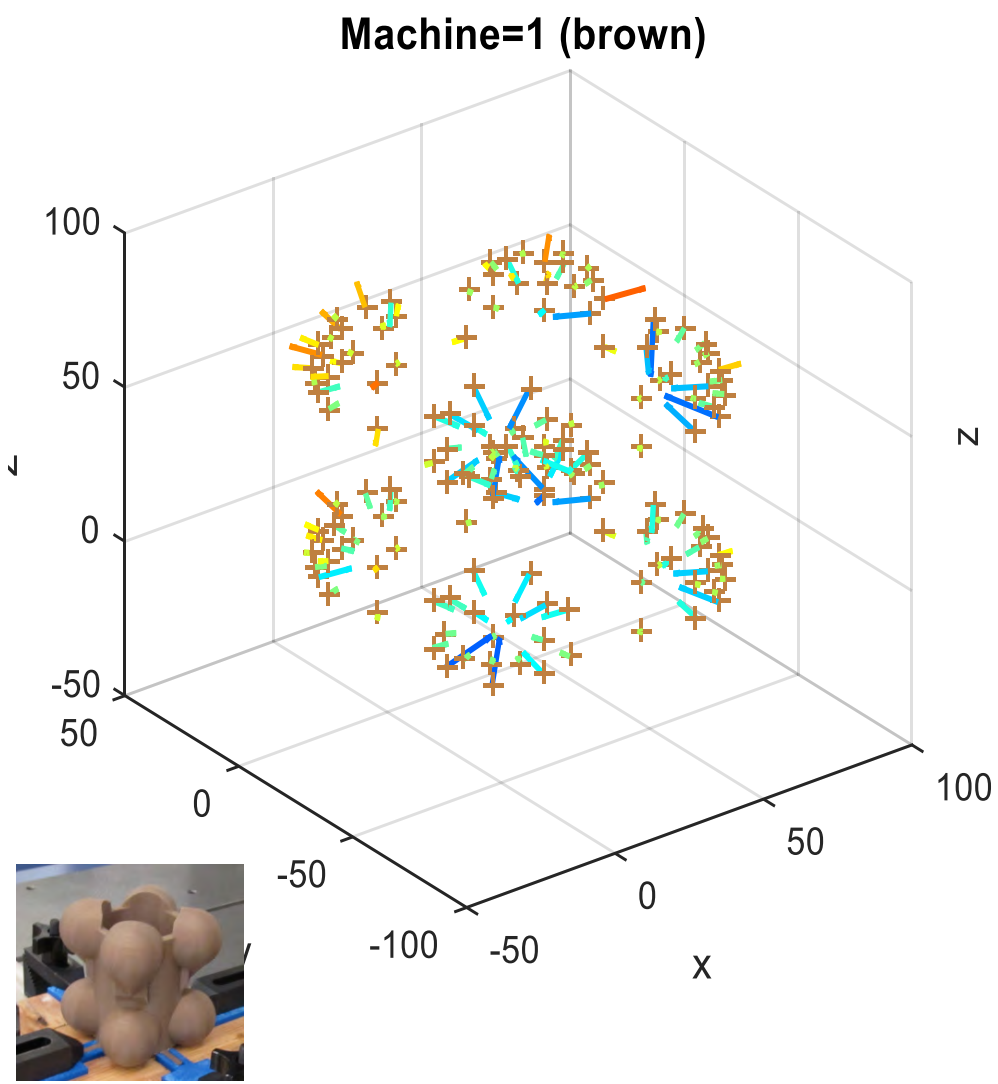
Position of spheres; low density

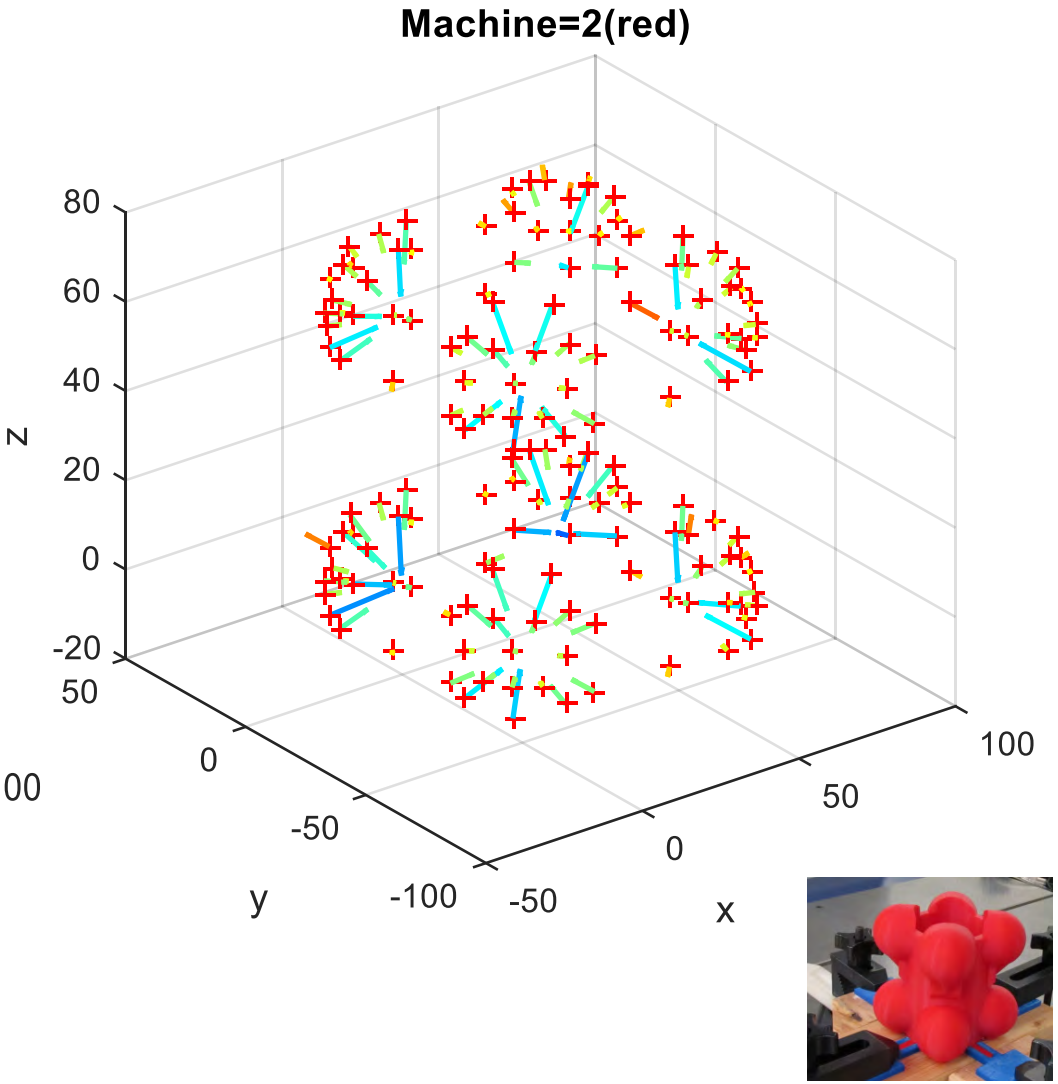




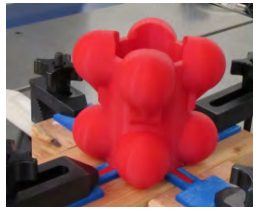


Difference from nominal; shape and size

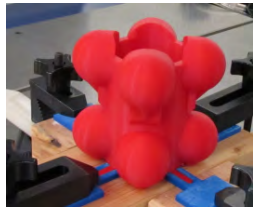


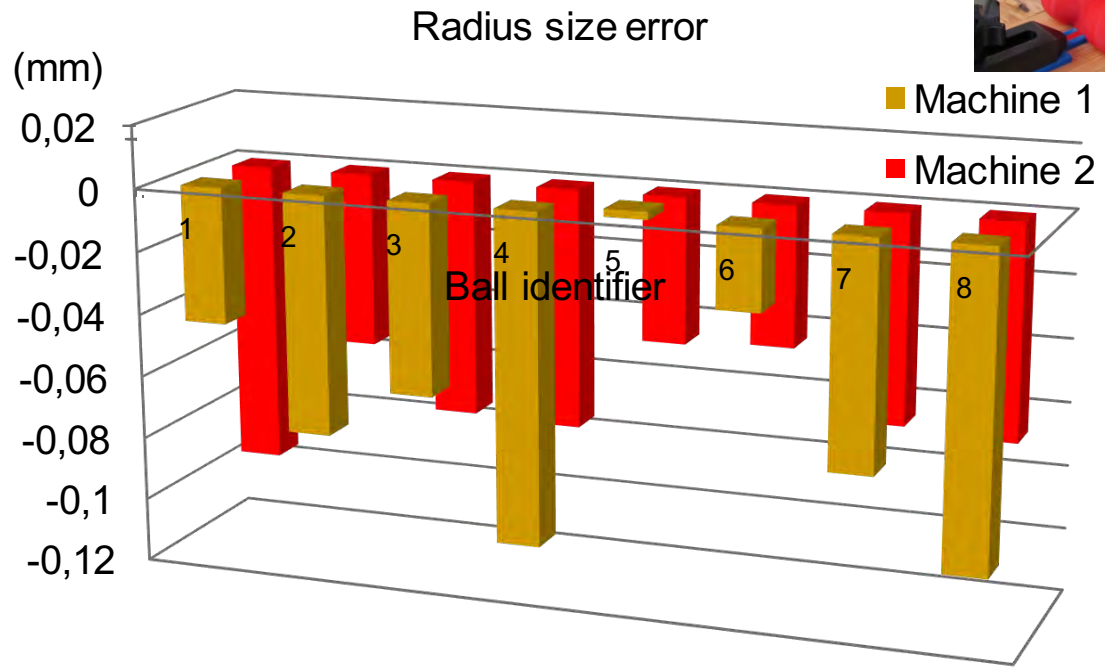


Sphericity of spheres; high density

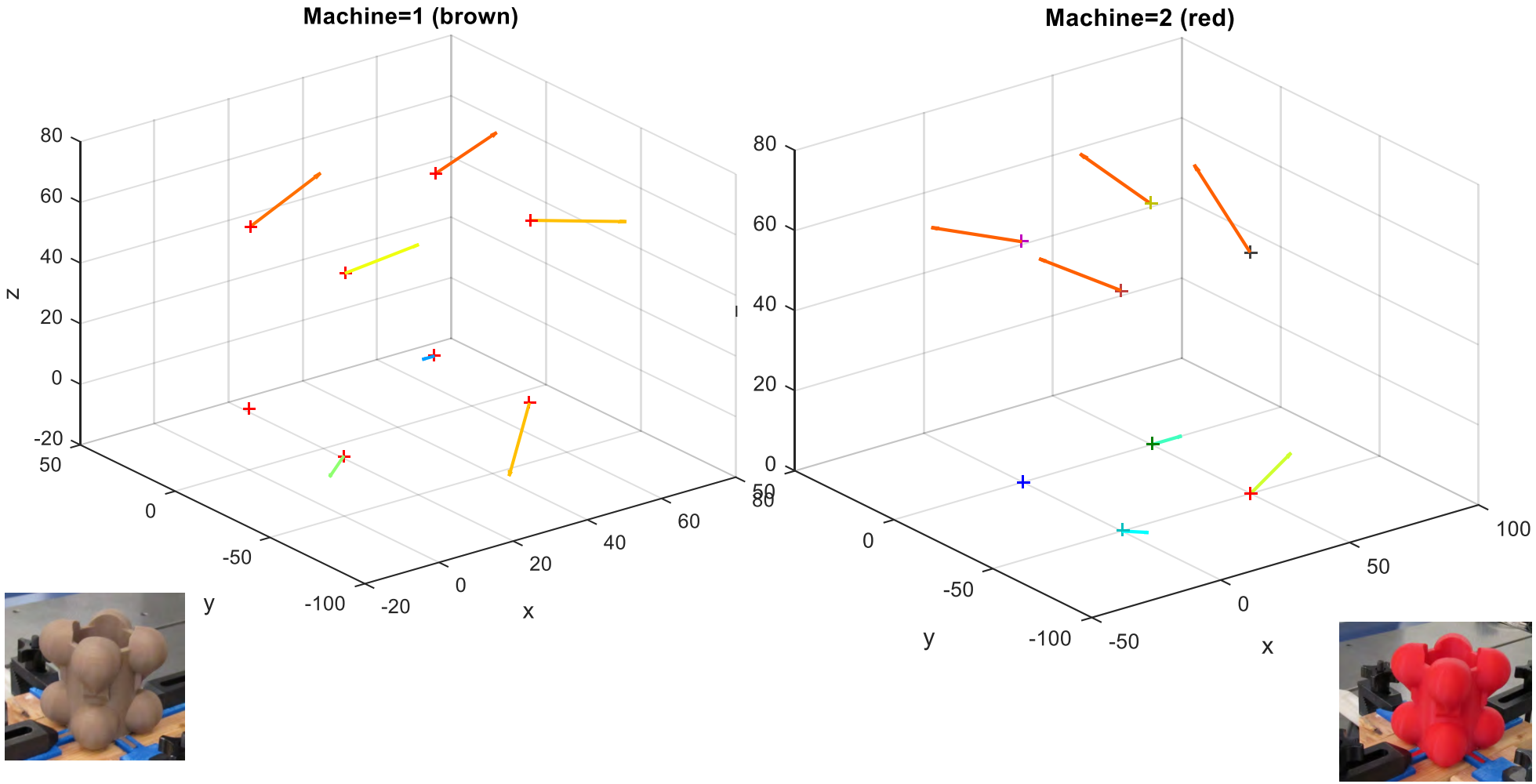


Size of spheres; high density

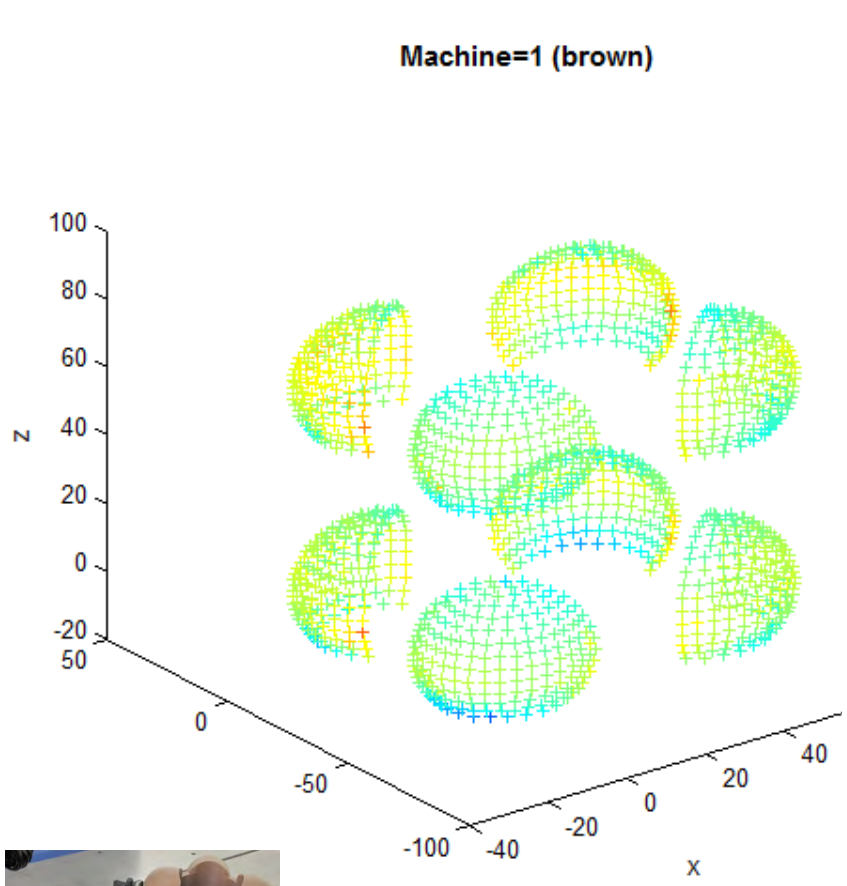


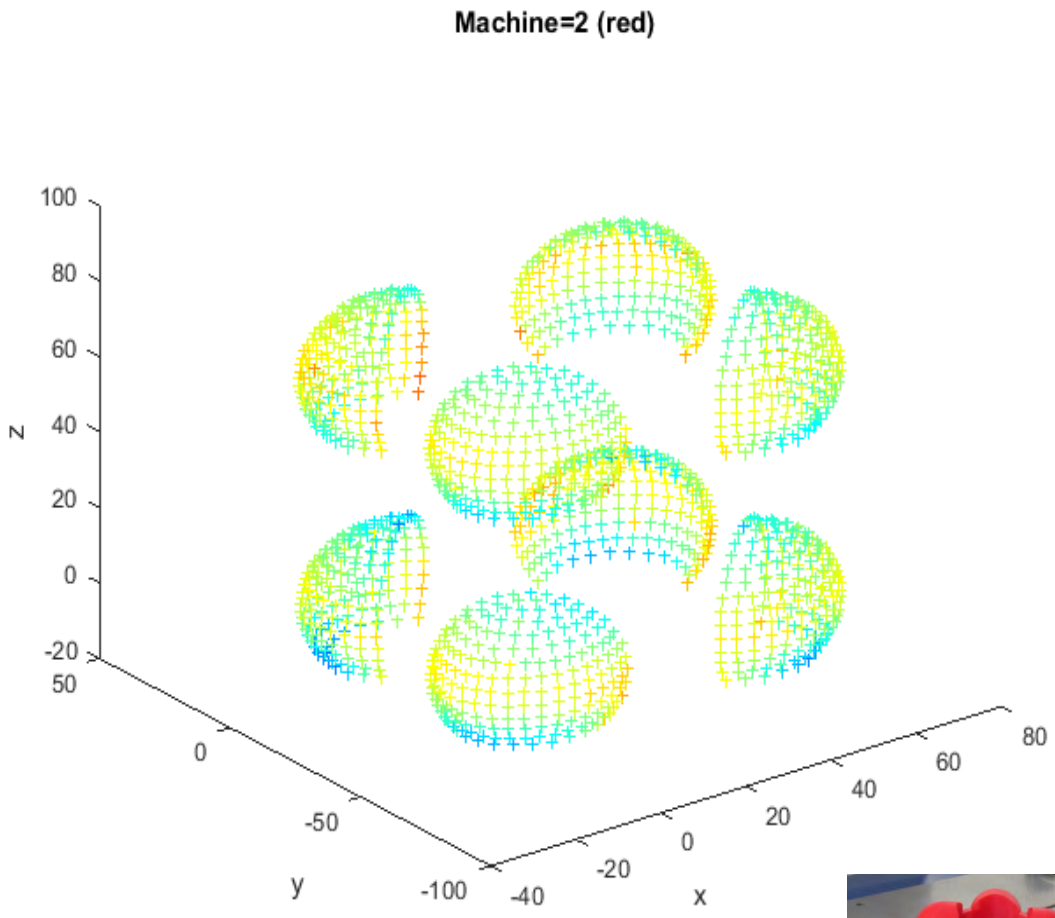


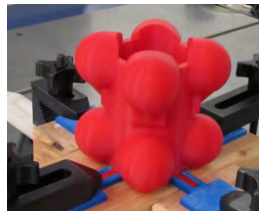
Position of spheres; high density



Difference from nominal; shape and size

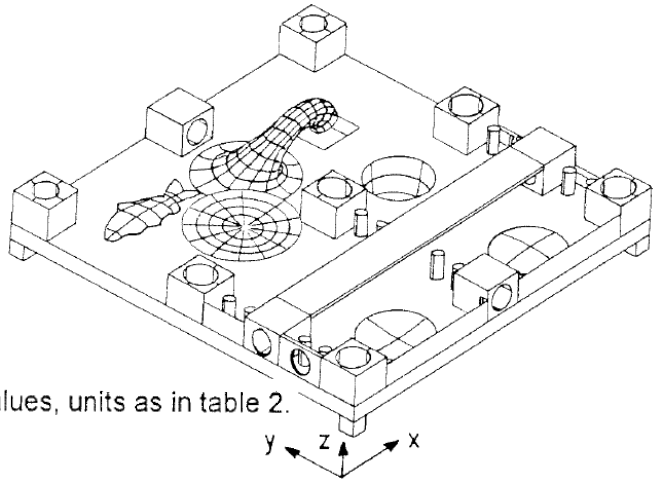






Literature review

- Childs, T. H. C. and N. P. Juster (1994). "Linear and Geometric Accuracies from Layer Manufacturing." CIRP Annals - Manufacturing Technology 43(1): 163-166. (FDM: 0.254 mm)
  - No balls.



sts	P300 polyamide	Perimeter passes, raster fill	0.254mm	Built in two parts, bonded, 80% full size

Table 2. Measurements made on the benchmark.

Grp	Measure	Feature involved	Nominal value(s)	N	sts
1	Flatness	base surface (datum)	0 mm	1	0.26
2	Straightness	y = 0 base edge datum	0 mm	1	0.31
3	Straightness	x = 0 base edge datum	0 mm	1	0.36
4	Angle	x-y datum edges	90°	1	0.07
5	x distances	square boss sepn.	107,215,240 mm	9	0.21
6	x distance	square boss width	25 mm	9	0.20
7	x distance	wall thickness	1 to 4 mm	4	0.55
8	y distance	square boss sep.	107,215,240 mm	9	0.29
9	y distance	square boss width	25 mm	9	0.34
10	z distance	square boss height	20 mm	10	0.15
11	radius	circular column	3 mm	12	0.19
12	diameter	square boss z holes	20 mm	5	0.22
13	form	circular column	0 mm	12	0.12
14	form	square boss z holes	0 mm	5	0.175
15	position	square boss z holes distance from x datum	12, 120, 227 mm	5	0.10
16	position	square boss z holes distance from y datum	12.5, 120 mm	5	0.16
17	draft angle	cone half angle	1, 2, 8°	3	1.27
18	form	cone form	0 mm	3	0.33
19	diameter	square boss y holes	16 mm	2	0.16
20	form	square boss y holes	0 mm	2	0.08
21	diameter	square boss x holes	16 mm	2	0.165
22	form	square boss x holes	0 mm	2	0.25

Table 5. RMS deviations from expected values, units as in table 2.

Literature review

- Keynote: Kruth, J. P. (1991). "Material Incress Manufacturing by Rapid Prototyping Techniques." CIRP Annals - Manufacturing Technology 40(2): 603-614.

F.D.M.: Fused Deposition Modeling

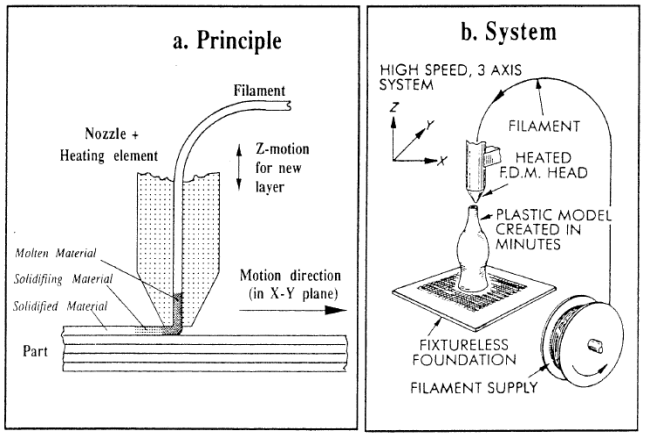
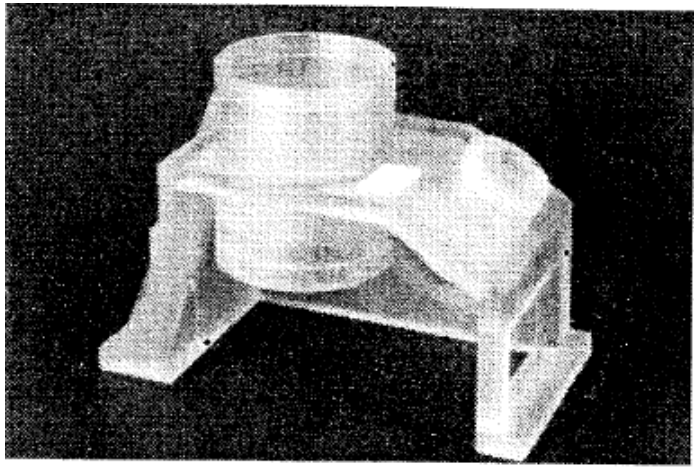


Fig.12. Fused Deposition Modeling.

ACCURACY	Layer thickness (mm)	0.025 to 1.25
	Grain, Voxel or Focus size (mm)	0.25 to 5 width of laminate
	Overall Accuracy (mm)	0.08% (±0.125mm on 305mm cube)



-Product not delivered (after 6 months)

Literature review

- Ippolito, R., L. Iuliano and A. Gatto, "Benchmarking of Rapid Prototyping Techniques in Terms of Dimensional Accuracy and Surface Finish." CIRP Annals - Manufacturing Technology 44(1): 157-160, 1995.

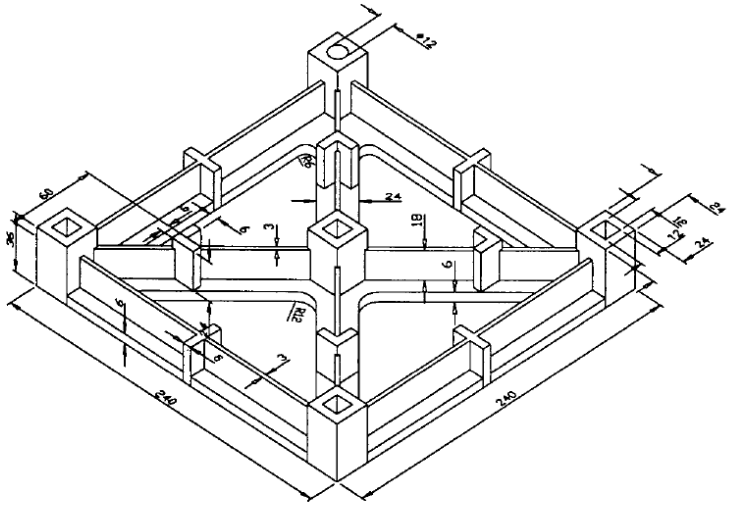


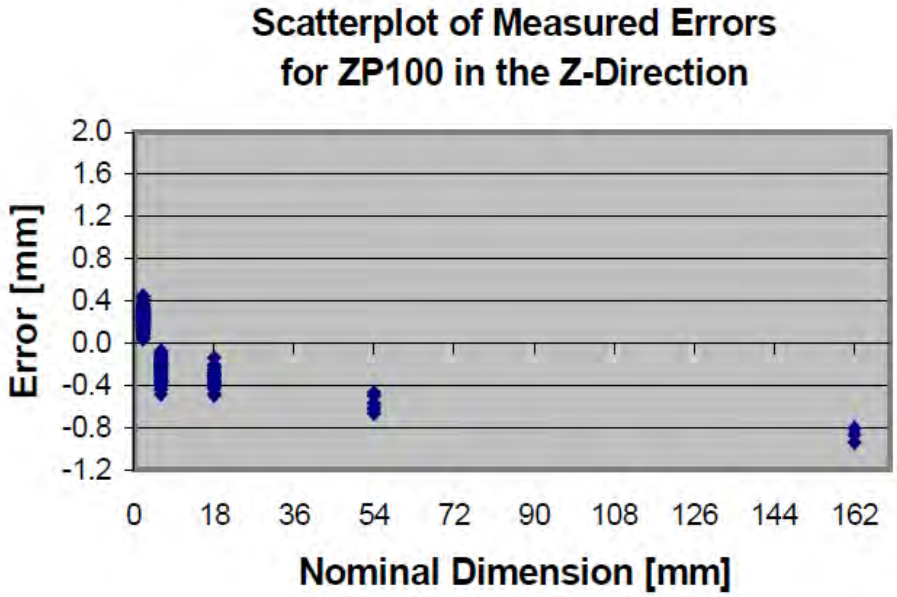
Figure 1: The decimalized version of the benchmark proposed by the 3D System

FDM Fused Deposition Modelling	Stratasys USA

Technique	Material	Error (mm)		
		mean	σ	p
FDM	P300 resin	-0.24	0.43	0.00
	P200 resin	0.03	0.32	0.00

Literature review

- D. Dimitrov, W. van Wijck, K. Schreve, N. de Beer, and J. Meljer, "An Investigation of the Capability Profile of the Three Dimensional Printing Process with an Emphasis on the Achievable Accuracy," CIRP Annals - Manufacturing Technology, 52(1): 189-192, 2003.



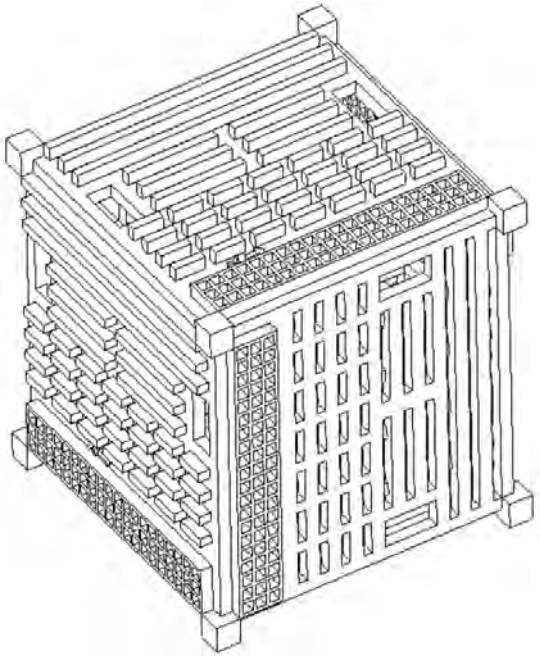


Figure 3. Benchmark part for dimensional accuracy.

Literature review

- L. B. Cindy Bayley, Colin Hurlbut, Moneer Helu, and D. D. Robert Transchel, "Understanding Error Generation in Fused Deposition Modeling," in 2014 SPRING TOPICAL MEETING VOLUME, 98-103.

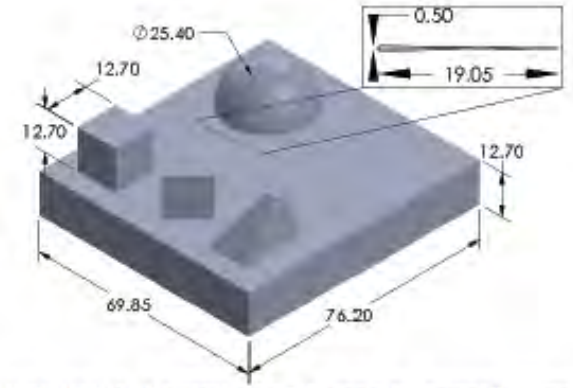


FIGURE 1. Control part #1 used to quantify form errors and resolution in FDM (all units in [mm]).

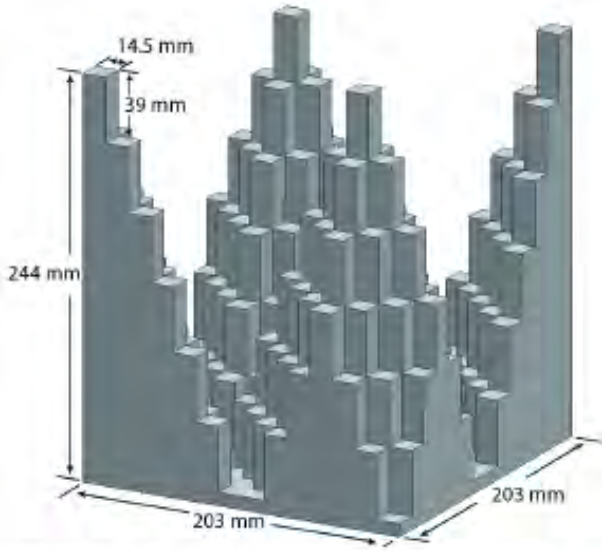


FIGURE 1. Control part #3 used to estimate the accuracy and precision of FDM.

FIGURE 2. Control part #2 used to investigate the staircase effect on surface roughness.