EXPERIMENTAL EVALUATION OF LASER TRACKER TARGET HOLDERS STABILITY

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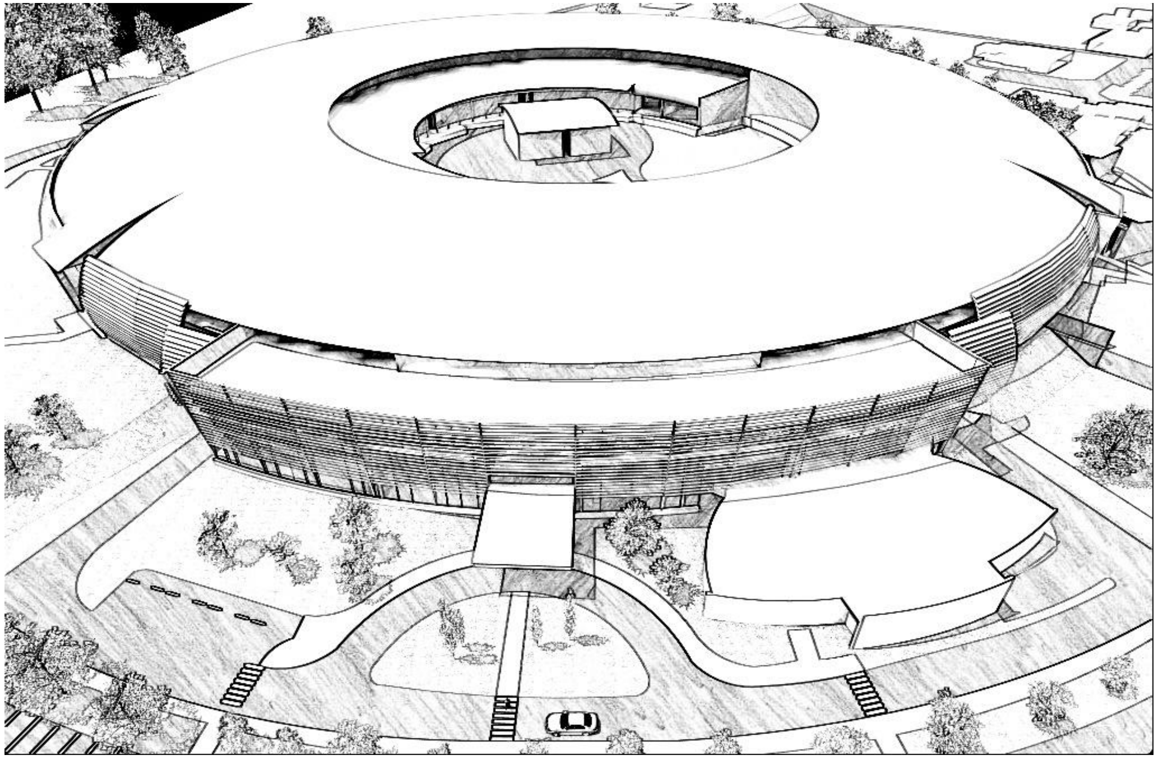
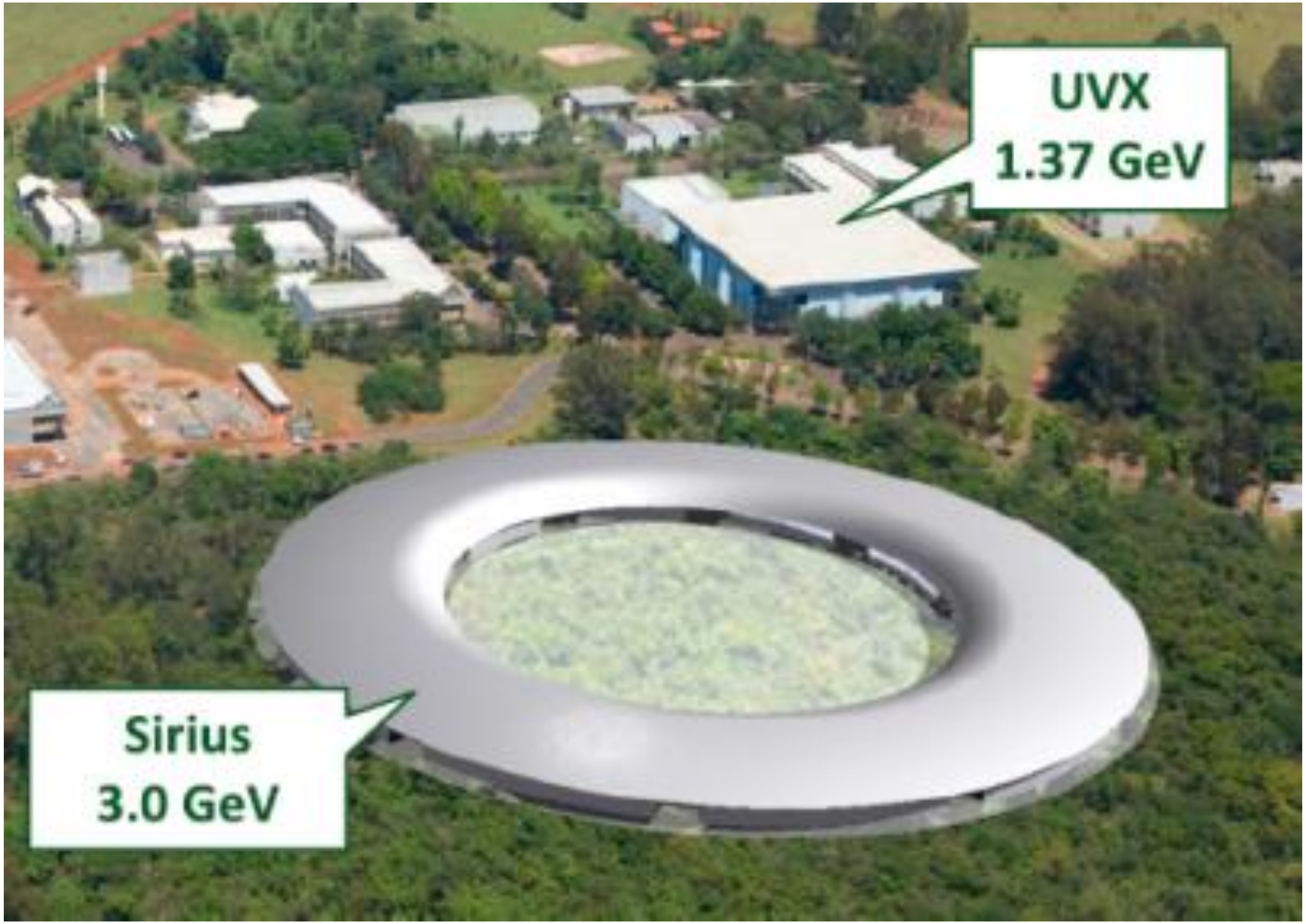


Motivation



Motivation

Floor

Walls

Objectives

Aluminum cone

Three stainless steel spheres

Segmented aluminum cone

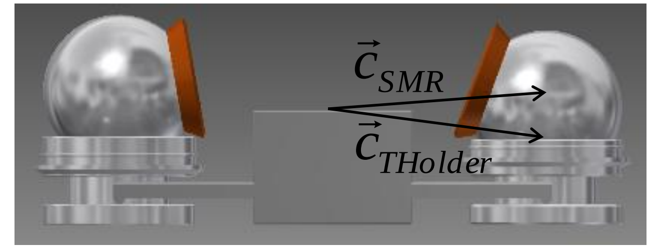
Eletrolitical nickel cone

Stainless steel cone

Chemical nickel cone

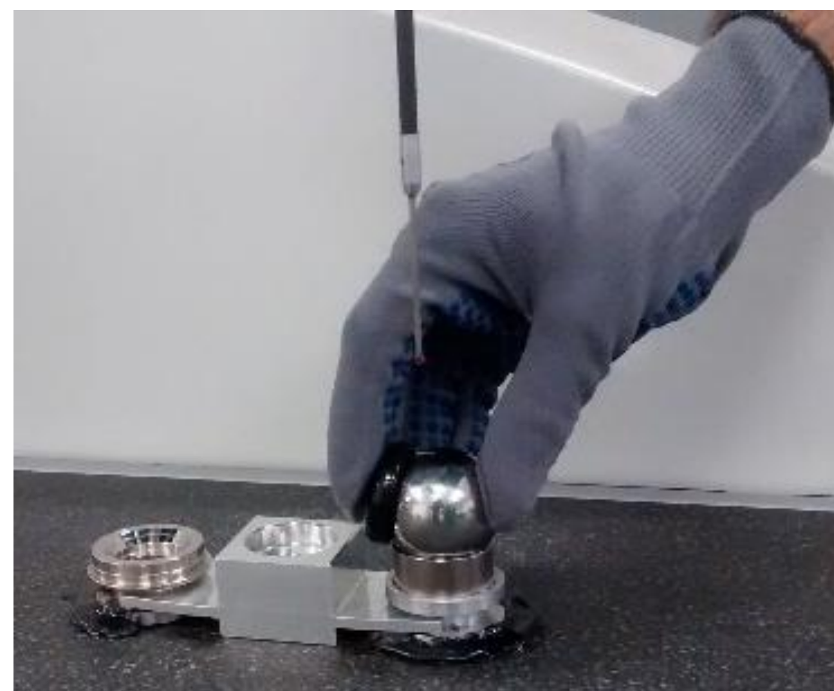
Materials and Methods

- Use of a Coordinate Measuring Machine – CMM in CNC mode;
- Location of the SMR with 16 hits;
- Temperature compensation disabled;
- Temperature variation smaller than 0.2 ºC;
- Location of the Target Holders measuring a plane and a circle;
- Location of the origin before each repetition;
- Execution of the experiment in a completely randomized manner;
- 30 observations of each model;
- Use of gloves to minimize thermal gradients between operator and apparatus;
- Screw fixation of the alignment support part and glue to avoid target holders displacement;
- Thermal stabilization of the tested models for at least 24 hours;
- Use of the same SMR in the same position during all measurements, to avoid the effect of sphericity errors;
- Cleaning of the contact region to remove possible deposited dust.

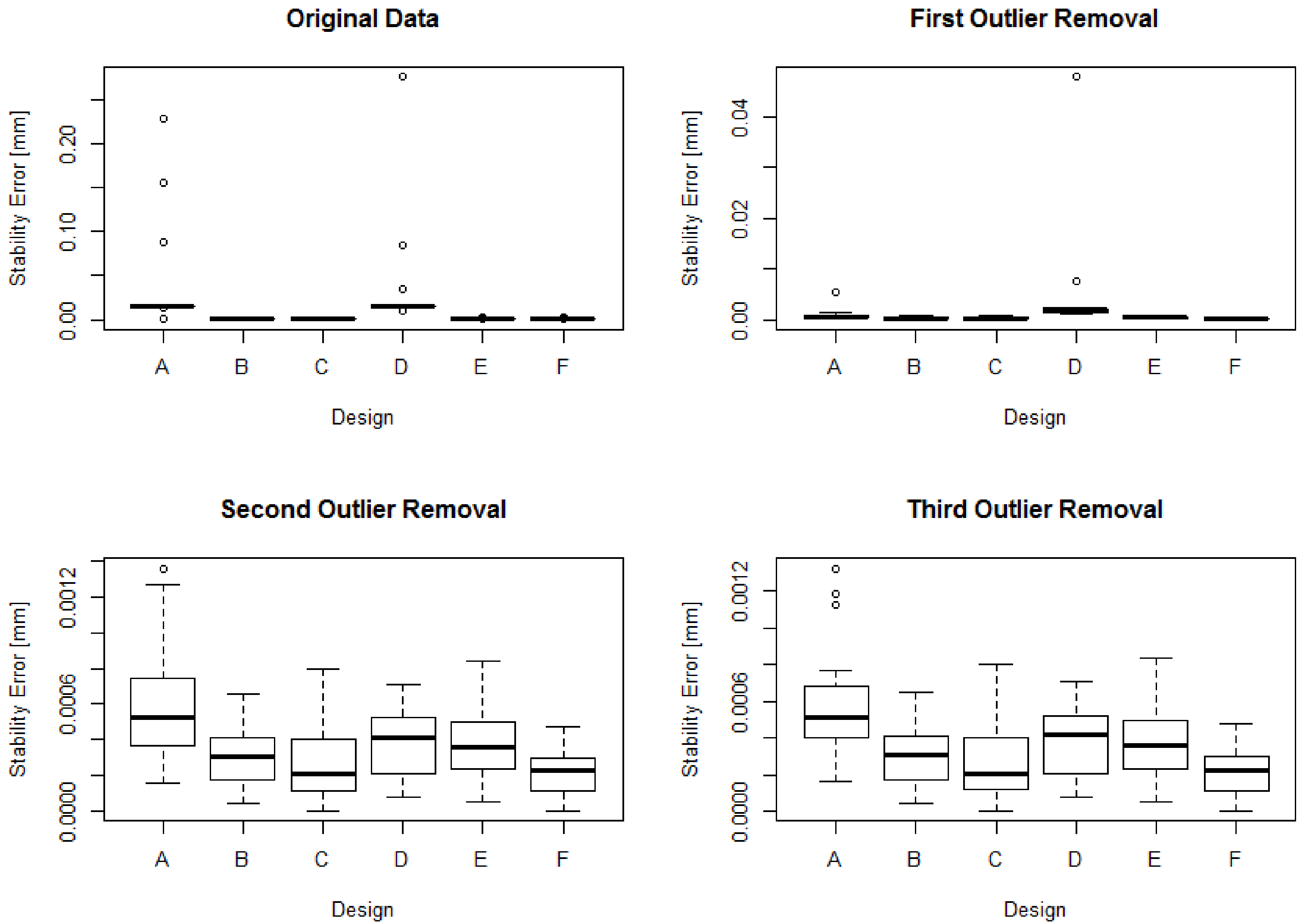


$$\vec{\mathrm{p}} = \vec{c}_{SMR} - \vec{c}_{THolder}$$

$$e_s = \sqrt[3]{\left|x_p - \overline{x_p}\right| \cdot \left|y_p - \overline{y_p}\right| \cdot \left|z_p - \overline{z_p}\right|}$$

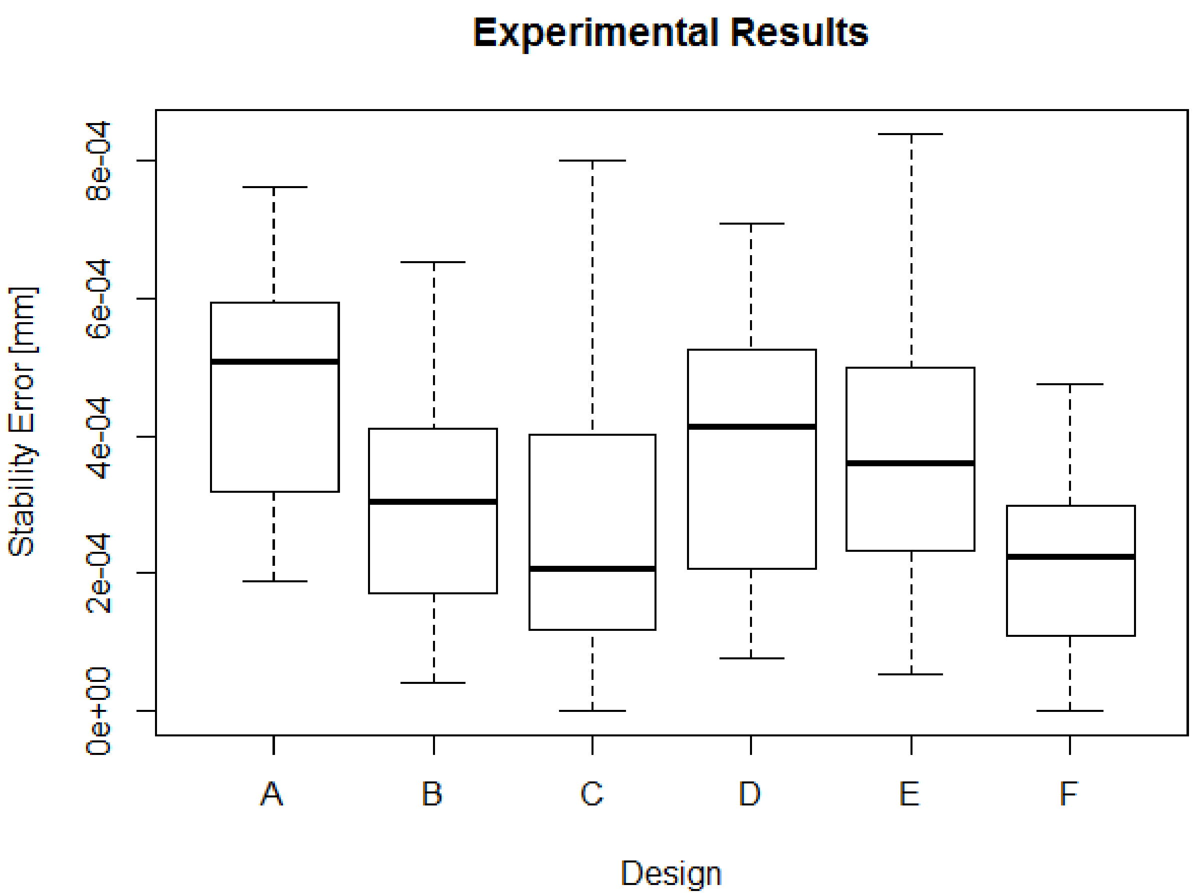


Materials and Methods



Materials and Methods

Qualitative result:



Data analysis

Analysis of Variance test (ANOVA)

Null hypothesis (H0): all target holder designs have equal mean stability error;

Alternative hypothesis (H1): some of the models have different mean stability error.

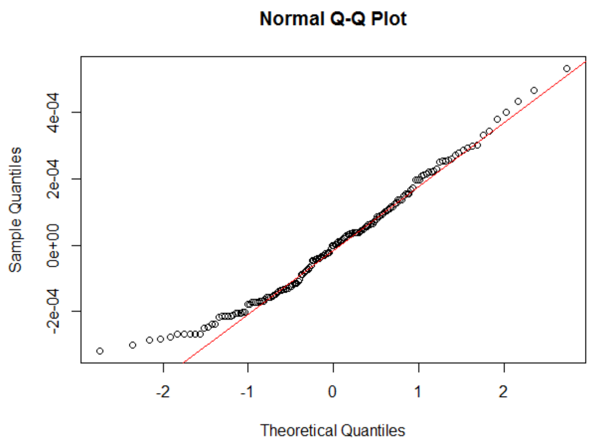
Model Adequacy Checking

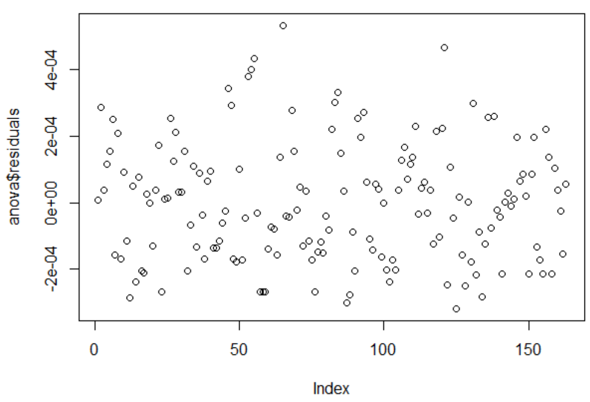
Assumptions:

-Independence of responses;
-Homoscedasticity (equality of variances);
-Normality;

Model adequacy checking:

-Experiment performed in a completely randomized way;
-Qualitatively, data is well distributed;
-Residuals do not seem to have any tendencies.





Model Adequacy Checking

Tests for Checking Homogeneity of Variances

Test Name	p-value
Batlett	0.1987
Fligner-Killeen	0.4243

Test for Normality

Test Name	p-value
D'Agostino	0.1262

P-values higher than 0.01 (99% confidence interval) -> null hypothesis is valid for those tests

Quantitative Results

The Analysis of Variances (ANOVA) gives us a p-value of 1.45e-05. For a level of significance of 0.01% (99% confidence interval), the **null hypothesis has been refuted**.

Tukey Honest Significant Test Results

Comparison	p-value
B-A	0.0168233
C-A	0.0008582
D-A	0.4164266
E-A	0.3564193
F-A	0.0000192
C-B	0.9376047
D-B	0.7385949
E-B	0.7661920
F-B	0.3477593
D-C	0.2089464
E-C	0.2216378
F-C	0.8842376
E-D	0.9999997
F-D	0.0160785
F-E	0.0166604

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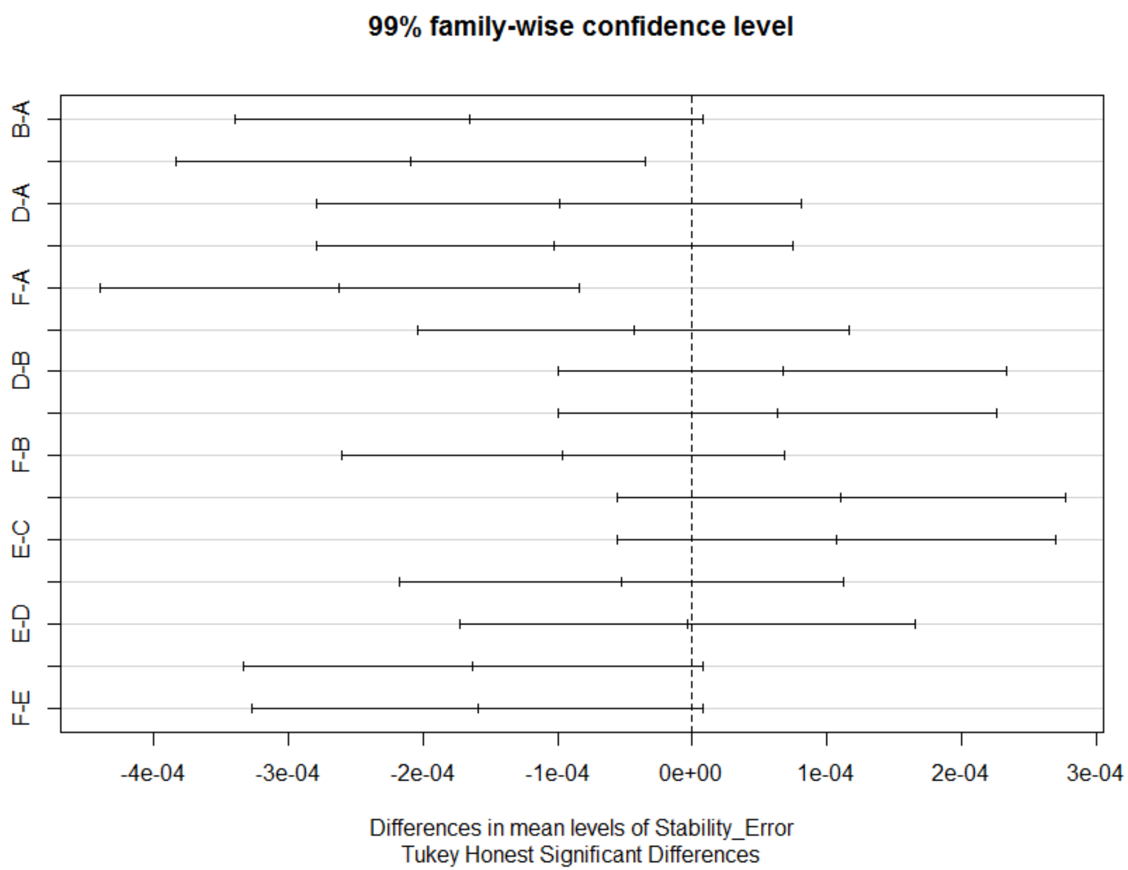
Quantitative Results

CNPEM



Conclusions

- Point of view from product design we could think about the possibility of combine concepts C and F (segmented cone and nickel chemical coating);

- Although there is a statistical difference between the designs, the magnitude of the stability error differ no more than **0.00026 mm** between all concepts. Considering the Laser Tracker uncertainty (MPE), the stability (or repeatability) error cannot represent a major decision factor.

Possible interpretations:
-Models with a smaller contact area have more deterministic positioning of the SMR;
-Models without the coating have marks that could cause bad stability errors;
-Superfitional hardness could explain differences between results;
-Quality of coating might explain the differences too;

Limitation of the study:

- Only one sample tested for each concept.

About the outlier removal

Data	Homoscedasticity Test (p-value)	Normality Test (p-value)	ANOVA (p-value)
Original	2.2e-16 (Bartlett)	2.2e-16 (D'Agostino)	1.79e-06
After first filtering	2.2e-16 (Bartlett)	2.2e-16 (D'Agostino)	0.00208
After second filtering	0.0001202 (Bartlett)	0.008629 (D'Agostino)	1.31e-08
After third filtering	0.00567 (Bartlett)	0.006427 (D'Agostino)	3.69e-08

Minor results

- Regarding the aluminium cone design (A), we run a t-test comparing a specimen already scratched with a brand new one. With a p-value of 0.03915, there is a statistical difference between the two samples with a 95% confidence interval. The mean stability error was **0.00065 mm against 0.00052 mm**. That fact indicates that an already scratched contact area is more stable than a new one (we used the specimen already scratched in the main experiment of this paper);

- Using the design F as a parameter, we performed a t-test between measurements following the procedure described in this paper and measurements where we did not rotate the SMR in its nest. There is a significant difference between these two treatments for 99% confidence interval (p-value of 0.0001129). The mean stability error is bigger in the last case (**0.00037 mm against 0.00099 mm**) and we performed the main experiment of this paper rotating the SMR because this is the worst-case scenario.

Thank you!

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Answer to possible questions

CNPEM

Statistical package I've used: R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org, 2013.

Literature on Design and Analysis of Experiments: D. C. Montgomery. Design and Analysis of Experiments, John Wiley & Sons Inc., 8th edition, New York, NY, USA, 2013.

CMM model: DEA Global Performance from Hexagon.

Why the last model is different: I didn't have time to machine and do the coating, then I just used one sample we had glued to a base to keep about the same height of the other models.

Unbalanced design, since I removed outliers from just two or three concepts: ANOVA algorithm from R software can handle this.

Why did I choose the geometric mean: Other performance measures I could think of didn't allow to see the difference between the designs according to simulations I've performed.